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Research paper

Ground improvement and rebuild of a district road in complex geotechnical-engineering conditions – case study

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Abstract: Local roads in Poland, built for the most part in the previous economic system, are mostly unsuited to the ever-increasing traffic load, often built on a low-load organic substrate and need to be renovated. Linear objects are most often characterized by a significant variability in groundwater conditions in their area. The economical and safe design of the rebuild of a road structure often entails the need to implement ground improvement design of the low-bearing soil substrate, but areas of improvement should be adapted to the occurrence zones of low-bearing soil. The article presents a case study of the district road, for which ground and water conditions were recognized and organic soil were found. In addition to the rebuilding of the road structure to fulfill the requirements of the current traffic load and repairing the culverts, the reconstruction also included the ground improvement. The authors reviewed the types of road categories according to the admissible traffic loads (KR), the most important and commonly used methods of ground improvement, discussed the characteristics of the Benkelmann beam deflection method, proposed a design solution adapted to the existing conditions in the substrate and, after implementing it, presented the results of the deflection of the road before and after the reconstruction and soil improvement.

Keywords: low-bearing soil, complex ground-water conditions, soil improvement, deflection method

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1. Introduction

Local roads – provincial, district and communal roads, which were mostly built in 70's and 80's and are often in need of renovation and improvement to safely transfer contemporary loads, mostly generated from intensified vehicle traffic. During the construction of roads carried out in the previous economic system, in many cases, the attention was not paid to ensuring the appropriate quality of materials constructed into the road structures, and often the proper preparation of earth structures was not carried out. Current research related to new investments or the need to reconstruct and renovate existing local roads allows to discover negligence and mistakes made in the past.

In cases of modernization of the road structures it is important to analyze the subsoil and in case of appearance of any "weak" soils or probability of unfavorable phenomenon to choose the best soil improvement method. Geotechnical engineering offers many solutions in this area, which differ in economical aspect, time-consumption, difficulty in execution and possibility to use in specific ground-water conditions.

The article presents the issues of determining the ground improvement method and construction of a district road, in subsoil of which complex geological and engineering conditions caused by the presence of organic and low-bearing manmade soils were found.

2. Road conditions

Road constructions in Poland were in 90% made before joining the European Union in May 2004 [18]. In terms of load capacity, the public road structures, in accordance to the Public Roads Act (1985), were designed for a single axle load lesser than 8 t (80 kN). The exception were the roads covered by the regulation o Minister of Transport, on which vehicles with a single axle load up to 10 t (100 kN) were allowed to travel. The observed significant increase in the share of heavy goods vehicles in total vehicle traffic means that the roads made in 1970's to 2000's are not adapted to carrying current loads. Due to preformed rebuilding and reconstruction and also design of new road structures, the maximum permissible axle loads have changed from 8 t to 10 t or 11,5 t. According to the Public Road Act (2020), vehicles with a permissible load of a single axle up to 11,5 t (115 kN) are allowed on national roads, expressways and motorways. Unfortunately, local roads, despite the increasing number of renovations and reconstructions, still cannot fully bear the higher loads.

In Poland, the division of public roads is specified in Public Roads Act (2020). They include national, regional, district and communal roads. Behind the Central Statistics Office, you can determine the number of hard paved roads [1] – communal roads (59 %) and district roads (29 %) constitute the largest percentage. The change in the structure of the number of kilometers of paved surfaces since Poland's accession to the EU is shown in Fig. 1.

The influence on improving road conditions are based on various types of funds from the national budget (e.g. from the Road Infrastructure Development Programs [29], the

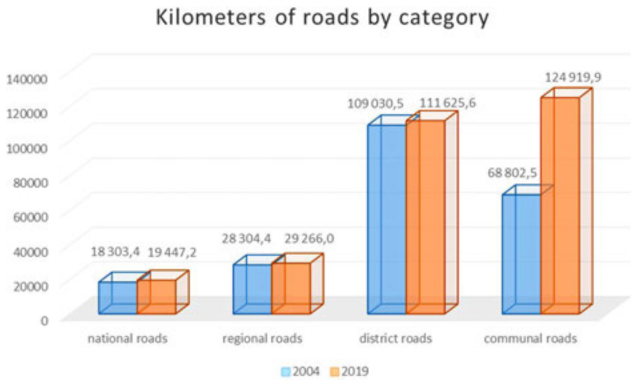

Fig. 1. The number of kilometers of paved surfaces in 2004 and 2019 [1, 6]

Government Road Development Fund [32], as well as EU subsidies – especially in the beginning period after accession). It should be stated that the needs are enormous and the number of works performed is insufficient. In addition to the increased load on the axles of trucks, a significant increase in the traffic flow of vehicles (mainly trucks), the outdated technology of works also has an impact on the road structure damage. Another aspect is improper geological conditions recognition and construction of the road structures on low bearing and organic soils. Following part of the article presents a description of the selected district road surface, which, being built on an incorrectly recognized subsoil, was damaged over the years and subjected to reconstruction.

3. The substrate of road constructions

The applicable PN-S-02205:1998 standard defines the procedure for earthworks (execution of embankments and excavations) for road constructions. It describes in detail the requirements for materials to be built into the subsoil. Materials suitable without reservations in the soil substrate are crumbled rocky soils (weathered, pebbles etc.), coarse and fine-grained non-cohesive soils (gravel, sand-gravel mix, coarse, medium and fine sands) as well as the anthropogenic soils (e.g. blast furnace slags, coal shales). The remaining soil, depending on the embedded depth (upper or lower layers in the freezing zones or outside of it) can be allowed under conditions, e.g. improvement with binders, no groundwater in the layer etc. The standard clearly states that the soil with organic matter $I_{om} > 2\%$ (except the humus sands) must not be present in top layers of the substrate in road constructions. An important issue is the frost heave, which is the resistance to frost damage (PN-S-02205:1998).

