EARTHEN STRUCTURES IN MINING AREAS[1]

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Abstract: The problem of lowered load capacity and stability of transportation and hydrotechnical earthen structures exposed to mining-induced influence is discussed.
Results of the author's model invesigation and site measurements are demonstrated, together with theoretical analysis of the phenomenon of plastic zones development in the mining subsoil.
Extensive influence of horizontal strains in mining areas on the resistance properties of the soil is evidenced. The author's proposal is to strengthen the load capacity of the subgrade and stability of earthen structures by the application of geosynthetics.

Additional Key Words: Load Capacity-Stability; Earthen Structures; Mining Deformations.

Introduction

Due to underground mining activities land subsidence "W" and its slope "T" increase, which, in turn, results in substantial deformation of elongated earthen structures such as: embankments, transportation cross-drifts, reservoir and water- course dikes.
The need to maintain the functional utility of earthen structures compels periodical rectification of their body grade line, which is illustrated in Fig.1.

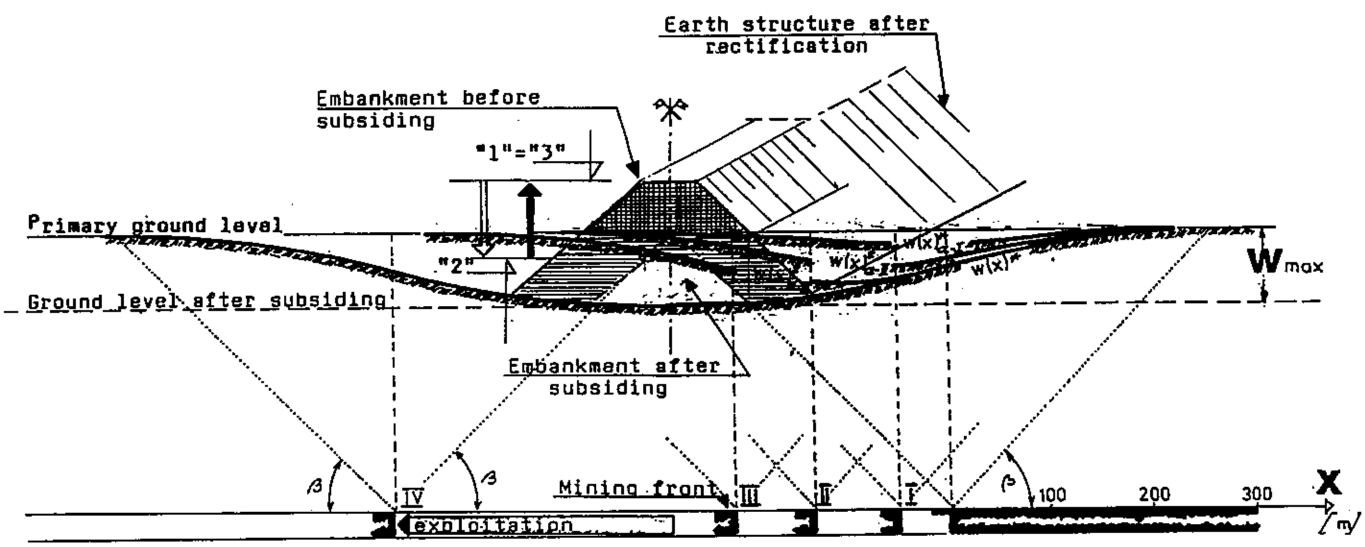

Figure 1. Changing of grade lineas in earthen structures on mining subsidence areas.
"1" - primary (designed) grade line
"2" - permanent grade line,
"3" - ultimate grade line, after rectification.

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Because of this, the height of embankments keeps rising, often reaching 20-30 m., especially if the deficiency of stowing within the zone of the worked deposit and numerous mining seams are considered. One of the most destructive factors acting on the structure load capacity and stability is the influence of horizontal loosening strains ε, (Kłosek, 1988/1994) which result in:

- loss of load capacity in the rail subgrade zone and embankment foundation due to sectional plasticization of the subgrade,
- lateral deformation of structure shape and its additional lowering below the level of land "W" mining -induced subsidence,
- loss of the stability of slopes due to landslip, landslide, land-flow. All these effects threaten the safety of earthen structures and their continuous utility, which in the case of transportation and hydrotechnical embankments may lead to dangerous failures and even catastrophes. Falling back on the experience of observing such phenomena in Poland, it is evident that in mining areas they occur 3-4 times more often.

