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Use of geosynthetics for strengthening road surface and subbase in areas with the mining activity

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ABSTRACT: The results of the orginal theoretical and experimental works are presented, concerning the utilisation of geosynthetics for strengthening of the subsoil, road - railway surface and embankment on the area subiected to mining influence. The tests were carried out on the analog ground medium of Taylor - Schneebeli type and on the natural ground. Numerical tests were based on finite elements method software, version CRISP-94 (Cambridge).

1 MINING DAMAGE TO TRANSPORTATION STRUCTURES

The impact of underground mining activity on the land surface is manifested in the form of multi-parameter deformations, as shown in Fig. 1.
The deformations describe:
- land subsidence w [m]
- slope $T = dw/dx$ [mm/m]
- curvature $K = d^2w/dx^2$ [1/R=1/km] (1.1)
- horizontal displacement u [m]
- unit horizontal strain $\varepsilon = du/dx$ [mm/m]

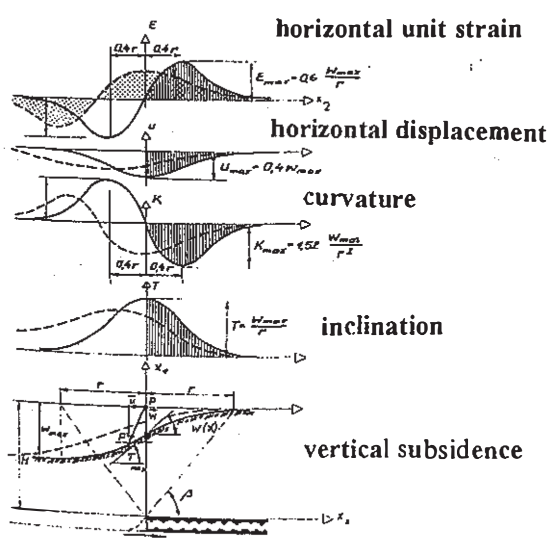

Fig. 1. Indices of surface deformation within subsidence trough

The occurrence of the deformations is practically unavoidable. Extensive range of damage to transportation structures was discussed by the author in paper [2].
The destructive phenomena observed in the subsoil [4,6] involve the propagation of horizontal loosening strain ε^l in the boundary zone of land subsidence trough. This deformation results in the loss of load capacity and stability of the subsoil, which, in turn, is induced by local zones of the boundary condition. The loss of load capacity is also caused by the reduction of the parameters determining the ultimate subsoil resistance [3].

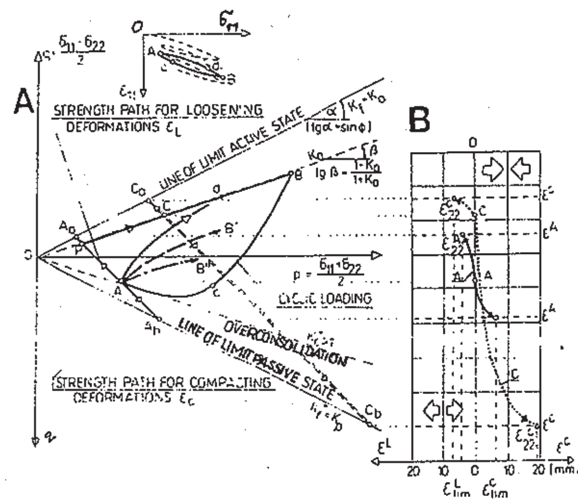

Fig.2 Analysis of subsoil behavior in mine-induced deformation areas in view of the stress path method:
a) normally consolidated C and over-consolidated soil A in the cyclical load conditions, b) boundary values of the subsoil strain

The cohesion od the loosened soil is reduced by 20-40% (65 % max), the porosity ratio decreases by 10%, and the concurrent value of the angle of internal friction is moderately lowered.
For the ultimate loosening strain value ε^{l}=3-6 mm/m horizontal stresses acting on the subsoil stabilize to the corresponding active Rankine state [2, 3].
In Fig.2. the analysis of subsoil behaviour in mining areas is presented, in view of the stress path method related to the estimation of the ultimate horizontal strain $\varepsilon_{lim}^{l,c}$ for normally consolidated (C) and over-consolidated (A) soil respectively.
In such case, the phenomena occurring in the subsoil may be described by the changes in the value of the earth pressure coefficient, determined by the following relations:
- for horizontal loosening strain:

$$K_{\varepsilon}=\sigma^{l}_{22}/\sigma_{11}=K_{0}-E_{e}(1+\varrho\nu)\alpha_{l}\sigma^{-1}_{11}\varepsilon^{l}_{22}\geq K_{min} \quad (1.2)$$

