GEOSYNTHETIC REINFORCED SOILS, APPLICATIONS IN AREAS OF HEAVY MINING ACTIVITIES AND SUBSIDENCE

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ABSTRACT: The paper presents the results of observations of relocation of points located in the first (old) embankment, built without reinforcement with geosynthetics, and the second (new) embankment, reinforced with geosynthetics, taking into consideration the ground conditions and mining activity carried out. Also, the results of calculations are presented, together with the system of geosynthetic reinforcement of the new embankment, for the construction of which the waste rock excavated directly from undergorund has been used. From the continuous measurements it can be concluded clearly that the concept of the project was correct, while the intense and substantial relocations are not reflected on the the surface of the constructed road.

The paper discusses the experiences in the application of modern geosynthetic materials made of PVA (polyvinylalcohol) for the construction of a steep and high embankment of an object of transportation infrastructure, in the area which has been and will be in the future influenced by mining activities, the subsidence being of category four (according to Polish classification).

1. Introduction.

The road viaduct put into operation on October 10, 2002 on the provincial road No. 933 (Wodzisław Sl. – Pszczyna; the Rybnik Industrial Region, the Province of Silesia, Poland) is, in the opinion of the authors, deserves a detailed presentation.

The provincial road No. 933 is the most important arterial road of the town of Jastrzębie Zdrój, running in the east-west direction. In Jastrzębie-Bzie that road intersects with the railway tracks from the coal basin, with intense traffic. Grade separation is required for continuous traffic on that road, so that it overpasses the tracks, used for transporting coal excavated in three mines, in amounts of about 40 thousand tons per day (24h), for that purpose a viaduct was built in the 1970s. That viaduct, further referred to as the „old" viaduct has been subject to the consequences of underground mining since mid-1970s, togehter with the railway tracks under it. The mining activity and raising of the railway tracks resulted in exhausting the vertical limiting outline under the viaduct, thus it has become necessary to build a new viaduct. The new viaduct was built in 2002, parallel to the old viaduct, on its south side.

Those viaducts are located at the border of mining areas of the two collieries: „Zofiowka" and „Pniowek", which makes the proper co-ordination of mining in that earea more difficult.

2. Geology of the deposit in the area near the viaducts.

The rock mass in the area of those viaducts consists of quarternary, tertiary, and carboniferous layers.

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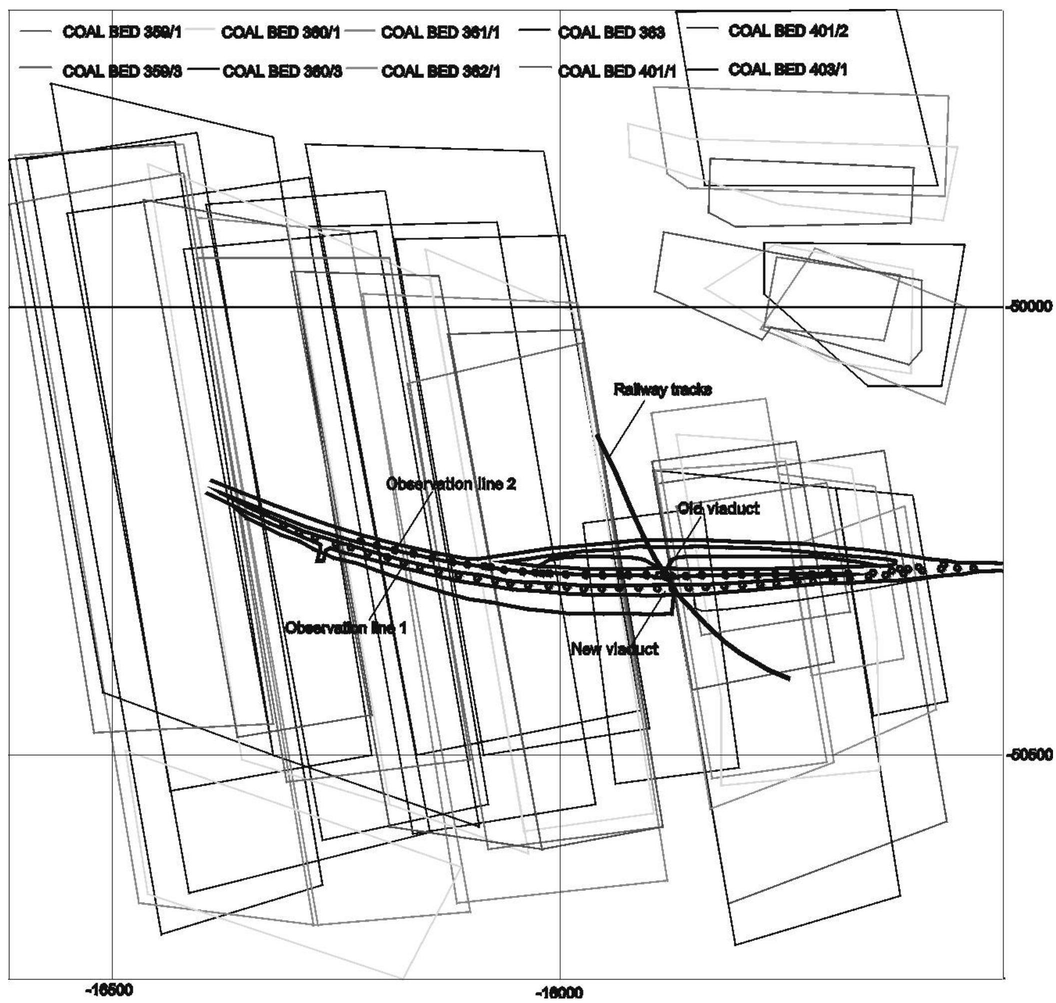