The paper presents the most important results of model investigation and site measurements concerning these phenomena, with indication to their origin and effective preventive measures.

Results of model investigation and site measurements

To carry out model geotechnical investigation (in 1:100 scale) the Taylor-Schneebely type analogue medium was applied, placed in a container simulating underground mining activity in the direction perpendicular to the linear axes of the investigated structure. Such location of embankments or cross-drifts in relation to the mining front is the least expedient.
Fig.2. illustrates the initial stage (1), successive phases of the deformation of the structure cross-section in relation to the mining front advancement (2-4) and the final stage (5). The embankment deformation is characterized by the "apparent sinking" of the structure in relation to the land site, especially in the boundary zone of subsidence through. Also, sectional zones of landslide off the embankment slopes and land uplift from the embankment foundation were observed.

Deformation of the cross-drift entailed no subsidence of the bottom zone (on the contrary, its upthrust was observed for deep cross-drifts), but, at the same time, the close-to-surface zone was lowered. As a result, the cross-drift was apparently shallowed and its cross-section permanently deformed. Similar results were observed for the existing structures, illustrated in Fig.3. Substantial deformation of the upper edge of the subgrade is caused by the rolling stock traffic and by lowered load capacity of the subsoil.
The phenomena described above result from temporary loss of the soil primary cohesion (Kwiatek 1982, Kłosek 1988), which is a consequence of the development of local boundary equilibrium states for the loosened subsoil, illustrated by the dependence:

$$\sigma_{ik}^{l} = \sigma_{22}^{*} - \Delta\sigma_{ik}^{l} \geq \sigma_{22}^{\min} \; ; \qquad (1)$$

where:

σ_{22}^{*} - horizontal strain of the subsoil [MPa],

$\Delta\sigma_{ik}^{l} = \dfrac{2E_h\,\varepsilon_l}{1-\nu'}$ - horizontal strain reduction in the loosened subsoil [MPa],

E_h - module of soil lateral elasticity [MPa],
ν - Poisson's coefficient,

$\sigma_{22}^{\min} = \sigma_{11}\, tg^2(\frac{\Pi}{4}-\frac{\Phi}{2}) - 2c\,tg(\frac{\Pi}{4}-\frac{\Phi}{2})$ - Coulomb's criterion for the boundary state,

Φ - angle of the internal friction of the soil [^{0}],
c - soil cohesion [MPa].