According to the Catalogs of Typical Road Constructions – Flexible and Semi-rigid [11] and Rigid [28] the parameter determining the suitability of the subsoil for road purposes is the Subsoil capacity group, which classifies its load-bearing capacity depending on the type and state of the soil, water conditions, susceptibility to frost heave and the characteristics of the road construction. The Catalogs [11, 28], similarly to the standard (PN-S-02205:1998), do not allow for the presence of organic soils in the subsoil, or even cohesive soils in state worse than hard plastic.

The soil substrate that meets the requirements for bearing capacity, compaction and resistance to frost heave is marked as G1 load capacity group. The remaining groups G2-G4 describe a substrate that requires improvement or by creating typical structural layers specified in the catalog [11, 28]. Unfortunately, in practice, the proper assessment of the suitability of the substrate is not simple, and errors are often observed, e.g. by determining several load-bearing capacity groups for one soil test or assuming the G4 group for the substrate not meeting the requirements (organic, cohesive in state worse than hard plastic). If the substrate is assessed as worse than G4, an individual method of improvement should be considered.

A serious problem for road construction is the occurrence of non-bearing soils, in particular organic soils with a high organic matter content ($I_{om} > 5\%$). Due to high deformability and low permeability of those soils, the design of embankments should be preceded by an analysis of the time course of the soil deformation [15]. The situation is particularly difficult when new routes are planned for which the route location should be changed or costly improvement performed. In the case of existing structures, accelerated or advanced degradation may be the result of improper preparation of the soil substrate. The BN-8932-01:1972 standard, which was in force from 1972 to 1998, i.e. when the most kilometers of road structures in Poland were completed, defines a "weak" substrate as marshes (peat bogs and layers of plastic, soft-plastic or liquid clay and loam, river muds and loess), for which the typical method of improvement was replacement (often difficult due to the presence of groundwater), or the construction of a consolidation embankment on it, allowing for high settlements and the implementation of a "temporary flexible surface" easy to reconstruct. Due to increasing axle loads of vehicles and traffic exceeded in many times in relation to the designed one, the road surfaces founded on low-bearing soils did not survive the fatigue test and require urgent reconstruction (modernization), i.e. treatments aimed at increasing the technical and operational parameters [25].

4. Improvement of a road construction and soil substrate

In construction practice, for existing roads, according to the catalog of reconstruction and renovation of the road constructions, three ways of improving the road structure and subsoil are distinguished [24, 25]:

a) in depth – reconstruction of the structure consisting in replacement of layers of the existing surface structure, without lifting the grade line of the road (it may be necessary only to slightly correct it);
b) upwards – reconstruction of the road surface consisting in making an overlay (one or several layers) with a thickness resulting from the necessary improvement of the construction;

c) in a mixed manner – reconstruction of a road structure consisting in combining the replacement of the existing layers and strengthening the structure and rising the grade line of the road.

One of the most important parameters determining the need for reinforcement is the load capacity of the road structure described by elastic deflection (for roads with KR1-KR4 traffic loading) or deflection bowl (KR5-KR7). In the case of local roads – district and communal roads, where due to their low transit importance, the load should not exceed KR4 category – the most common method of assessing the load-bearing capacity of the road structure is the measurement of deflections with a Benkelman beam [3, 25]. For higher categories and in the case of more precise tests for local roads, the load capacity measurements according to the FWD method are used.

According to the modified algorithm of Benkelman beam deflection method [33], after the measurements have been made homogenous sections should be distinguished for which individual values of elastic deflections are calculated:

$$\text{valid:}\ \ U_m = U_{\text{avg}} + 2 \times S_u\ \text{(mm)}$$

where:

U_{avg} – average elastic deflection for a given homogenous section,

S_u – standard deviation of elastic deflections for a given homogenous section,

$$\text{design:}\ \ U_{\text{obl}} = U_m \times f_t \times f_s \times f_p\ \text{(mm)}$$

where:

U_{obl} – the value of design deflection with coefficients,

U_m – representative elastic deflection,

f_t – temperature coefficient, correcting the deflections due to the measurement of the temperature,

f_s – seasonality coefficient, correcting the deflections for the season during the measurement,

f_p – foundation coefficient, correcting deflections due to the type of foundation.

Then, the obtained value of the design deflection is compared with the limit values specified for each load category. The authors [33] suggest that for road structures designed according to regulations earlier than the 2014 catalog [11] and made by 2014, the limit values from the catalog [24] (higher limit values) should be used. After calculating the deflection for a specific traffic category the equivalent thickness of the reinforcement plate is read from the nomogram. Depending on the materials used, the final thickness of the layer – overlays can be optimized.

If the design deflection value exceeds the permissible range of the nomogram for determining the required equivalent reinforcement thickness [25], which is related to the low load-bearing capacity of the tested structure, it is unjustified to design a reinforcing overlay and it becomes necessary to rebuild it into depth, requiring the removal of the existing structure and improving the subsoil.

In order to select an appropriate method of soil improvement, the necessary field and laboratory tests should be performed [12, 23]. Depending on the parameters of the subsoil, determined in field and laboratory tests, an appropriate method of improvement is selected, which is technically and economically justified. According to the authors, decisions should not be made only taking into account the cost of improvement.

The most common method of soil improvement is the replacement. The method is supported by the availability of replacement material, which may be natural or anthropogenic soil. In the case of near-surface deposition of low-bearing soil layers with a small thickness, in which no groundwater table is found, a complete replacement is applied (up to the top of the bearing layer). Partial soil replacement takes place when the thickness of the non-bearing layers is significant or when there is a low-depth groundwater table in the soil substrate [5].