- for horizontal compacting strain:

$$K_{\varepsilon}=\sigma^{c}_{22}/\sigma_{11}=K_{0}+E_{e}(1+\varrho\nu)\alpha_{c}\sigma^{-1}_{11}\varepsilon^{c}_{22}\leq K^{max} \quad (1.3)$$

The boundary values of the earth pressure coefficient result from the condition of subsoil flexibility:
- for loosened soil:

$$K_{max/min}=tg^{2}(\pi/4\pm\Phi/2) \quad (1.4)$$

- for cohesive soil:

$$K_{max/min}=tg^{2}(\pi/4\pm\Phi^{*}/2) \quad (1.5)$$

$$\Phi^{*}=arctg(tg\Phi+c/\sigma_{11}) \quad (1.6)$$

where: Φ^{*} = generalized form of the internal friction angle; σ_{11}=normal stress; $\sigma_{22}^{l,c}$=horizontal stress in mine-induced loosening strain or compacting strain; K_0=earth pressure coefficient in the geostatic condition; E_e=module of soil susceptibility, dependent on soil porosity index e; ϱ =relation of horizontal strain to the main direction of land subsidence trough $(\varepsilon_{33}/\varepsilon_{22})$; $\alpha_{l,c}$=coefficient of the changes in soil compressibility module in the loosened or compacted soil:

$$\alpha_{l}=E^{l}_{\varepsilon}/E_{o} \quad (1.7)$$

$$\alpha_{l}=1+\frac{\sigma_{01}}{\sigma_{01}+\sigma_{11}}[1-\exp(1+e_{o})(1-K_{o})(1+\varrho)A^{-1}\varepsilon^{l}_{22}]$$

where: E_{ε}^{l}=compressibility module of the loosened subsoil induced by mining; E_0=initial subsoil flexibility module; σ_{01},A=parameters of the stress curve; e_0=initial soil porosity index.
It may be observed that for $\varepsilon^{l}_{22}\neq0$ coefficient $\alpha<1$,

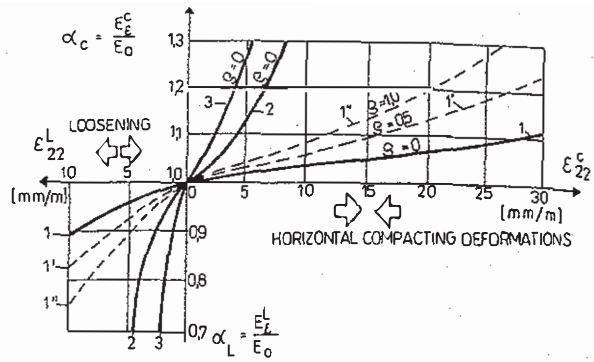

Fig.3 Coefficient of the changes in subsoil compressibility module for loosened soil: 1- loosened state, 2- medium- compressed state, 3- compressed state

which leads to the reduction of the initial value of soil compressibility module by:

$$\Delta E^{l}_{\varepsilon}=E_{o}(1-\alpha_{l}) \quad (1.8)$$

In Fig.3. the changes in coefficient α_l for the loosened soil of compressibility ratio are presented. Horizontal loosening strains ε^{l}_{22} occurring in mining areas reduce the value of the subsoil flexibility module, which is the main geotechnical parameter of the subsoil, by 30-50 %.
Therefore, road surface and subbase must be strengthened, and railway embankments and other earthen structures reinforced and stabilized. Such protection measures constitute a serious maintenance, engineering and financial problem, as in Silesia the total length of railways is 600-800 km.

2 EFFECTIVE METHODS OF STRENGTHENING THE SUBSOIL IN MINING AREAS

The theoretical solutions discussed above are verified by practical field tests. Only few of the currently applied methods of subsoil strengthening are effective in mine-induced deformation areas. Effective strengthening of the subsoil characterized by low-load capacity must combine two, partly contrary requirements: maximum reduction of horizontal stresses acting in the subsoil of structures and, at the same time, increase of its load capacity by diminishing local plastic strains inducing further vertical subsidence [1, 2].
Currently applied methods of underground stabilization of the subsoil such as: dynamic compacting, deep soil replacement, over-consolidation, injection or petrification, do not fulfill the above mentioned requirements.
As far as surface strengthening is concerned,