Fig. 1. Scope of mining done in the area of viaducts in the years 1976-2003

Quarternary layers contain clays, sands, and gravels. They reveal high level of variability in lithology, as well as substantial changes in thickness along short distances. The average thickness of those layers is between 30 and 50 m.

Tertiary layers consist of silts and malms, with high content of sand in places, interbedded with thin inserts and lenticles of dusts, and dusty sands. The sandy inserts make up isolated water horizons, containing salty relic water. The thickness of tertiary layers is about 330 m.

The productive Carboniferous period is represented by Orzesze, Ruda, and anticilne layers, deposited in monocline to the east, at the angle of 2^o to 8^o.

The Orzesze layers are formed mainly of clayey rocks and mudstones. Sandstones are represented marginally

The Ruda layers, in their upper parts, are formed clayey-mudstone facies, whereas in the lower part sandstones prevail over mudstones.

The anticline layers consist mainly of thick sandstones, with thick to medium grains, sometimes with insets of pudding stone. Clumps and arenaceous stones make up the strate of moderate thickness, and appear mainly in the roof and floor of the coal beds.

In the area of the viaducts, tectonic disturbances appear,, of which the major ones are :

- „Pniowkowski” fault, with the throw of 25-35 m;
- „Centralny” fault, with the throw of 10-20 m.

The investment is located in the area of mining subsidence category IV. The tightened water table is located, at present, because of post-mining deformations, at the depth of 2÷3 m, directly under a 2 m layer of clay, on which the embankment is located. Over the period of over 30 years of mining activities, the area where the investment project is located subsided by 5÷11 m, in the coming years further subsidence is assumed, by at least 4,5 m. Under such unfavourable ground and water condituions, with exceptionally poor subsoil and specific geometric assumptions, it has been assumed that the best solution, technically and economically speaking, will be to strengthen the embankment with geosynthetic reinforcement.

In the subsoil directly under the approach roads on the embankment, of uncontrolled anthropogenic origin, the free surface of water has been found at the surface or at the depth of up to 0,5 m under the ground. The subsoil of the embankments also contains tightened water table, found by drilling in the roof of loose ground strata, thus at the variable depth between 4,5m and 9,1 m under the surface. In the area od the new viaduct to be constructed, the stabilized water table was found at the depth from 0,9 to 2,0 m under the surface, while in exploratory bore-holes at the eastern side water outflows of water to the surface, or the water table stabilized at insignificant depth.

3. Mining activities performed

In the area where the viaducts are, forming part of the provincial road No. 933, mining activities are carried out by the „Zofiowka" and „Pniowek" collieries. Between those collieries, along the border of their respective mining activities, a safety border pillar has been established, with the width of 50 to 80 m (cf. Fig. 1). The consequence of establishing that pillar was that mining lines overlapped in numerous coal beds. Where the viaducts are located, the „Zofiowka" colliery mined for coal in nine beds, while the „Pniowek" colliery in seven. Main data concerning the mining performed have been gathered in Table 1, whereas the scope of the mining is presented in Fig. 1.