One of the well-known and used for many years is the impact compaction method, with the use of a compactor free dropping from the height reaching up to 30 m, known as dynamic soil replacement. The method is applicable in moist cohesive soils as well as organic soils. Useful materials are natural aggregates, as well as slags, mine waste or crushed construction rubble [7].

Another way to improve low-bearing soils (especially organic ones) is consolidation by preloading the subsoil. The aim of the method is to realize most of the settlement during the construction phase and to limit the settlement of the structure during the use phase. Consolidation takes from a few months to a year or more. One of the ways of loading is to lower the groundwater level, which eliminates the buoyancy and adds weight to the substrate [8]. The process of consolidation can be accelerated up by using vertical drains. The water is removed from the soil pores as the layer gets more compacted [2].

In the case of organic soils, where the road structures exhibit significant depressions and deformations, the repair of the structure itself may turn out to be ineffective, because the implementation of another reinforcing layer will additionally load the compressible organic substrate and cause deformation growth. Convenient solution to this problem may be to relieve the organic soils by replacing the mineral or anthropogenic embankment with a layer of light material, which may be: expanded clay, foam concrete or polystyrene [21].

Improving the soil substrate under the road structure can also be done by using injections – displacement columns CMC, DSM-dry technology or prefabricated reinforced concrete columns.

For several years, methods related to the use of geosynthetics have been popular method of improving low-bearing soils. In order to increase the stiffness of the substrate and increase its resistance to tensile stresses, reinforcing structures in form of geomaterials are implemented into substrate, as a solid base for upper layers of road structure. They consist of very compacted aggregate layers, approx. 0.3 m thick, which are bound on the top and bottom with a geosynthetic in the form of a rigid geogrid. Strengthening occurs by taking over concentrated forces and distributing them evenly over larger area. As a result, the upper surface of the geomaterial, even on a weak base, can be characterized by much better resistance and deformation properties. In the case of non-load bearing substrates, the mixture of aggregate with reinforcement is placed in multiple layers. Shear strength is of particular importance, as it is conditioned by the high angle of internal friction of the material used as a filler of the geogrid. It is recommended to use crushed aggregates or recycled materials. The geosynthetic material is no less important, the role of which is to absorb tensile stresses occurring in the structure distributing the pressure on a weak soil substrate. The most important mechanical feature of a geosynthetic is stiffness in terms of a deformations occurring during the use of a geosynthetic "mattress", which can be estimated in the range 0.0–0.5 % [17].

The appropriate selection of the soil improvement method is aimed at solving the problems of the damaged road infrastructure. The presence of organic soils is often the cause of road structure failure. The article presents a method of strengthening the district road by selecting various solutions depending on the load-bearing capacity of the soil substrate and the road structure.

5. Case study

The research works were carried out on the section of the Sączkowo – Bucz route (described km: 14 + 077÷15 + 452) along the district road no. 3820P Przemęt – Bucz. The road is located in the Przemęt commune, in the Wolsztyn district, in the Wielkopolska voivodship. The administrator of the road is the Wolsztyn district. The road was designed for a single axle load of 80 kN and was created in 1976. The top layers are made of asphalt concrete, 5 to 10 cm thick. In 1997, due to the deformations that arose, the section from the town of Sączkowo to culvert between the ponds (the area described by the distance of approx. 14 + 077÷14 + 594) was reinforced with a 4 cm asphalt overlay.

Due to the appearance of anthropogenic organic soils, the analyzed road section is characterized by numerous damages including undercutting and chipping at the edge of the road, potholes, longitudinal and transverse rutting as well as mesh cracks (Fig. 2). Above mentioned road failures can be effect of several subgrade processes and phenomena: low density of non-construction embankments, the consolidation of organic soils, as well as the heaping nature of the subsoil and frost damage.

Fig. 2. Typical road damages, left – mesh cracks, right – longitudinal ruts

5.1. Geological structure of the area

In reference to the division of Poland into physical and geographical units according to Kondracki (2011), the research area is located in the macroregion of Leszczyńskie Lakeland, on the border of two mesoregions of Sławskie Lakeland and Kościańska Plain. The Leszczyńskie Lakeland is located in the extreme range of the Leszno phase of the Vistula glaciation and is characterized by numerous lakes, little afforestation and moraine hills up to the height of 160 m above the sea level [13].

In the subsoil of the studied section of the district road, there are tills of the North Polish glaciation associated with the presence of a flat moraine valley in this area, which is cut by Pleistocene lake channels and river valleys. The lake channel in the area of Sączkowo and Bucz villages is filled with fluvioglacial sands and gravels as well as river-fluvioglacial sands and gravels, on which there are successively Holocene organic sediments formed in the form of peat, gyttja, lake chalk, alluvia and sandy alluvia, as well as sands and silts of valley floors (Fig. 3) [26, 27].