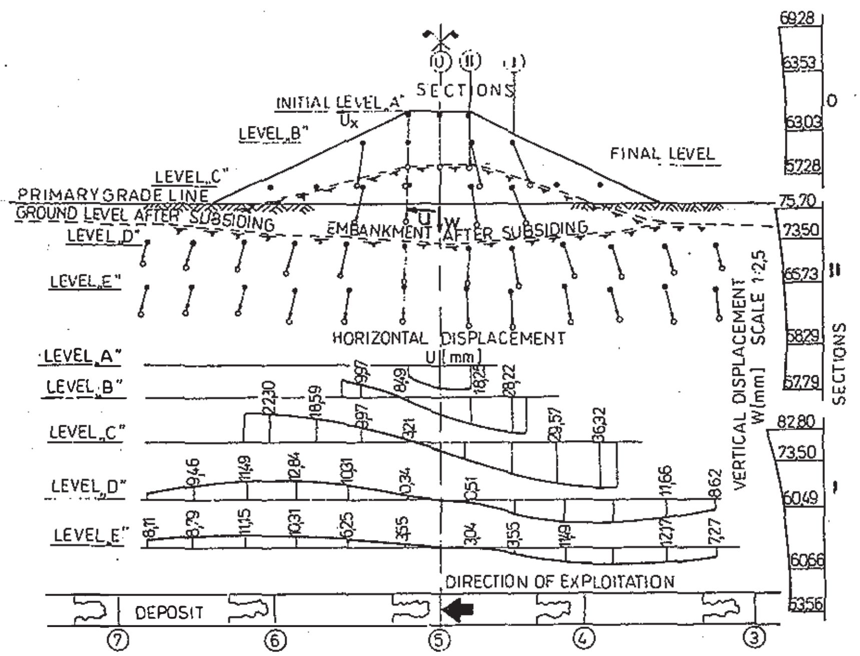

Fig.4 Kinematic interaction of the subsoil and embankment without strengthening in a mining area

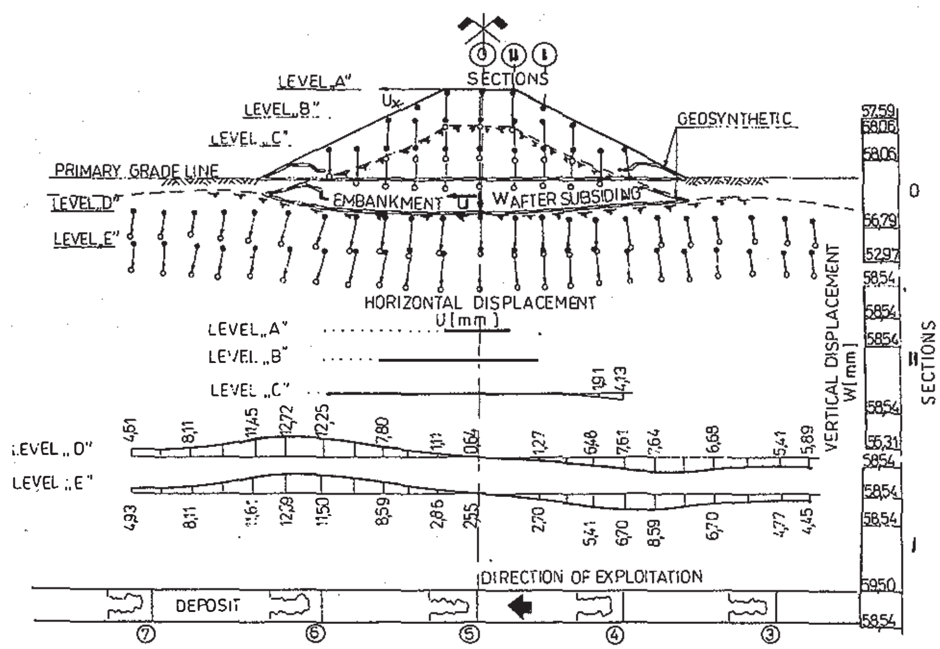

Fig.5 Kinematic interaction of the subsoil and embankment strengthened by geosynthetic layer in a mining area

dynamic compacting, surface layers replacement and surface stabilization techniques are also ineffective. On the other hand, soil reinforcement techniques and horizontal separation of subsoil layers seem to be rendering promising effects, confirmed by the results of experimental tests.