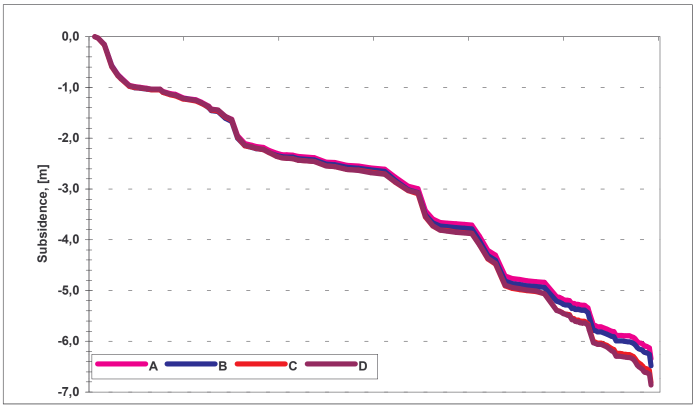

Fig. 2. Subsidence of old viaduct in time, in the years 1979-2003

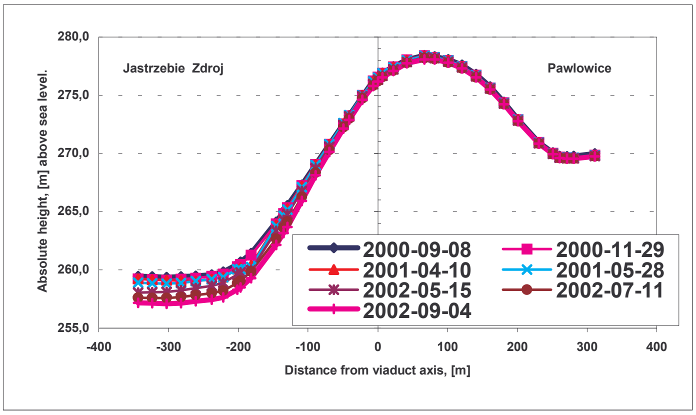

Fig. 3. Subsidence of the old viaduct in the period between 09. 2000 and 09.2002

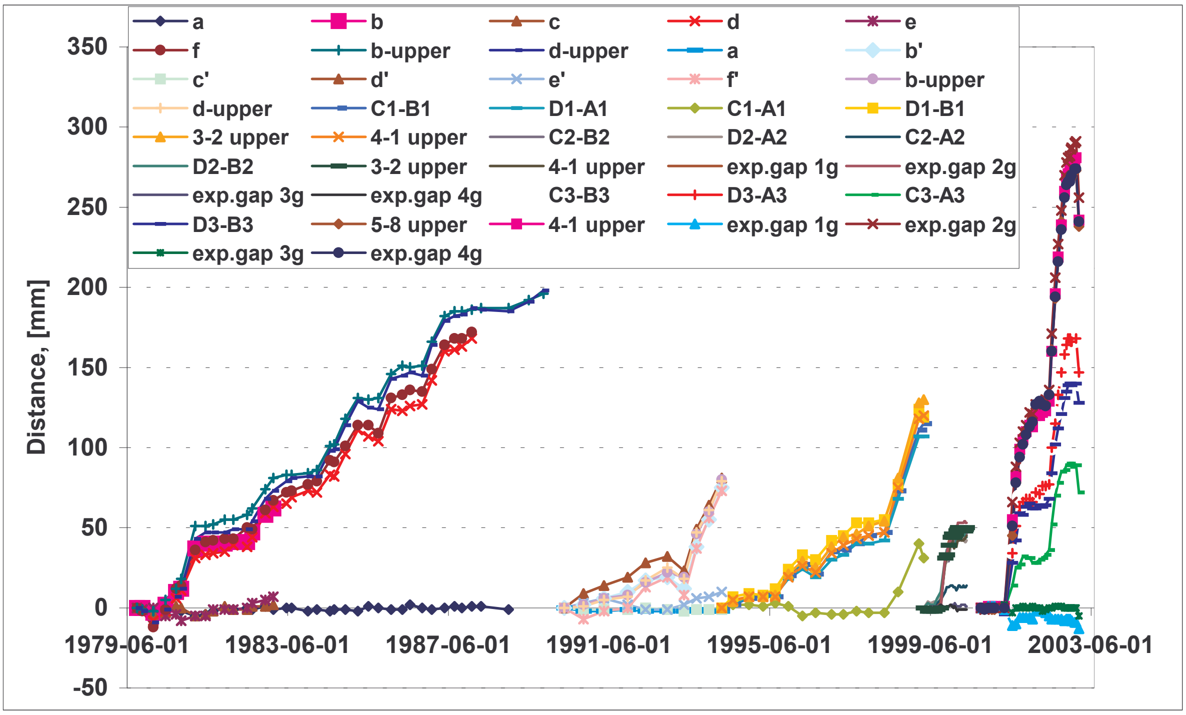

Fig. 4. Changes in width of expansion gaps of the old viaduct

Table 1. Mining activities performed by the collieries „Zofiowka" and „Pniowek"

Coal bed	Longwall	Thickness m	Depth m	Time of mining
„ZOFIOWKA" colliery – mining done				
359/1	F-5, F-7, F-9	1,2-1,6	496-512	1976-1981
359/3	F-5, F-7, F-9	1,6-1,7	509-516	1979-1983
360/1	F-9, F-11, F-13	2,1-2,2	525-535	1983-1986
360/3	F-9	1,3-1,4	530-540	1986-1987
361	F-9, F-11	2,9-3,0	553-565	1991-1993
362/1	F-9, F-11	1,5-1,6	567-578	1994-1997
363	F-15, F-17, F-19	2,6-2,8	617-633	1997-1999
401/2	F-15, F-17	2,3-2,4	638-647	1999-2000
403/1	H-7, F-15	3,4-3,5	648-659	1989-2001
„PNIOWEK" colliery – mining done				
359/1	S-1, S-3, S-4	1,3-1,4	517-552	1974-1976
359/3	S-2, S-3, S-4	1,2-1,5	522-570	1975-1977
360/1	S-2, S-6	2,0-2,3	538-567	1976-1978
361	S-1, S-2, S-3	1,7-2,4	564-587	1980-1984
362/1	S-2, S-3	1,4-1,6	577-585	1983-1985
363	S-1, S-2, S-9, S-9A	2,1-2,4	628-674	1987-1993
401/1	S-8	1,7-1,9	640-650	1995-1996