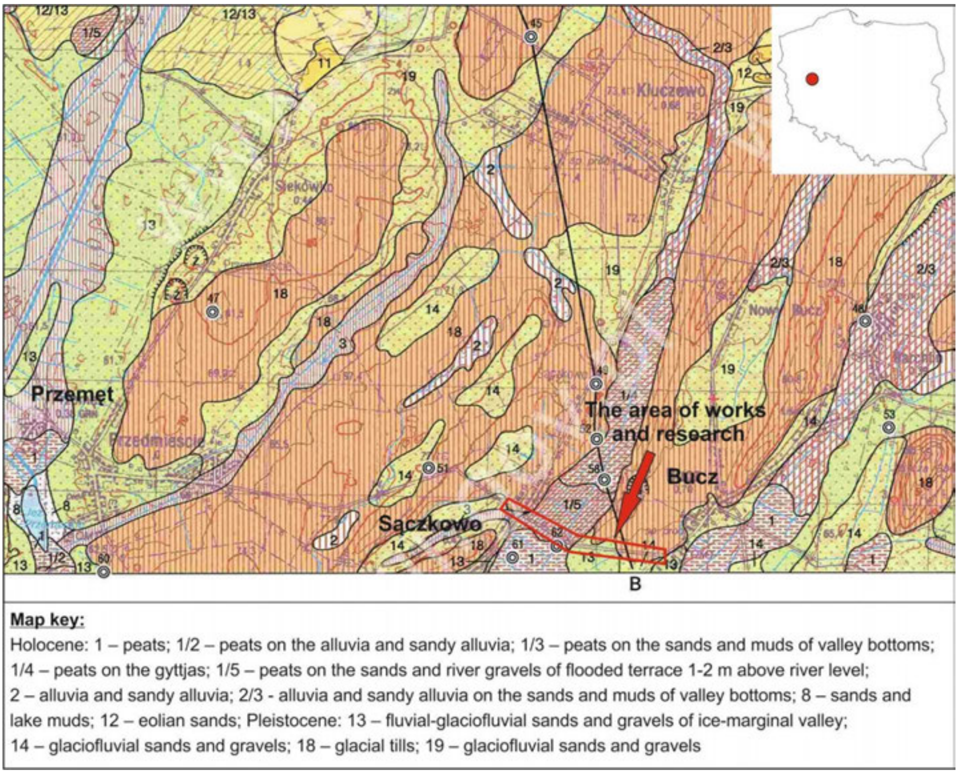

Fig. 3. Location of the research area (fragment of the Detailed Geological Map of Poland, sheet 541 – Rakoniewice, scale 1: 50 000)
(source: http://bazadata.pgi.gov.pl/data/smgp/arkusze_skany/smgp0541.jpg)

There was a lake chalk mine situated between Sączkowo and Bucz for several years [20]. After its closure, the excavations created during the exploitation were flooded to form ponds with an average depth of 4 m and, sometimes up to 12 m. Afterwards the ponds were stocked with fish and, from 1997, fisheries were established there [16]. They are connected with a channel system, the waters passing through which fall in sequence into Lake Boszkowskie and are bound with the Błotnicki Channel. The discussed section of the district road connecting Przemęt and Bucz at the height of Sączkowo runs in a depression between fish ponds. These ponds are connected by a channel running in a culvert made under the road surface (14 + 599 km).

The discussed section of the district road no. 3820P constitutes the border of the "Natura 2000" area included in the bird protection area – Sławskie Lakeland, extending southwards from the road. In addition, the road is the northern border of the Przemęcki Landscape Park, established in 1991, with a total area of 21,450 ha [9].

5.2. Test results and their analysis

Optimization of the costs related to the renovation of the road structure is a decisive factor for the public investor (County Board). Therefore, the pavement reconstruction project should be made reliably, on the basis of field tests and analysis of the existing structure and subsoil, and cannot be based solely on assumptions and numerical models.

Pavement load capacity tests – the stage of investment preparation

Due to the assumed traffic load category KR2, the wheel load capacity was assessed using the deflection method, using the deflection measurement device, the Benkelman Beam Apparatus. The characteristics of the tests are presented in Table 1, and the deflection values calculated on the basis of the formulas (provided earlier) and publications [33] – in Fig. 4.

Table 1. Characteristics of the calculation model for deflection tests

Spacing of measuring stations per lane	**every 25 m**	Values of the correction factors [25]	
Type of construction	**susceptible**	f_s – seasonality factor [–]	**1.04**
Temperature of bituminous layers	**10°C**	f_p – foundation coefficient [–]	**1.00**
Date of measurements	**IV 2018**	f_t – temperature coefficient [–]	**1.20**

Due to the clear differences in the values of elastic deflections in each traffic lane, the deflection was calculated for the entire road section, in the variants – right lane, left lane and the mean deflection in the road cross-section. The results are summarized in Table 2.

Summarizing the obtained results, it should be noted that the value of the wheel load capacity of the right traffic lane is twice as low as the left one. In accordance with the recommendations of the deflection method, it was decided to separate road sections homogeneously in terms of the value of wheel load capacity. Additionally, in the section

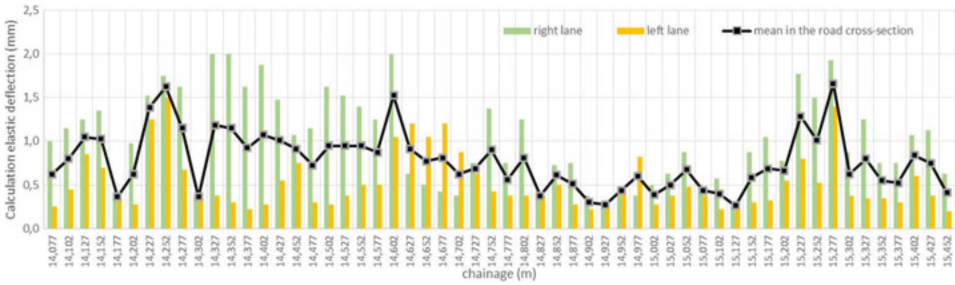

Fig. 4. Values of elastic deflections of the tested pavement – investment preparation stage

Table 2. The results of the deflection calculations for the entire road cross-section

	Right lane	Left lane	The cross-section of the road
Mean representative deflection [mm]	1.02	0.53	0.78
Standard deviation [–]	0.52	0.32	0.33
Design deflection [mm]	2.06	1.17	1.44

where the highest values of elastic deflections were found and thus the lowest bearing capacity, supplementary tests were carried out to determine the soil and underground water conditions of the substrate.