The tests were conducted on an analogue ground medium of the Taylor-Schneebeli type [5] to exemplify the use of geosynthetics to strengthen embankments, Fig.4, 5 and the railway subbase, Fig.6, exposed to mine-induced deformations.

The analysis of the kinematic interaction between the subsoil and a given structure proves that effective reduction of horizontal loosening strains has been achieved in the layers above the geotextile cut-off-wall.

Thanks to this, the stability of the subsoil physical and mechanical parameters may be improved with

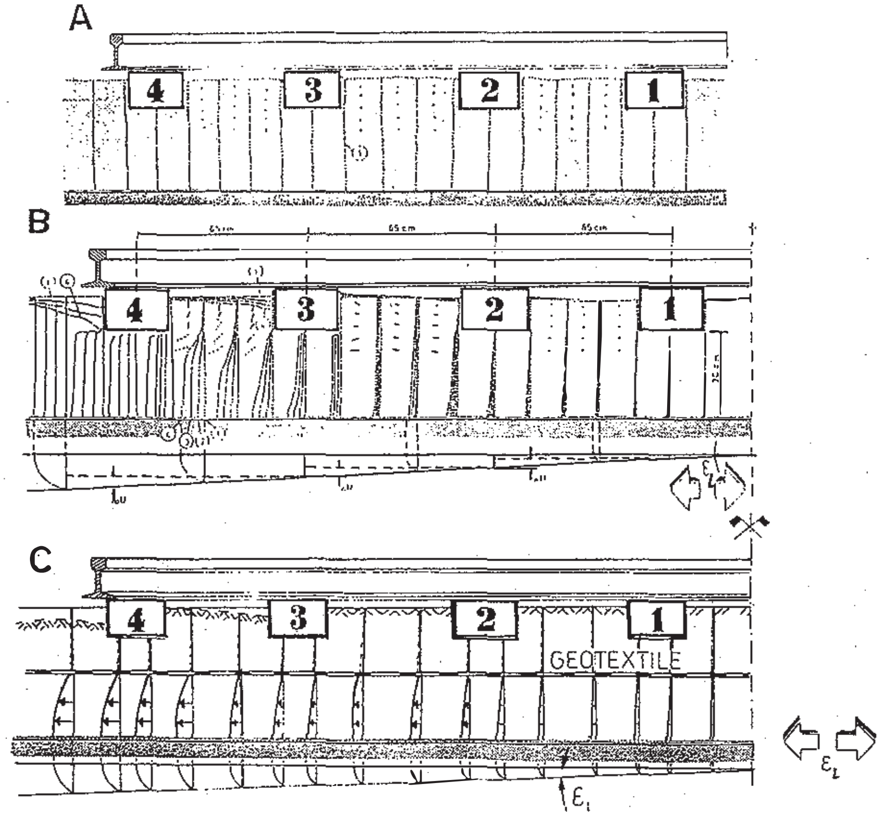

Fig.6 Kinematic interaction of the subsoil and railway subbase strengthened by geosynthetic

regard to earthen and transportation structures, which, in turn, secures better load capacity and stability of operation.

3 NUMERICAL ANALYSIS OF THE SUBSOIL STRENGTHENED BY THE GEOSYNTHETIC IN MINE-INDUCED DEFORMATION AREA

The numerical calculations involved the comparative estimation of all stress components in the subsoil characterized by low load-capacity, with module E_2=30MPa, strengthened on the surface by the layer of E_1=300MPa and additional geosynthetic reinforcement of module E_3 = 600 MPa.
The calculations were made by means of the finite elements method and the British CRISP'94 program package, describing a triaxial stress state of the system: wheel-pavement-subsoil of low load capacity in a mine-induced deformation area.
The discreted form of ground half-space by a network of 80/112 finite elements is presented in Fig.7A-B.
The isobars of the stress state components $\sigma_{z,x,y}$ and τ_{xy} for the load of vehicle wheel P=50kN are shown in Fig.7-10.
The discussed results indicate diverse conditions of the subsoil behaviour, which in the axial cross-section of the zone strengthened by the geosynthetic is characterized by a 30 % reduction of vertical stresses σ_y and a 65 % reduction of horizontal stresses σ_x respectively.
Horizontal loosening stress zones occurring in the subsoil are a consequence of the even distribution of contact stresses q assumed in the introduction of the paper.