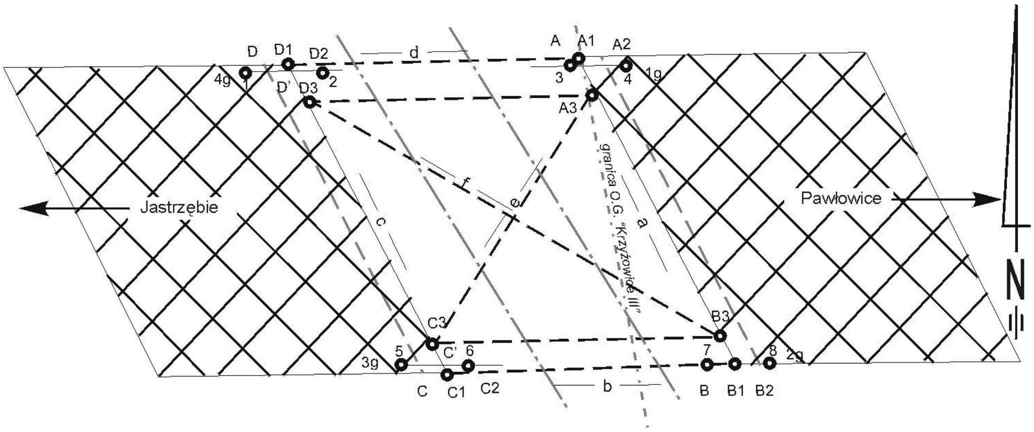

Fig. 5. Placement of bench-marks on the old viaduct

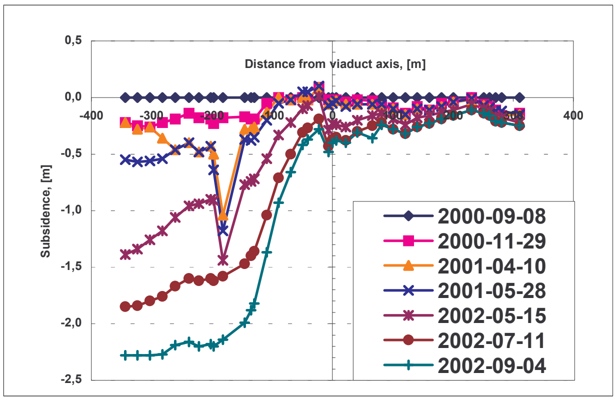

Fig. 6. Subsidence of the old viaduct in the period between 09. 2000 and 09.2002

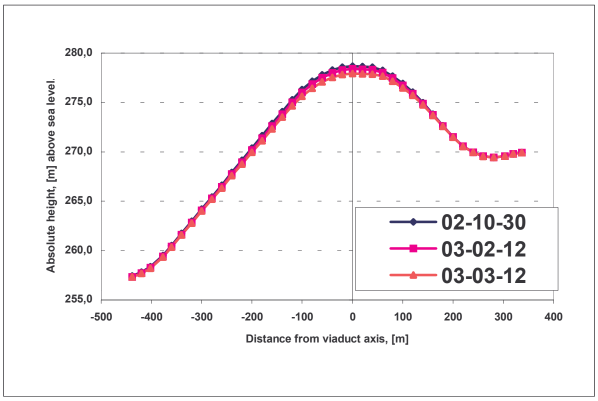

Fig. 7. Subsidence of the new viaduct in the period between 30.10.2002 and 12.03.2003

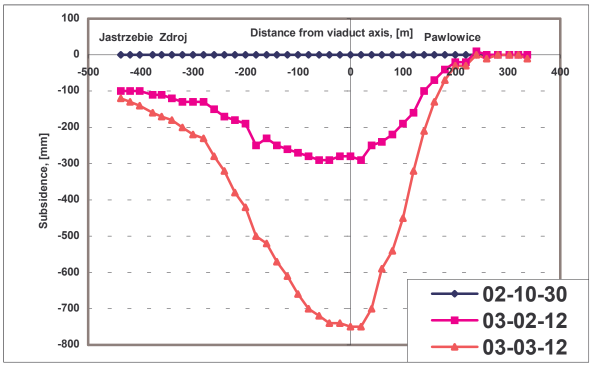

Fig. 8. Subsidence of the new viaduct in the period between 30.10.2002 and 12.03.2003

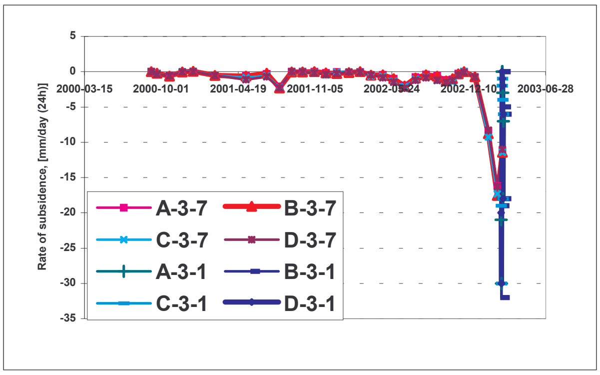

Fig. 9. Rate of subsidence in time of bench-marks of the old viaduct

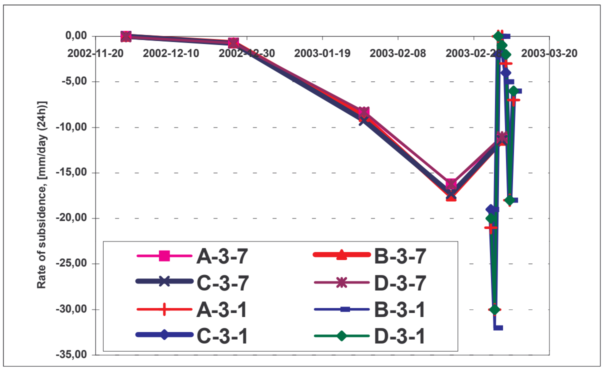

Fig. 10. Rate of subsidence in time of bench-marks of the new viaduct, calculated from measurements made over longer periods of time as well as made daily

4. Construction of a high and steep embankment of material strengthened with geosynthetics.

The focal point for the construction of the new embankment, strengthened with geosynthetics, has been the reinforced concrete viaduct, designed by Ph. Dr Eng. J. Śliwka, running over the railway tracks used by the mining industry. The inside height of the viaduct is 9,0 m; the design provides a reserve for subsidence and correction of the railway tracks formation line, amounting to 4,5 m. The earthworks comprised the construction of two embankments leading to the viaduct, having the total cubic capacity of about 120 000 m^3 , and the total length of 775 m. The inroads have been delineated with a arc of the radius R=2500 m. The gradients of the embankment slopes at internal arc amount to 1:0,7. The maximum height of the embankment amounts to 16,5 m. The operational load by vehicles has been assumed as q= 33,3 kN/m^2.