Recognizing of soil and underground water conditions of the substrate

The assessment of the soil and underground water conditions of the substrate was carried out with the use of field methods, by performing small-diameter drilling in the ground with macroscopic evaluation of the soils (9 test boreholes with the depth of 4.0–8.0 m, 52 running meters in total and 5 Cone Penetration Tests with the total depth of 41 m). In the laboratory, the content of organic substance was determined for 13 samples taken from embankments and native organic soils. Archival test boreholes made in 2015 were also used [10]. The hydrogeological conditions in the subsoil of the pavement are shown in the engineering geological cross-section through selected test holes (Fig. 5).

The following soil layers were found in the subsoil of the road pavement:

– construction embankments composed of sand-gravel mix, coarse and medium sand, non-swelling, medium compacted;
– non-construction embankments composed of fine humus sand, sandy alluvium, fine and medium sand, sand-gravel mix, clayey sand-gravel mix, gravel and cobbles, classified as potentially or highly swelling in terms of heaving, in a loose and medium-compacted state;
– organic soils, developed as lake chalk, peat, gyttja, clayey alluvium, humus till and humus sand, classified as potentially or highly swelling in terms of heaving;

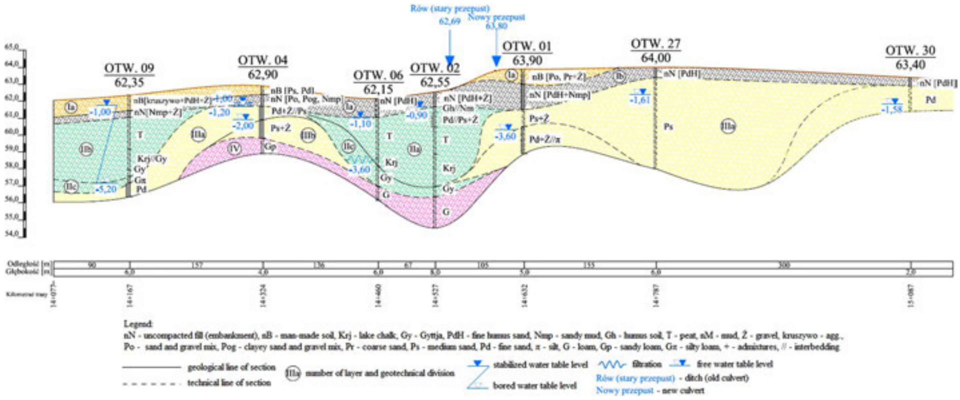

Fig. 5. Geological and engineering cross-section

– native non-cohesive soils – fine sand, medium sand and coarse sand with admixtures and interlayers, loose and medium compacted, non-swelling;

– native cohesive soils – silty till, till, sandy till, in a hard-plastic and soft-plastic state (the value of liquidity index: $I_L = 0.20 - 0.65$), classified as very swelling.

Taking into account the results of the laboratory tests and Cone Penetration Tests, on the basis of lithology and soil states, the identified soils were classified into 4 geotechnical packages, within which geotechnical layers with different physical and mechanical parameters were separated. Table 3 summarizes the geotechnical parameters for the separated geotechnical layers.

Groundwater was found in all test boreholes made in the research area. It occurred in the form of a free or confined water table, stabilizing at a depth of 0.8 m to 3.6 m below the drilling level. Taking into account the presence of groundwater and unpaved roadsides, the water conditions were assessed as good (borehole no. 1), average (borehole no. 3, 7 and 8) and bad (borehole no. 2, 4–6 and 9).

In accordance with the requirements of Polish instruction – Catalog of Typical Flexible and Semi-rigid Pavement Structures [11], the subsoil in the area of the reconstructed district road has been classified into the following subsoil wheel load capacity groups:

– G1 (not requiring reinforcement) – in the area of test borehole no. 8.

– G4 (requiring reinforcement), e.g. with one of the typical methods proposed by the catalog [11] – in the area of test boreholes no. 3 and 4.

– Not meeting the requirements of G4 substrate (worse than G4) – due to the presence of non-construction embankments of considerable thickness, formed of unsuitable materials, as well as cohesive soils in a plastic state ($I_L > 0.25$) or organic soils, for which an individual type of reinforcement should be designed – area of test boreholes no. 1, 2, 5, 6, 7 and 9.

Table 3. Table with geotechnical parameters for the separated geotechnical

geotechnical layer	type of soil	resistance of the cone (CPTU)	state of soil	degree of compaction	relative density	liquidity index	effective angle of internal friction	effective cohesion	shear strength without drain	primary compressibility modulus
	symbol of soil	q_C [MPa]	–	I_s [–]	I_D [–]	I_L [–]	i [°]	c' [kPa]	S_u [kPa]	M_0 [MPa]
1	2	3	4	5	6	7	8	9	10	11
Ia	NB(Pr, Po)	4.9	dense	0.97	[0.67]	–	38.5	–	–	24.6
Ib	NN(Pd, PdH)	1.9 ÷ 2.4	loose	0.9	[0.30]	–	17.7 ÷ 33.1	–	–	10.6 ÷ 11.9
Ic	NN(Ps//Nm, Pr. Po)	0.8 ÷ 1.1	loose	0.86 ÷ 0.88	[0.07 ÷ 0.18]	–	29.2 ÷ 32.0	–	–	5.0 ÷ 6.0
IIa	T/Nm	0.7 ÷ 0.8	–	–	–	–	14.0 ÷ 17.2	14.7 ÷ 15.9	57.2 ÷ 59.3	2.7 ÷ 3.1
IIb	T	0.2 ÷ 0.5	–	–	–	–	8.5 ÷ 13.0	5.1 ÷ 10.2	20.4 ÷ 42.4	0.8 ÷ 1.9
IIc	Gy, Krj. Gp	0.2 ÷ 0.3	–	–	–	–	5.1 ÷ 12.4	0.5 ÷ 5.6	13.2 ÷ 22.7	0.4 ÷ 1.2
IIIa	Pd	6.4 ÷ 7.9	medium dense	–	0.5	–	36.0 ÷ 36.6	–	–	31.5 ÷ 39.1
IIIb	Pd	2.9 ÷ 5.0	loose /medium dense	–	0.22 ÷ 0.37	–	30.8 ÷ 34.6	–	–	13.9 ÷ 24.5
IV	G// Gp	0.7 ÷ 1.4	plastic	–	–	0.36 ÷ 0.49	13.5 ÷ 16.7	1.8 ÷ 5.6	54.5 ÷ 65.2	6.3 ÷ 13.8
Ia – construction embankment, Ib, Ic – non-construction embankment, II – organic soils, III – non-cohesive soils of glaciofluvial accumulation, IV – cohesive soils of moraine accumulation (consolidated)										