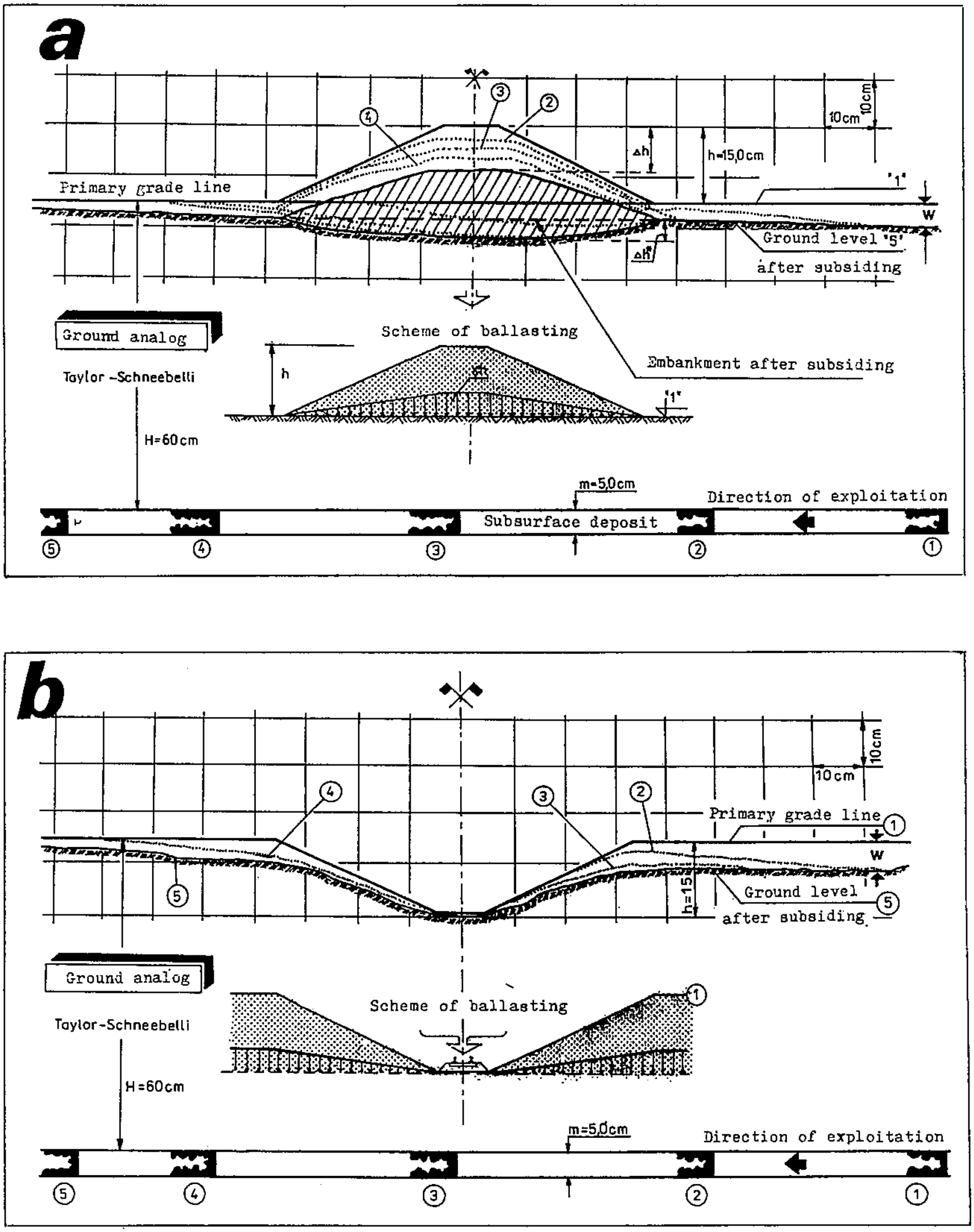

Figure 2. A model representation of the effect of dynamic subsiding trough on embankments and cross headings making use of the ground analog of Taylor-Schneebeli type.