Most probably the new construction is first of such kind in Europe, perhpas also first all over the world, to be constructed in the area having the fourth, the highest permissible, category of mining subsidence allowing for construction of engineering objects, with the use of highly salinated and sulphurized waste rock as material for construction of the embankment, which would obtain proper shape and form of consecutive layers of the embankment, the whole embankment consisting of a number of layers reinforced with properly calculacted and selected geosynthetic materials. The mineral material (fresh unrelieved waste rock delivered directly from the colliery was arranged into construction layers (thickness 50 and 70 cm) in the form of full matresses, half mattresses, and quarter mattresses made of geogrids produced of material (fibres) of highest chemical resistance (scope of resistance to pH: 2÷12 over up to 120 years): PVA (polyvinylalcohol). The fact of builing on the area where undergroung mining is continued demanded utmost caution of the constructors when designing and selecting technological solutions. During the implementation phase, problems appeared which could weigh heavily upon the stability of the entire object, which required continuous consultations with respective specialists and bodies performing the supervision, as well as taking rational engineering decisions, design correction included.

The old viaduct, functioning so far, lost its limiing outline due to post-mining subsidence (cf. item 5), which threatened with stopping the continuous transport of coal out of the three collieries. Under such circumstances, reinforcement of new constructions with geosynthetic materials was beyond discussion. A series of preparatory works had to be carried out in connection with the reinforcement of the subsoil. In the foredesing it has been assumed that the construction will subside by 4,5 m by the year 2011.

In developing the geometry of the construction, elements of the existing structures have been used, located beside but damaged embankment, for partial leaning of the northern slopes of the new embankment against them.

The entire construction has been based upon: own experiences [5-10], norms from several European countries [11-15] as well as professional literature available in that respect [16-18].

After levelling the site and installing the French drainage systems in the base of the embankment, the work proceeded to prepare the subsoil for the layers of the construction proper. In order to enhance the static properties of the construction, the foundation has been provided with a strengthening mattress made of mechanically compacted aggregate, with double sided shielding (full mattress) of geogrid FORTRAC® R 250/30-30M, uncoiled perpendicularly to the embankment axis. The thickness of breakstone/aggregate in that layer was 70 cm. That was followed by forming the construction layers of the embankment, each of which was 50 cm thick. The geosynthetic reinforcing inlays/inserts were of geogrid FORTRAC® M. For the facing of individual layers, the geotextile FIBERTEX® type F-4M was used. To strengthen the body of the embankment, every seventh layer had the form of full mattress. Proper tension of the grid was obtained via the grid-pulling system developed and adjusted by INORA Company. Individual layers were formed using special special boarding installed inside the embankment (Photo 1). The basic parameters of geosynthetics applied are listed in Table 2.

Table 2. Abridged technical characteristics of some geosynthetics used

Type of material: Geogrid producer: *HUESKER Synthetic* Geotextile producer: *FIBERTEX A/S*		FORTRAC R250/30-30M	FORTRAC R80/30-30MP	FORTRAC R55/30-30MP	FIBERTEX F-4M
Technical Approval Number	Unit	AT/2000-04-0977	AT/2000-04-0977	AT/2000-04-0977	AT/99-04-0707
Nominal immediate strength [F_k] Tensile strength (UTS) -longitudinal -transverse	kN/m min. min.	 ≥250 ≥30	 ≥80 ≥30	 ≥55 ≥30	 ≥18 ≥19
Ultimate elongation: -longitudinal -transverse	% max. max.	 ≤6 ≤6	 ≤6 ≤6	 ≤6 ≤6	 65 80
Calculated strength for 120 years of use (for ultimate elongtation of ε≤3% for 120 years) [$F_{d,120}$]	kN/m min.	82,5	25,2	17,3	-

Photo 1. Installation of subsequent layer of reinforcement using the climbing shuttering by INORA® Ltd.

