

EFFECT OF COMPACTION, REINFORCEMENT AND RECLAMATION AS A PROTECTION OF SLOPES AGAINST EROSION IN ROAD ENGINEERING EARTHWORKS

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ABSTRACT

The development of building engineering, both transport, hydrotechnical and industrial as well as housing induces the growth of the volume of earth mass at the building sites, which cause the need for a proper protection against destructive influence of water from precipitation and snow melting. The increase of the volume of earth works directly influences their technology, characterized with translocation of large amounts of mass. The paper presents characteristics of reclamation and earth works with emphasis on preparing escarps of earth buildings to their natural finishing.

Key words: road engineering, earthworks and reclamation, geotechnic, road slopes, pratotechnic

INTRODUCTION

Linear earthworks round the waist of road, and particularly road-slopes of embankments and excavations are exposed on the water erosion superficial and windy during the construction and the exploitation (Coppin & Richards, 1990).

Slopes, due to strongly inclined surfaces, are subject to processes of the accelerated erosion. Therefore their execution, relying on the suitable molding, strengthening and farm implements, is very essential in the process of reclamation and maintenance works (Głazewski, 2007).

Essential is, effectively to protect surfaces of slopes before the action of denudation factors. Storm sewages from road surfaces cannot directly flow on non-reinforced ground roadsides and slopes (Fig. 1). Roadsides should be strengthened biologically and

technically simultaneously with the construction of foundations and the surface, and grasses on slopes must have developed third leaflet. The removal of the erosive destructions absorbs up to 20% costs of earthworks (Głazewski & Piechowicz, 2009).



Fig. 1. Concrete reinforcement devastated by through flowing water from the slope

CHARACTERISTICS OF EARTHWORKS AND OF RECLAMATION

Earthworks are actions which rely on the extraction, the displacement and renewed building in the ground. These works occur also at the constructions of embankments and road-excavations.

Reclamation works have for the task a preparation of embankments and road-excavations to biological engineering farm implements (Głazewski, 1999). Such farm implements are necessary to producing of conditions eliminating the superficial erosion and to the preparation of the mineral useful ground to the plant production and the revegetation. The basic medium in the reclamation is the biological mixture, which should be the fertile soil. If while the ground is vain, then one ought to implicate substances replacing soil or synergistic in producing of her main nutrients (Ziaja, 1993). Therefore, necessary is the exact estimation, whether the ground contains the sufficiency of components to biological farm implements and then, whether to designed type of the vegetation will be suitable; for that purpose, necessary will be not only geotechnical research, but also soil, environmental and biological analyses. The essential influence will have also a connection of issues of the stability of slopes with vegetative possibilities of the development of the vegetation in the function of their inclination (Głazewski, 1999).

Road-endeavor maintenance concerns cultivation of the wayside-green, with their utilization and the care of roadsides, slopes, ditches and sewage in a good condition, to be able to fulfil their functions, such as protect slopes of embankments against the erosion and unobstructed to drain drop (Ziaja, 1993).

Designed earthen structures require regards of geotechnical properties of grounds in respect of the foundation, the stability and the maintenance (Pisarczyk, 2015). Without the regard these factors will occur material damages which even if they will not lead to the building disaster, then will cause the increase of investment outlays or the excessive cost-of-living increase. To face up these conditions, necessary is the preparation of technical specifications of the execution and the receipt of works.

GENERAL TECHNICAL SPECIFICATIONS

Technical specifications complies in many countries as the inseparable element of the auction system working in the market economy. This is an attachment to the contract signed by the employer and the performer, binding within the range the construction and the reception of works. Since many years on provincial and highways in Poland technical specifications are the constant (stood) factor, the regulating course of action at the construction of the investment. All however what new, particularly in the legislation matter, cause within the row of the doubt and provisions, till will remain worked out appropriate standards, particularly in case of technical specifications concerning earthworks.