4 CONCLUSIONS

Multi-parametric land surface deformations induced by mining activity constitute a serious threat to the load capacity and stability of the subsoil of linear transportation structures.
Most of the current techniques used to reinforce the ground are not effective in mining areas, due to the "activity" of the subsoil involving horizontal loosening and compacting strains $\varepsilon_{l,c}$.
The character of the changes occurring in the subsoil in mine-induced deformation areas determines the selection of geosynthetics as the most effective tech-niques of strengthening the pavement of transporta-tion structures and other earthen structures. They function as effective elements of reinforcing the subsoil, separating soil layers, filtrating and draining, and, last but not least, separating the active subsoil subjected to the propagation of local

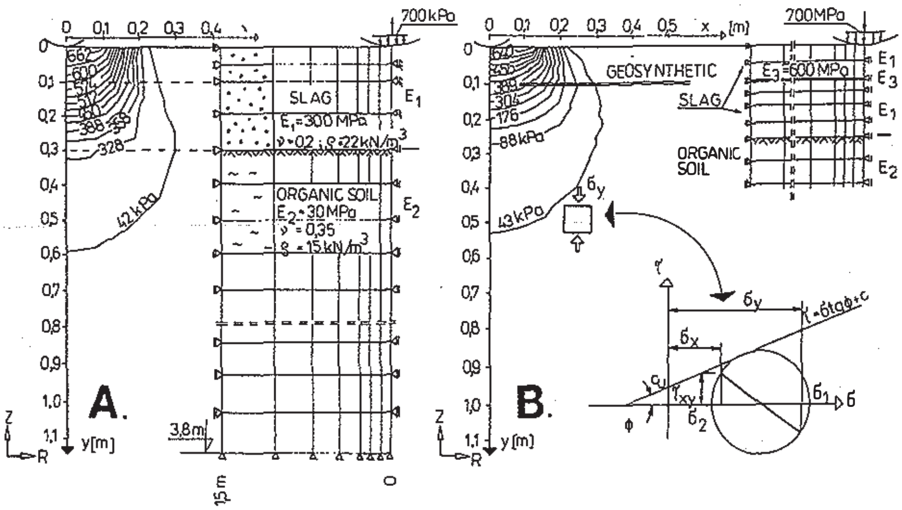

Fig.7 Isobars of vertical stresses σ_y in the low-load capacity subsoil of a local road in a mining area, together with the calculation scheme for: A) subsoil without reinforcement, B) subsoil reinforced by geosynthetic

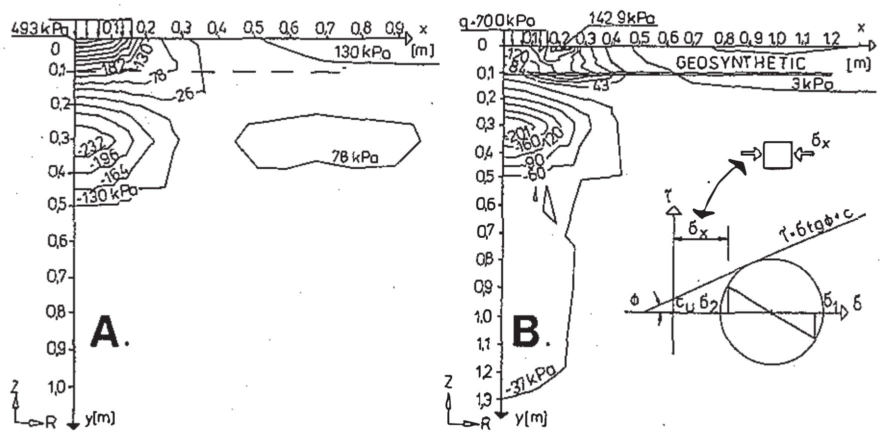

Fig.8 Isobars of horizontal stresses σ_x in the subsoil: A) subsoil without reinforcement, B) subsoil with geosynthetic