6. Analysis of the bearing capacity of the subsoil and pavement structure and design solution

The assessment of ground-water conditions made it possible to unequivocally state that within the subsoil weak organic soils, as well as non-construction embankments of considerable thickness occur. These soils caused damage to the road structure in the form of a grid of cracks, bumps, fractures as well as areas of transverse and longitudinal unevenness. Probably the same type of damage required the reinforcement carried out in 1997. The low degree of compaction in embankments (loose and medium compacted state) and in non-cohesive subsurface layers causes their increased settlement. Additionally, the presence of organic soils, as well as locally occurring layers of cohesive soils, which should be assessed as swelling ones, is related to the formation of damage caused by exogenous heaving processes.

The carried out measurements of the wheel load capacity made it possible to assess the usefulness of the construction layers and the possibility of their potential use during the "upward" reconstruction. Due to the destruction of the structure, the presence of weak soils and the decreased wheel load capacity, in order to optimize the scope of paving works, having the presented results, the designer divided the analyzed section of the district road into three test sections, which he separated on the basis of road structure deflections and the condition of the subsoil (Table 4) [22].

Table 4. Separate test sections of the district road no. 3820P Przemęt–Bucz

	Mean deflection	Standard deviation	Design deflection	Reinforcement height	Reinforcement layers height
	U_{avg} [mm]	s [–]	U_{obl} [mm]	H_z [cm]	H_n [cm]
Section I, km: 14 + 077÷14 + 337					
right lane	1.21	0.52	2.25	44	22
left lane	0.64	0.41	1.47	24	12
cross-section	0.93	0.41	1.74	32	16
Section II. km: 14 + 337÷14 + 757 (in the culvert area)					
right lane	1.24	0.54	2.31	46	23
left lane	0.62	0.34	1.30	20	10
cross-section	0.93	0.20	1.33	21	11
Section III. km: 14 + 757÷15 + 452					
right lane	0.82	0.43	1.67	30	15
left lane	0.43	0.24	0.92	8	4
cross-section	0.63	0.30	1.23	18	9

Taking into account the necessity to make an expensive reinforcement, it was decided that in sections I and II, the reinforcement of the structure would be made in the "deep" technology along with the removal of the structure and the top layer of the subsoil, and for the III section, only a bituminous cover plate would be made.

In the case of section no. I, an additional strengthening and frost-proof layer made of a mixture of soil stabilized with cement with a designed value of R_m = 2.5 MPa and a height of 10 cm.

For section II, which includes the location of a culvert between water reservoirs, where the presence of organic soils of considerable thickness and low values of deformation modulus was found, advanced reinforcement methods were considered. Due to the limited financial resources, it was not decided to perform deep soil stabilization or soil replacement. Due to the mere local importance of the road, the possibility of constructing a considerably time-consuming overload embankment, was rejected. Analyzing the costs and the simplicity of the solution, a reinforcement technology using a mattress made of crushed aggregate of 0/31.5 mm fraction reinforced with a three-axis hexagonal geogrid with rigid knots was proposed. The reinforcement function of the geogrid is achievable due to three reinforcement mechanisms (see also Fig. 6):

– Lateral restraint, associated with the confinement of the aggregate in the grid during the loading, which results in an increase in the modulus of the base course material.
– Improved bearing capacity, which is a result of the shift in failure envelope of the pavement system from the subgrade to the base course.
– Tensioned membrane effect [34], which is based on the concept of improved vertical stress distribution from tensile stress in a deformed membrane, after applied loading [35].

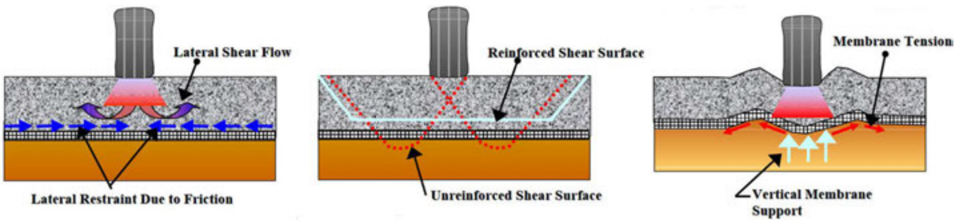

Fig. 6. Geogrid reinforcement mechanisms [35]

The number of reinforcing layers depended on the parameters of the bearing capacity of the subsoil (determined in Cone Penetration Tests). The parameters of layer IIa were adopted as the minimum value of the subsoil deformation modules (cf. Table 3). The reinforcement scheme is shown in Fig. 7 [14]. The view from the implementation of the works is shown in Fig. 8.