Technical specifications ordinated on 18 May 2004 by the Minister of the Infrastructure (Dz.U. 2004 Nr 130 poz. 1389), is a separate document not component of the project-documentation, but are an integral part of the contract. The essential range and the form of technical specifications determined in the ordinance, are brought closer to adopted in technical specifications elaborated and initiated earlier on the instruction of the General Directorate for National Roads and Motorways (Generalna Dyrekcja Dróg Krajowych i Autostrad – GDDKiA) already from 1992 the abolition of the bindingness of standards and acceptance rules of the European standardizations, simultaneously with the ascension of Poland in 2004 to European Union, changed the status of the general technical specifications of elaborated on order the General Directorate for National Roads and Motorways, but as a result the lack of local rules of the initiation of European standards to the practice, individual designing departments and designers had independently to put modifications to previous records in the general technical specifications. Effects of this state are different. It appeared also some errors especially technical specifications. It seems also that some designers forget often enough about those technical specifications are supposed to reveal details in a documentation, to give an information omitted in projects, and relevant in the earthworks, are supposed to indicate a strictly determined technology of the construction, providing an obtainment

proper, determined in the specification, geotechnical parameters. Often committed error in detailed technical specifications is excessive attaching importance by their authors to describe the modality of the given work, and not to the final result, which should be characterized the performed element. In many technical specifications concerning of the construction of earthen structures, it pretends to be e.g. the type and the number of road rollers, number of passages during the inspissation, the thickness of thickened layer, and omits the thing most important, i.e. the required compaction ratio of the ground (I_s). In this case the performer is not responsible for the final result, and only is obliged to the compliance of recommendations regarding the technology of the construction of earthworks (Głazewski, 2007).

CONSTRUCTION OF ENBANKMENTS

During construction of embankments process one ought to obtain compaction ratio (I_s) of the ground in following arranged layers of the embankment which would protect the earthen structure against the subsidence and provided the durability, the capacity and the stability directly after the end of earthworks, according to mentioned reasons one ought to select the proper technology of the compaction (Wiłun, 2007; Dąbska & Pisarczyk, 2017).

The compaction of the ground in embankments, for the purpose of the protection them against the later subsidence, one ought to apply in cases, when the construction of the surface follows directly the end of earthworks, while the embankment is supposed to constitute a permanently stabilized and bearing ground of the surface (Yuyu, Wanyyun & Zouren, 2017).

The technology of compaction grounds in the embankment uses the different kind of equipment, such as road rollers static or vibratory smooth, ribbed, picketed or on pneumatics, and also various rammers and compaction plates. So that possible be the safe inspissation of embankments, user of the roller must keep the safe distance from the edge of the embankment, minding the wedge of the faction and the angle of the natural slope (Jodłowski, 2008; Fig. 2).

The wedge of the faction is a part of the slope whose prolapse (tearing off) can follow under the

own weight of the accumulated ground, and the prolapse of the ground does not require the application external force, e.g. loading the edge of the embankment (excavation).

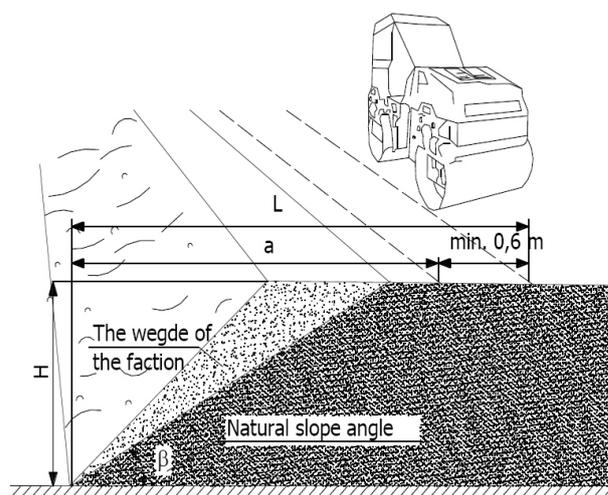


Fig. 2. The wedge of the faction securing of the safe distance from the edge of inspissated embankment (Jodłowski, 2008)

The angle of the natural slope refers to loose grounds and means the maximal angle which the ground can remain in the slope (to the slope) in equilibrium permanent, e.g. during the formation of embankments before and after compaction of the layer.

The definition of the range of the wedge of the faction is about the calculation of the safe distance from the lower edge of the embankment according to the formula (1):

$$L = a + 0.6 \quad (1)$$

where:

H – depth of the excavation [m],

a – range of the wedge of the faction [m],

L – safe distance of the setting of the machine from the edge of the excavation [m].