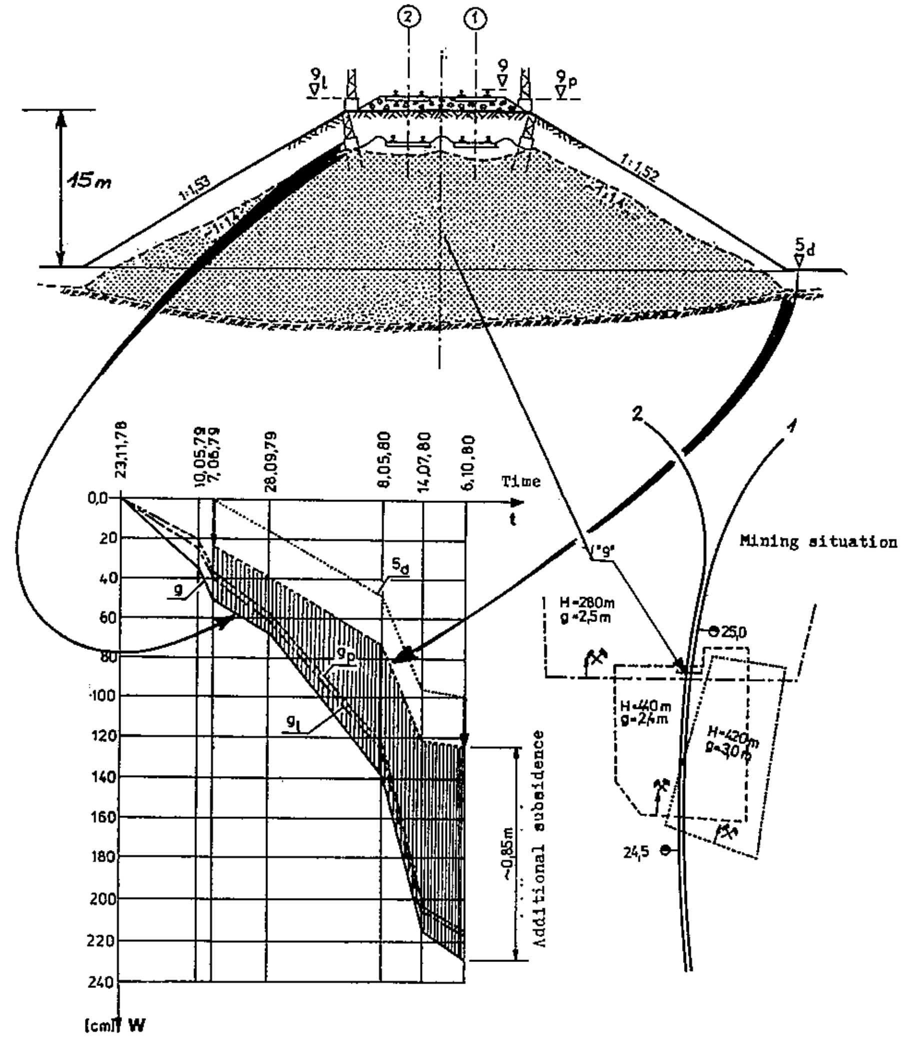

Figure 3. The results of proof ground investigations of railway embankment (H=15m) located within a range of influances of underground mining.

The strain resulting in the occurrence of boundary state for given subgrade point is described as critical strain:

$$\varepsilon_{cr} = \frac{1-\nu}{2\,E_b}\left[\sigma_{22}^{*} - \sigma_{11}\, tg^2\left(\frac{\Pi}{4}-\frac{\Phi}{2}\right) + 2c\cdot tg\left(\frac{\Pi}{4}-\frac{\Phi}{2}\right)\right]; \tag{2}$$

For a trapezoid diagram of the subgrade elastic half-space loaded by a half of the symmetrical embankment, according to Fig.4.,
the following equations were assumed:

$$\sigma_{11} = \frac{P}{\Pi\, a}\left[a\,\beta + x\,\alpha - \frac{az}{r_2^2}\,(x-b)\right]; \tag{3a}$$

$$\sigma_{22} = \frac{P}{\Pi\, a}\left[a\,\beta + x\,\alpha + \frac{az}{r_2^2}\,(x-b) + 2\,z\cdot \ln\frac{r_1}{r_0}\right]; \tag{3b}$$