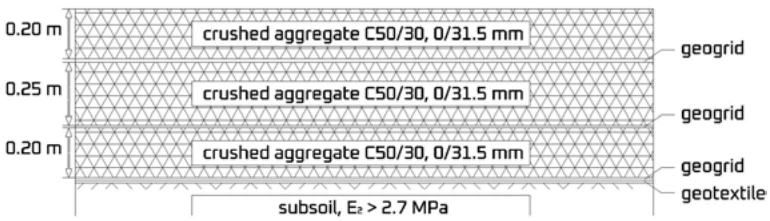

Fig. 7. The arrangement of reinforcing layers in the area of the added section II

For section III, where the highest load-bearing capacity of the structure was found, an "upward" reinforcement was provided. It is a reinforcement using a package of bituminous layers with an anti-cracking layer (slurry seal made of steel mesh), with a total height of 15 cm. The detailed arrangement of the reinforcing layers and the pavement structure is shown in Fig. 9.

Fig. 8. Realization of the reinforcing layers of aggregate reinforced with a geogrid (section II)

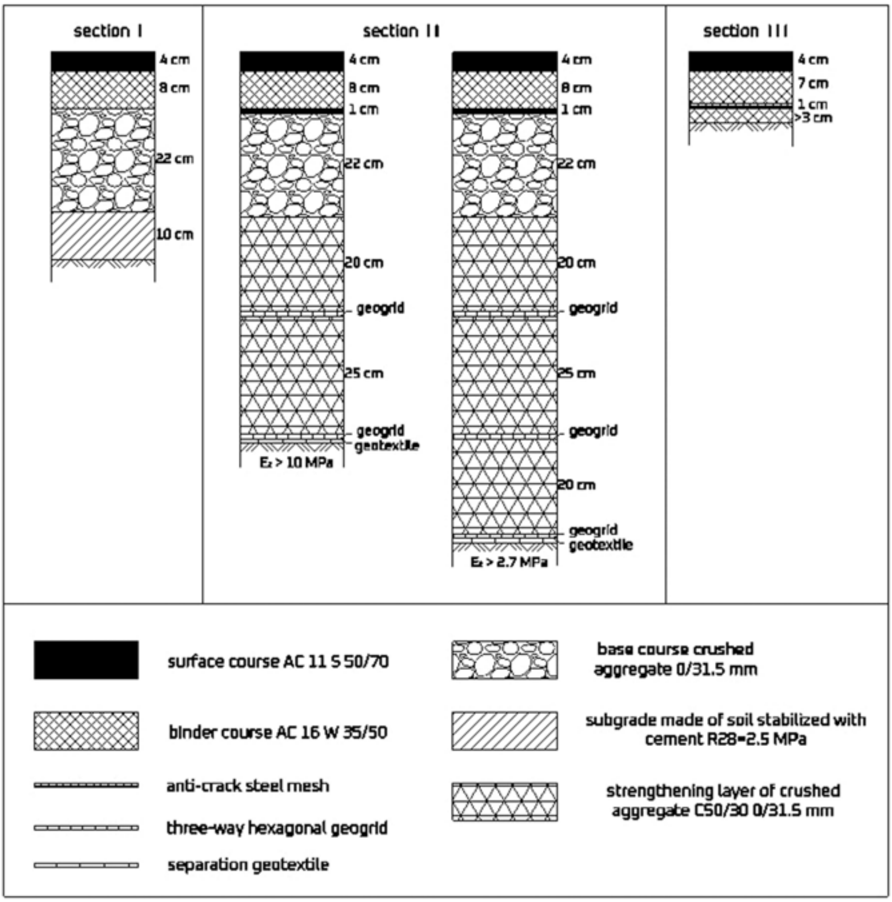

Fig. 9. Design solutions for strengthening the subgrade and pavement [22]

After the reinforcement layers and new construction layers had been made, the pavement deflection was tested again as part of the comparative analysis. The model calculation parameters are summarized in Table 5, and the deflection diagram is illustrated in Fig. 10. The values obtained for the separated sections together with the reference to the values obtained at the investment preparation stage are summarized in Table 6.

Table 5. Calculation parameters of the model of the deflection method of the reconstructed road section

Spacing of measuring stations per lane	**every 25 m**	Values of the correction factors [25]	
Type of construction	**susceptible**	f_s – seasonality factor [–]	**1.15**
Temperature of bituminous layers	**26°C**	f_p – foundation coefficient [–]	**1.00**
Date of measurements	**VII 2020**	f_t – temperature coefficient [–]	**0.88**

Table 6. Comparison of deflection values obtained before and after road reconstruction

	Mean deflection	Standard deviation	Calculation deflection after rebuilding	Calculation deflection before rebuilding	Difference with respect to deflection before rebuilding
	U_{avg} [mm]	s [–]	U_{obl} [mm]		[%]
Section I, km: 14 + 077÷14 + 337					
right lane	0.78	0.24	1.26	2.25	–79
left lane	0.88	0.28	1.43	1.47	–2
cross-section	0.83	0.20	1.22	1.74	–43
Section II, km: 14 + 337÷14 + 757 (in the culvert area)					
right lane	0.63	0.20	1.03	2.31	–124
left lane	0.65	0.20	1.04	1.30	–25
cross-section	0.64	0.19	1.01	1.33	–32
Section III, km: 14 + 757÷15 + 452					
right lane	0.47	0.10	0.67	1.67	–151
left lane	0.50	0.11	0.73	0.92	–26
cross-section	0.48	0.09	0.66	1.23	–86
Comprehensive analysis, km: 14 + 077÷15 + 452					
right lane	0.58	0.21	0.99	2.06	–108
left lane	0.62	0.23	1.08	1.17	–9
cross-section	0.60	0.20	0.99	1.44	–45