In case of cohesive soils $a = H$, in case of loose soils $a = 1.5H$.

The construction vehicle during the work should be placed within at least 0.6 m besides the range of

the natural wedge of the fraction of the ground. This is the dangerous area tearing of the slope and should be marked.

The compaction ratio (I_S) is calculated according the formula (2):

$$I_S = \frac{\rho_d}{\rho_{ds}} \quad (2)$$

where:

- ρ_d – bulk density of the ground structure [$\text{Mg} \cdot \text{m}^{-3}$],
- ρ_{ds} – maximum bulk density, estimated (density with optimum water content resulted in a Proctor test) [$\text{Mg} \cdot \text{m}^{-3}$].

This indicator I_S in upper layers of embankments should amount approx. 0.98–1.00 depending on purpose of the embankment, in lower layers can smaller approx. 0.90–1.00, depending on the kind and purpose of the earthen structure (Pisarczyk, 2020).

As result of compaction of the ground his weight by volume in the embankment after the compaction is greater, than the weight before compaction (in the excavation), it is caused by over compaction the ground in relation to natural state (Ogundipe & Adekemi, Akinkurolere & Ale, 2019).

The compaction ratio (I_S) should be totals $I_S \geq 0.95$ under the surface 0.3–0.5 m (Fig. 3).

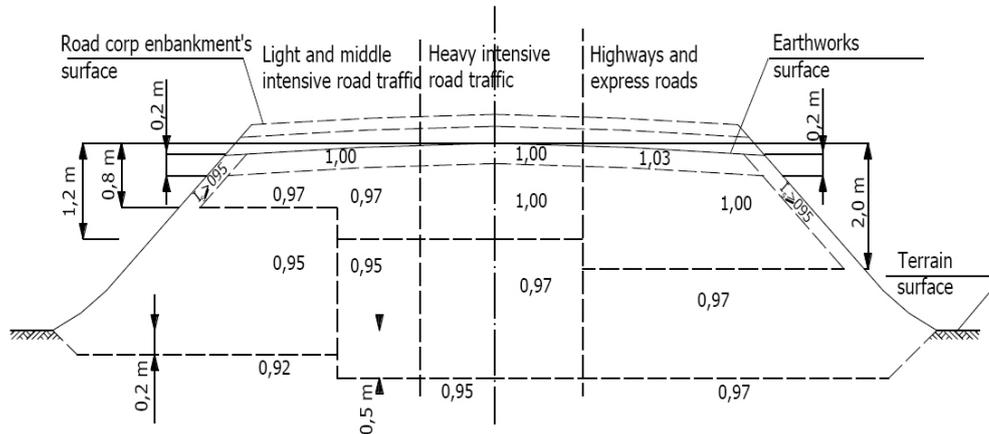


Fig. 3. Required values of the compaction ratio in individual areas of the embankment depending on purpose of the road according to the PN-S-02205:1998 standard (Polski Komitet Normalizacyjny [PKN], 1998)

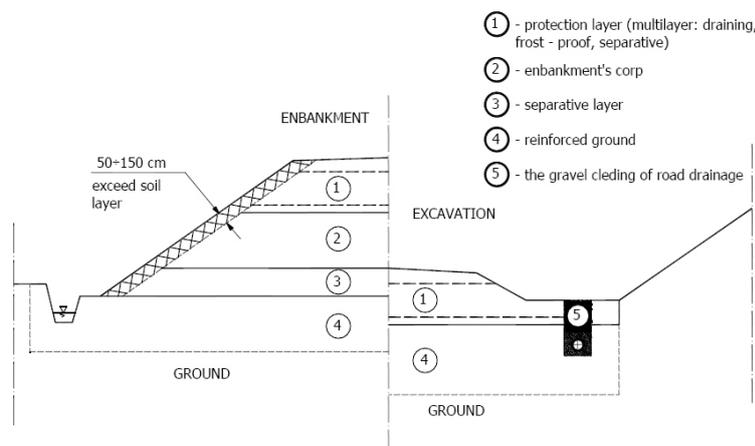


Fig. 4. Surplus of soil on slopes required to be scooped off due to obtain required compaction ratio (I_S) and minding the wedge of the fraction

As the supplementary appraisal factor of the required compaction of grounds where measuring I_S is difficult to estimate, is accepted the value of the deformation ratio (I_0) of equal to the relation (3) of the module of the secondary deformation E_2 to original E_1 , according to the PN-S-02205:1998 standard (PKN, 1998).

$$I_0 = \frac{E_2}{E_1} \quad (3)$$

Values of the deformation ratio I_0 balance between 2.0–4.0 according to kind of soil and his compaction ratio (I_S). Value of I_0 measured directly after compaction should not exceed 2.2.