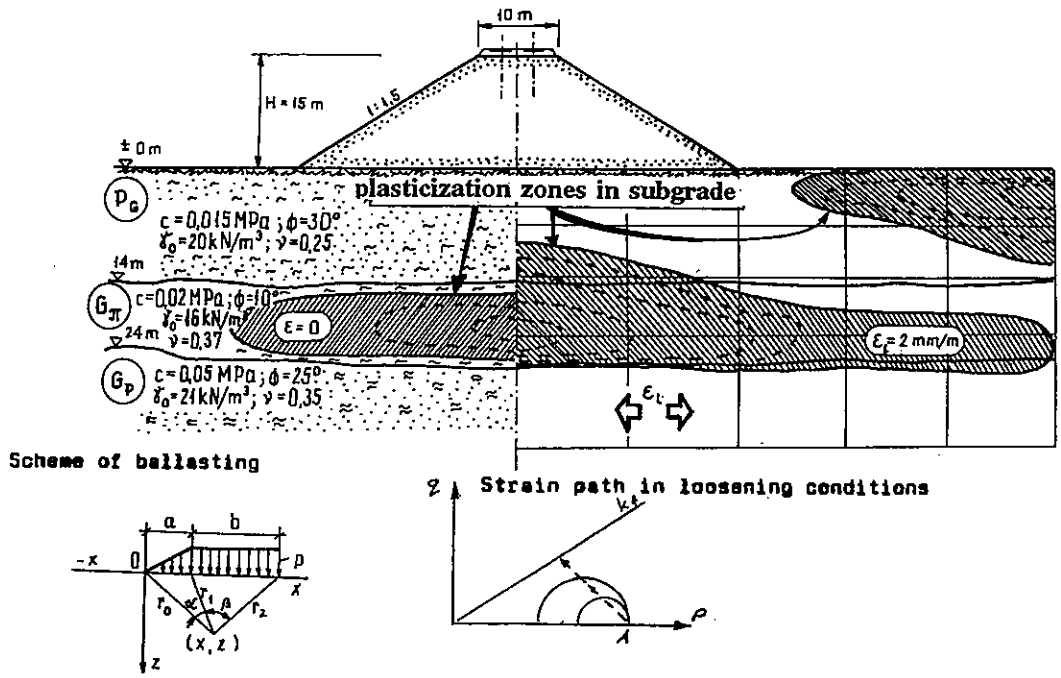

Figure 4. Calculation of plasticization zones in subgrade on mining areas.

Next, numerical calculations were made for the numerical data illustrated in Fig.4 and for equation (2) replaced by dependencies (3a) and (3b). The result of the calculations is the determination of the progression of plasticity zones in the subgrade and in earthen structures with the rise of horizontal loosening strains ε_L. The compilation of calculation results with land surveying measurements (Fig.3.) proves the relevance of the above analysis.

Permanent loss of the subgrade load capacity

Mining-induced deformation of the subsoil, especially its horizontal unit strain ε, influence the soil resistance.
This condition, confirmed by the results of site measurements,
has an impact on the level of the subgrade load capacity.
The core of the problem consists in the intervention of parameter ε_L into the physical and mechanical properties of the soil, which is illustrated in Fig.5 and 6. The loss of the soil primary cohesion leads to permanent loss of the subgrade load capacity (Kłosek.- Graffiaux F.1986). A considerable fall of the soil cohesion by 20 - 45 % (max. value about 65 %) was observed, accompanied by a slight rise of the value of internal friction angle by 7 - 10% and the rise of the porosity ratio by 10 %.
It should be indicated that these changes are not entirely reversible, especially with regard to the soil cohesion:

$$|\tau|_{\max} = \sigma'_{11}\, tg\Phi'_{w} + C_s + \beta(t)\Sigma w \geq \tau'_{\varepsilon_L} = \sigma'_{11}\, tg\Phi'_{w} + \beta(t)\Sigma w \geq \tau_{\min} = \sigma'_{11}\, tg\Phi'_{w}; \tag{4}$$

where:

σ'_{11} - ordinary component of effective stress,

$tg\Phi'_{w}$ - angle of internal friction of the soil with humidity w,

C_s - structural part of soil general cohesion,

Σw - soil cohesion, caused by water and colloid systems,

$\beta(t)$ - coefficient of mining deformation intensity $0 < \beta(t) < 1$.