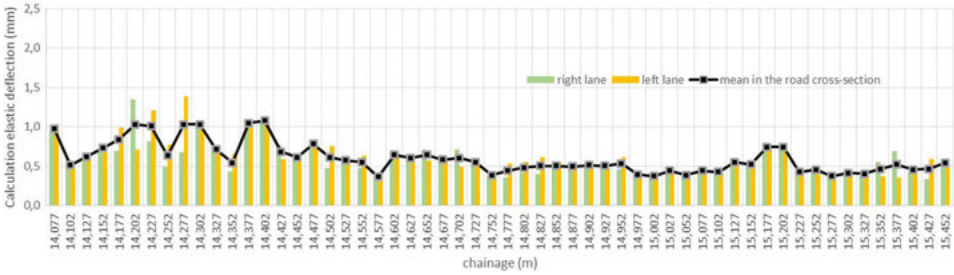

Fig. 10. Values of elastic deflections of the tested pavement – tests of load capacity after pavement reconstruction

In respected case, the assumed load category is lower than KR 4, therefore the mechanistic method is not necessary and wasn't used. The simplest and fastest method for developing the reinforcement is the deflection method, used in this case. The elastic deflections of the pavement before and after renovation with reinforcement are presented in a collective Fig. 11.

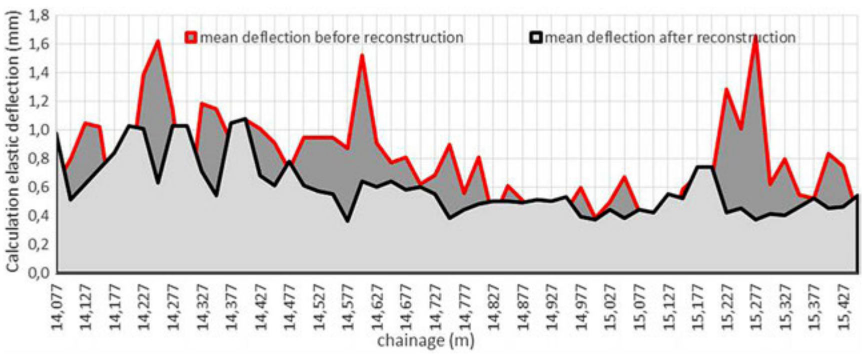

Fig. 11. Values of elastic deflections of the tested pavement – tests of load capacity before (red line) and after (black line) pavement reconstruction

7. Conclusions

1. This work is a case study of soil improvement under the road construction. In this case, after analyzing the ground-water conditions, it was decided to replace the low-bearing capacity soil with a non-cohesive soil characterized by high mechanical parameters. In addition, reinforcement with a triaxial geogrid filled with coarse-grained embankment material was used. The system works like a composite – the geogrid wedges and limits the possibilities of vertical and horizontal grain movement, working as a rigid system, allowing the road load to be evenly transferred and minimizing the occurrence of differential settlement.

2. The performed treatments and optimization of reinforcements on individual three sections of the district road no. 3820P Przemęt–Bucz (km: 14 + 077÷15 + 452) allowed to increase the load capacity of the pavement to 10 t (100 kN) and for the traffic load of the KR2 category.
3. The division of the road into sections and the selection of various methods of soil improvement depending on their bearing capacity and ground-water conditions turned out to be beneficial. Reconstruction by means of only one technology could not provide the required performance and be associated with higher costs (e.g. removal of the structure and then construction of the building embankment and new layers in the area of section no. III, instead of the reinforcement made with an cover plate). In the area of low-bearing soils, the necessary soil improvement was followed by the properly dimensioned road structure.
4. The presence of low-bearing soils (peat, alluvia, gyttja and lake chalk) and loose non-construction embankments were of great importance in the bearing capacity of the subsoil. Thanks to modern soil improvement methods, e.g. the use of geosynthetics, stabilization with binders, etc., it is more and more often not necessary to completely replace low-bearing soils, but only to improve them in situ.
5. Ultimately, in the authors' opinion the selected economic solutions for the reconstruction of the discussed road (also satisfying the road administrator), will allow its long-term service without the need for another costly reconstruction.

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Wzmocnienia podłoża oraz przebudowy nawierzchni odcinka drogi powiatowej w złożonych warunkach geologiczno-inżynierskich – studium przypadku

Słowa kluczowe: grunty słabonośne, złożone warunki gruntowo-wodne, wzmocnienie podłoża nawierzchni drogowej, metoda ugięć

Streszczenie:

Drogi lokalne w Polsce, wybudowane w przeważającej większości w poprzednim systemie gospodarczym, są przeważnie niedostosowane do ciągle rosnącego obciążenia ruchem, często wybudowane na słabonośnym podłożu organicznym i wymagają renowacji. Obiekty liniowe charakteryzują się najczęściej znaczną zmiennością warunków gruntowo-wodnych na swoim obszarze. Ekonomiczne oraz bezpieczne zaprojektowanie przebudowy konstrukcji drogowej wiąże się często z koniecznością wzmocnienia słabonośnego podłoża gruntowego, lecz obszary wzmocnienia powinny być dostosowane do występowania lokalnych pokładów gruntów słabonośnych. Artykuł prezentuje studium przypadku drogi powiatowej, dla której dokonano rozpoznania warunków gruntowych oraz wodnych i stwierdzono występowanie utworów o pochodzeniu organicznym. Przebudowa oprócz dostosowania konstrukcji nawierzchni do aktualnego obciążenia ruchem oraz remontu przepustów zakładała również wzmocnienie podłoża gruntowego. Autorzy dokonali przeglądu typów kategorii ruchu drogowego (KR), najważniejszych i najczęściej używanych metod wzmacniania podłoża gruntowego, omówili charakterystykę metody ugięć belką Benkelmana, zaproponowali rozwiązanie projektowe dostosowane do występujących w podłożu warunków i po zaimplementowaniu go zaprezentowali wyniki ugięć drogi po przebudowie i wzmocnieniu podłoża.

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