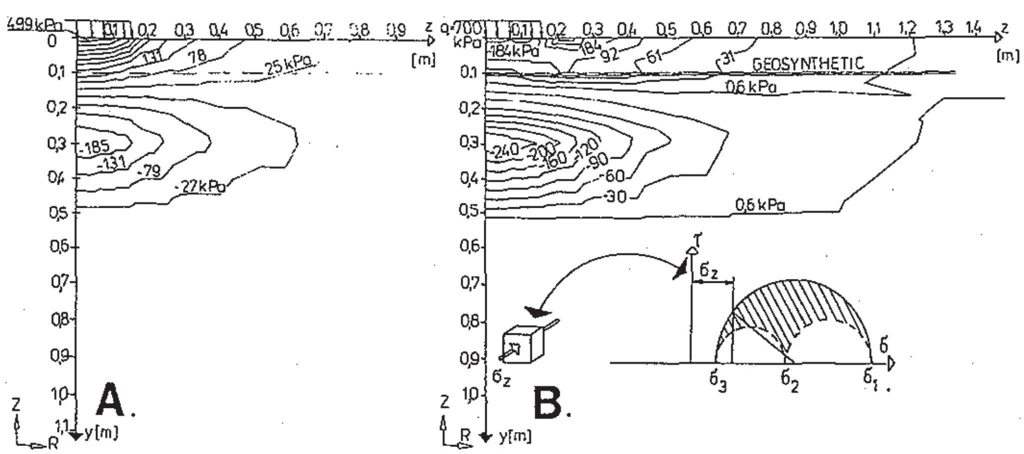

Fig.9 Isobars of horizontal strains σ_z in the subsoil: A) subsoil without reinforcement, B) subsoil with geosynthetic

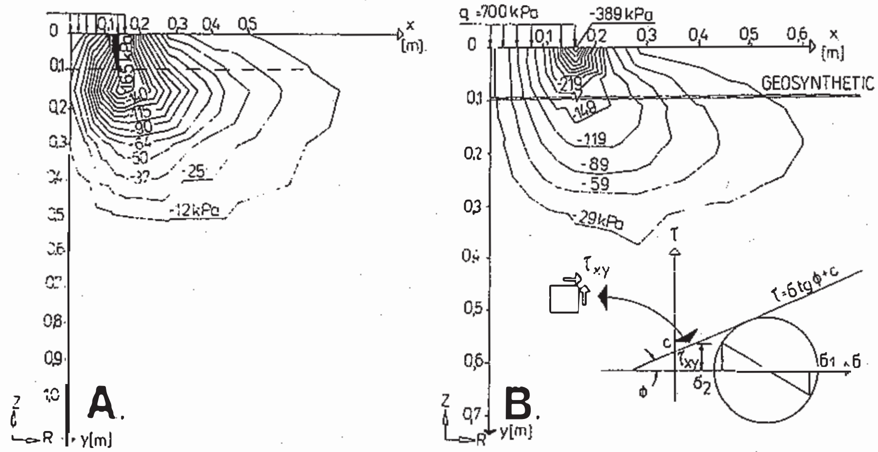

Fig.10 Isobars of tangential stresses τ_{xy} in the subsoil: A) subsoil without reinforcement, B) subsoil with geosynthetic

boundary states from the upper load-bearing layers of the road surface or subbase.

Field observations correspond to the results of the discussed model tests, theoretical analyses and numerical calculations.

The calculation procedures recommended in the paper have been based on the reduction of the flexibility module of the subsoil in mining areas, which made it possible to diminish the load of road surfaces by 15 -30 % and to simplify the technology of maintenance works; yet, at the same time, improving road durability and reliability of operation.

The road and railway segments, together with earthen structures (embankments) reinforced by geosynthetics, are more resistant to the destructive impact of mining deformations arising in the subsoil, which confirms the relevance and practical advantages of using geosynthetic technology in geo-engineering works in mining areas.

REFERENCES

Kłosek K. 1992. Efficiency of geosynthetic strengthening of railway bed in conditions of dynamic reactions of vehicles. Field tests of "SFCM prototype". International Symposium on "Applications of Geosynthetic Technology", IGS, Jakarta: 7-12. [1].

Kłosek, K. 1994. Prevention of damages to highways and railroads in mining areas. International Land Reclamation Conference, ASSMR, Pittsburgh, PA, USA: 101-110. [2].

Kłosek, K. 1995. Earthen structures in mining areas. International Land Reclamation Confe-rence, ASSMR, Gillette, WY, USA: 495-501. [3].

Kłosek, K. & Frydrych K. 1995. Technologies of mining waste utilization in engineering struc-tures with the application of geosynthetics. The 11th International Conference on Solid Waste Technology and Management. Philadelphia, PA, USA: 311-318. [4].

Kłosek, K. 1996. Use of analogue ground medium of Taylor-Schneebeli type for modelling of multiparametric deformations arising in mine-influenced area. International Land Reclamation Conference. ASSMR, Knoxville, TE, USA. [5].

Kłosek, K. 1995. Geotextiles in designing and construction of transportation structures in mining areas. Conference " Surface and Earthen Structures Protection against Mining Damage", GIG, Katowice, Poland: 349-354. [6].