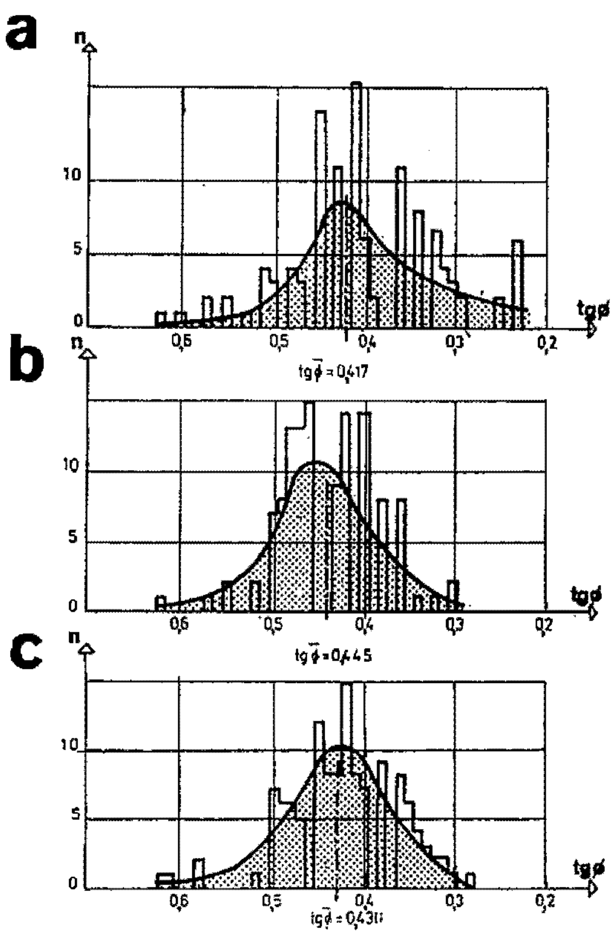

Figure 5. The effect of mining ground strains on the variability of internal friction angle of grounds
a) before occurence of mining effects,
b) during interaction of mining with surface,
c) after discontinuation of mineral exploitation.

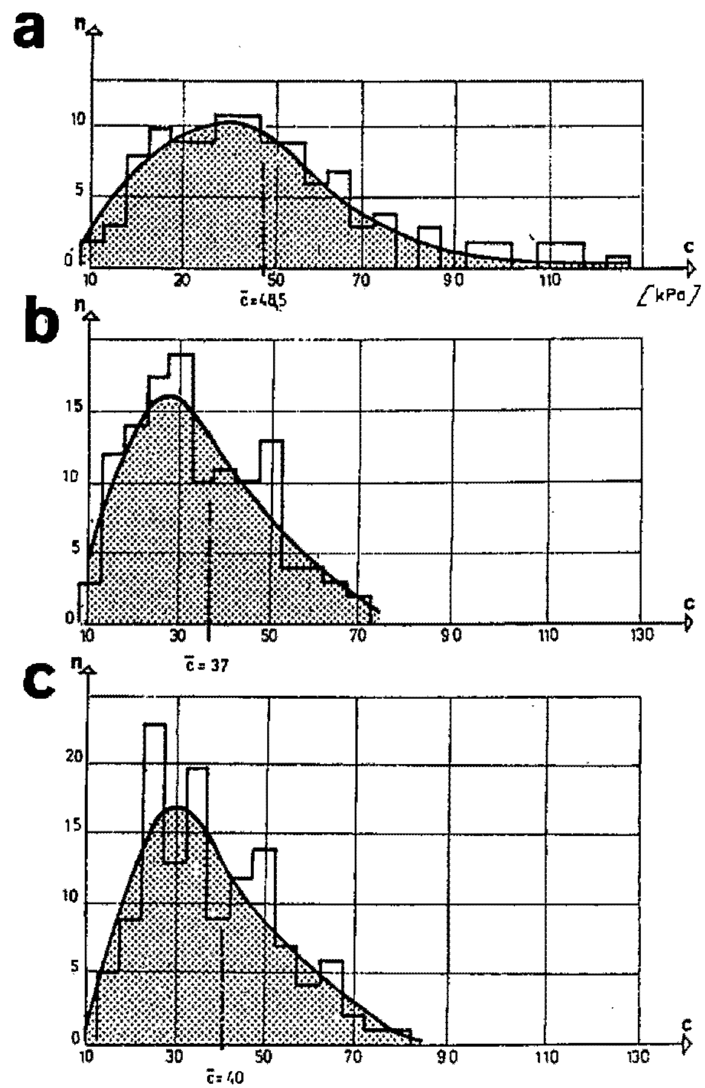

Figure 6. The effect of mining ground strains on the variability of foundation ground cohesion.

Methods of strengthening earthen structures in mining areas

As far as recognized and widely applied methods of surface and underground soil strengthening are concerned, geo-nets and geosynthetics used as reinforcements are effective in mining areas, due to considerable resistance of these materials to additional tensile forces caused by horizontal strains ε, their adaptability to horizontal displacement of the land, relative simplicity of technical treatment and low costs.
Fig.7. presents an example of geo-reinforcement applied to the rectified road embankment in a mining area.