Detailed construction calculations proved the necessity to use three types FORTRAC® grid: R250/30-30M, R80/30-30MP, and R55/30-30MP, which provide the most economically efficient ratio between long term strength (F_d) and nominal (ultimate) tensile strength (UTS) for assumed permissible elongation of the reinforcement: up to 2% during installation and maximum 1% additionally during the 120 years of use of the construction. In that specific case additional 2 % has been provided as reserve elongation because of mining subsidence, thus the maximum total elongation excluding post-mining deformations has been assumed at: $\varepsilon \leq 3\%$. The total amount of geosynthetic materials used approached 240 000 m^2. The filling of mattresses was mudstone, a waste rock originating from the current activities of the colliery KWK „Pniowek", which contained about 10% of coal. For fear that self-ignition of that material might occur, individual reinforced construction layers were separated with layers of sand, thickness about 10 cm. French drainage of varying dimensions (from 50 to 120 cm deep) was made of geotextiles FIBERTEX® type F-4M, filled with natural mineral material having good compacting properties, grain size 40/63 mm. Also in that case the construction was put into operation without any consolidation period.

The main goal of the undertaking, on the part of the authors of the project, was to prove that it was possible to use recently excavated waste rock as cheap material for civil engineering constructions, roads, and motorways. In particular they had in mind the construction of the A1 motorway section: Gliwice – Gorzyczki, to be built soon, a substantial part of which will run in areas with active mining.

Photo 2. View of the completed embankment from the town of Jastrzębie Zdroj on the day of commissioning the completed construction

5. The influence of mining activities carried out so far upon the viaducts

Measurements on the old viaduct have been carried out since 1979. Bench marks have been installed on the viaduct (Fig. 5), and have been used for the measuring of subsidence and changes in expansion gaps. Because in the years 1985, 1990, 1994, and 2000 the viaduct was repaired, some bench marks were destroyed temporarily, and were restored later.

On the basis of geodetic measurements (surveys) and interpolation of the subsidence over a few short periods (replacement of bench marks) it was possible to find out about the subsidence of the viaduct since the time when the influence of the mining activities upon the viaduct became known, that is in the years 1979-2002. The subsidence of bench marks on the old viaduct, in the period 1979-2002, are presented on Fig. 2. The maximum subsidence of the viaduct in that period amounted to 6,86 m.

Also the distances between bench marks and widths of expansion gaps were measured on the viaduct (Fig. 5). The results of those measurements in periods between repairs of the viaduct are presented on Fig. 4. The widest opening of expansion gaps appeared in the years 2000-2002 and amounted to about 290 mm. Due to the fact that the viaduct is located on the bordering pillar (Fig. 1), there were stretching deformations along the road axis.

The subsidence of the old viaduct in the period between September 2000 and September 2002 are presented on Figs. 3 and 6. The maximum subsidence for that period of two years amounted to 2,28 m. In April 2001, a non-continuous deformation in the form of threshold formed on the access embankment from the western side.

The subsidence of the new viaduct in the period between 30.10.2002 and 12.03.2003 is presented in Figs. 7 and 8. The new viaduct subsided by maximum 0,75 m in that period.

For the engineering objects on the ground the rate of surface subsidence is crucial. The measurements indicate that the rate of subsidence, especially in the recent period, increased substantially. The subsidence rate of the old viaduct in the period between 09.2000 and 11.03.2003 is presented in Fig. 9. The maximum subsidence rate until the end of 2002 was less than 2,5 mm/day (24h). In connection with the fact that towards the end of December 2002 mining started in the first coal bed of the bordering pillar directly under the viaducts, the subsidence rate increased substantially in 2003, measured in monthly periods they reached a maximum of 17,5 mm/day (24h) (Fig. 10). In the period between 04.03.2003 and 11.03.2003 the measurements of subsidence were taken daily on the viaducts. The results of those measurements indicate that the subsidence rates were different in each day of the week, and amounted to between 0 and 32 mm/day (24h). Those measurements confirm the results of studies [2÷4] concerning the influence of frontage progress and breaks in ining activities upon the subsidence rate. They also testify to a substantial loosening of the rock mass, which will be an unfavourable circumstance considering the planned further mining activities under the viaducts.

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