In case of soils modified with hydraulic binders is required value of the compaction ratio $I_S = 1.0$ in improved substrate layer, and $I_S = 0.97$ in freezing depth area.

On inclined slopes, layer thick 20 cm, should be compacted up to $I_S \geq 0.95$. The compaction on slopes can be omitted if the layers of the embankment were stacked wider at least 50 cm more, and after construction the surplus of soil was scooped up (Głazewski, Nowocień & Piechowicz, 2011; Fig. 4).

DRAINAGE OF ROAD EMBANKMENT AND SLOPES

The grade line of the road should be raised above the ground water surface at least 0.7 m in permeable soils, and 1.1 m in grounds about the average permeability

and 1.6 m in impermeable grounds. In cases high-level ground water surfaces one ought to lower it applying drainer sequences placed under roadsides or under ditches (Wiłun, 2007; Fig. 5).

At the established spacing of drains L calculates depression of the lowered ground water surface in relation to the construction of the road pavement H according to formula (4):

$$H = h_0 + h_1$$

$$h_0 = \frac{L}{2} \cdot \sqrt{\frac{q_0}{k}} \quad (4)$$

where:

- h_0 – lowered ground water surface [m],
- h_1 – original settlement of ground water surface [m],
- q_0 – unit water flow to drain [$\text{m}^3 \cdot \text{day}^{-1} \cdot \text{m}^{-2}$],
- k – filtration ratio of the soil [$\text{m} \cdot \text{day}^{-1}$].

The drainage of slopes one performs, to prevent against leaks on surfaces, leading to erosive destructions. The drainage of slopes usually is performed in the form of rock filters and gathering water is piped away perpendicular filters to the tubular drain (Fig. 6).

The local drainage of slopes with smaller water leakages one can be constructed according as in Figure 7. The base of the drainage of slopes should be placed submarginal frost penetrations of the ground.

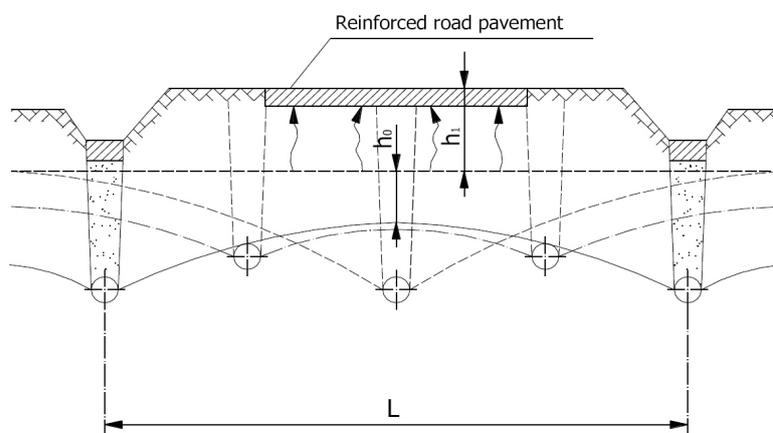


Fig. 5. The spacing of drains in section transverse of the road-embankment

Superficial outflows on slopes should be strengthened a rock filling (Fig. 8). The lack of such reinforcement or the only partial reinforcement cause the erosion and deterioration on slopes (Fig. 9).