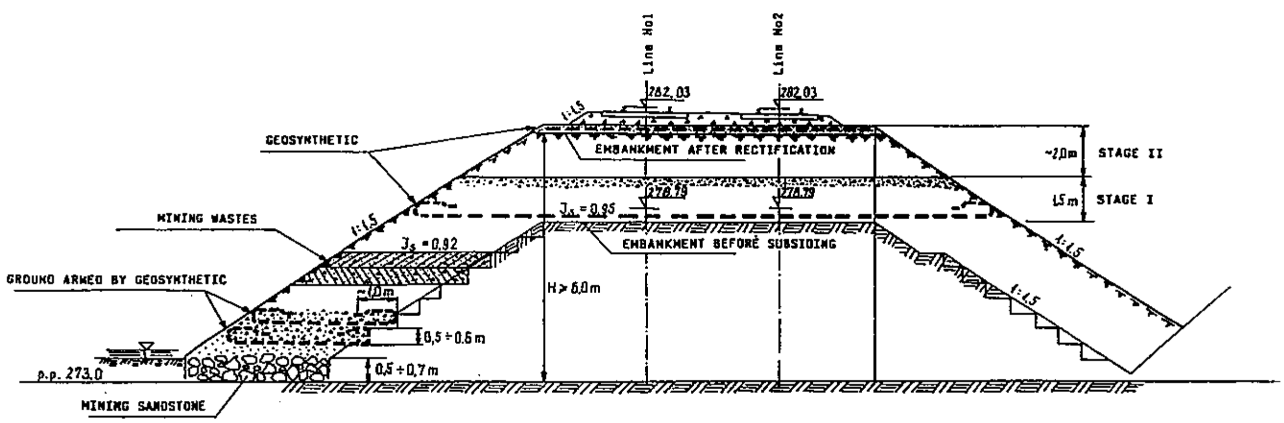

Figure 7. Embankment reinforced by geosynthetics on mining subsidence areas.

Conclusion

Earthen structures in mining areas are exposed to multi-parameter deformations resulting from the influence of horizontal loosening strains ε_L. Because of mining-induced land subsidence, earthen structures must be rectified and their height risen to 20 -30 m. This, in turn, leads to the rise of stresses in the structure and its foundation. Structure load capacity and stability are subject of essential redistribution. Temporary or even permanent loss of the subgrade load capacity is particularly dangerous, it may occur for relatively small loads in the range of $\varepsilon_L = 3 \div 6$ mm/m.
The application of geosynthetics as elements reinforcing the subgrade in mining areas is a very effective solution. The solution secures the increase of load capacity of the uplifted embankment, increasing the stability of the slope zones and of the upper foundation layer, which, for transportation embankments is of great importance.

References

Kłosek, K. 1988. Effect of mining foundation strains on a co-operation of subgarde with a track structure. Proc. Silesian Technical Uniwersity, vol.66, Gliwice-Poland, p.160.

Kłosek, K. and F.Graftiaux, 1986. Interactions des foundations des ouvrages d'art et du sol d'assise en terrain d'exploitation minière. Industrie Minerale-Mines et Carrieres - Les Tchniques, vol.6. Saint-Etienne, Cadex, France: 283-292.

Kłosek, K. 1994. Prevention of damage to highways and railroads in mining areas. Int. Land Reclamation and Mine Drainage Conf., Pittsburgh, PA. April 24-29; 102-110.

http://dx.doi.org/10.21000/jasmr94040101

Kwiatek, J. 1982. Some problems of geotechnics on mining areas. Polish Acad. of Sc., Katowice, Poland; p.127.

Lambe, T.W. and R.V.Witman, 1969 Soil Mechanicis. New York - London - Toronto.

Schneebeli, G. 1975. Une analogie mécanique pour l'etude de la stabilite des ouvrages en terre in a'duex dimensions. Proc. IV ICOSMEF, vol.II, London.