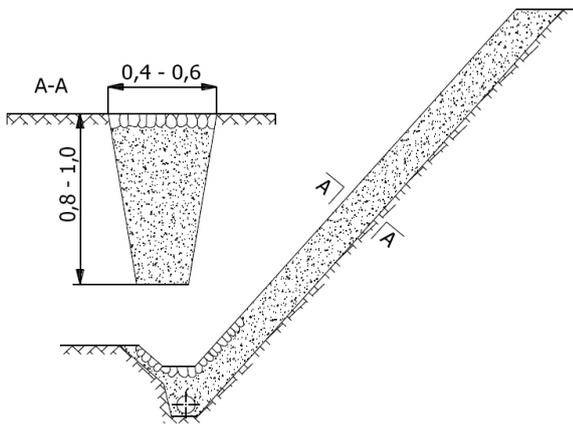


Fig. 6. The section of the superficial filter

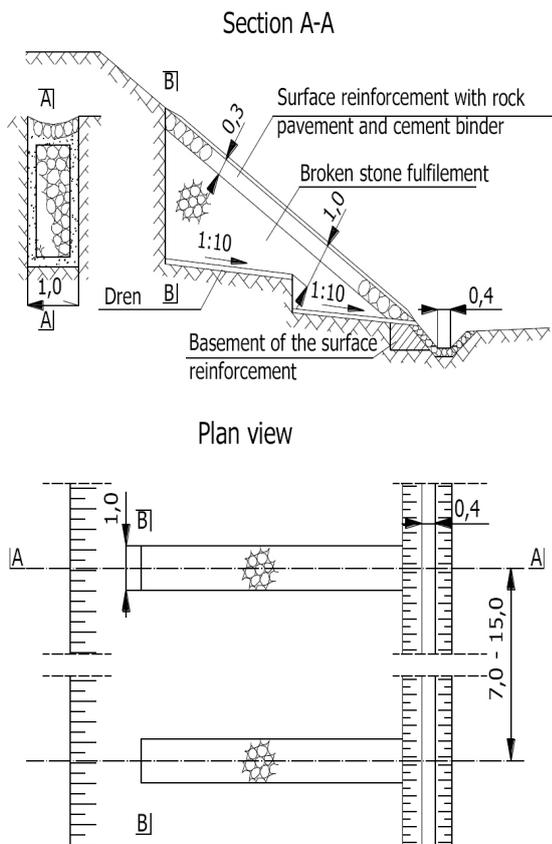


Fig. 7. Deep-seated transverse filters draining of slope

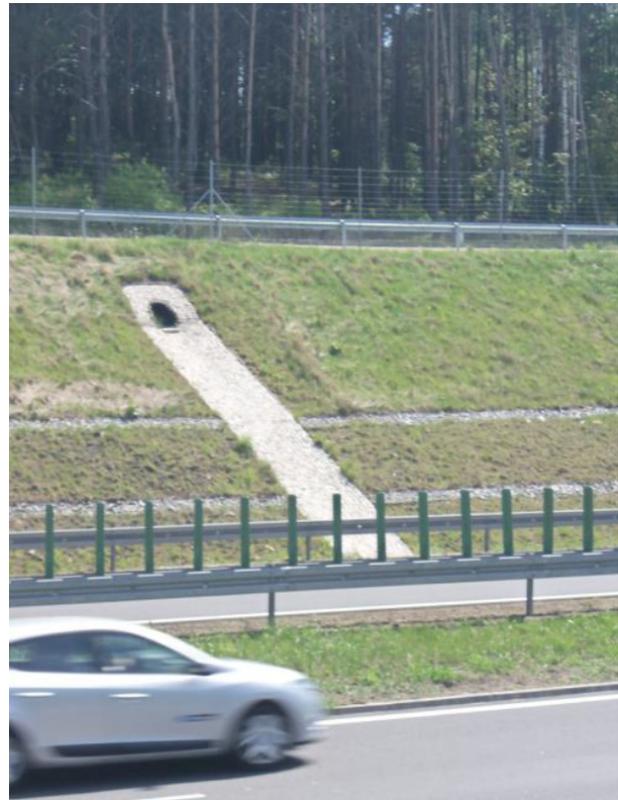


Fig. 8. The outflow the superficial reinforcement with the rock filling



Fig. 9. The partly reinforced outflow. The lack of the full causes silting of the outlet

PREPARATION OF SLOPES TO GREEN COVER

Construction embankments is required the compaction their corps and slopes at the optimum soil moisture. With optimum soil moisture the windy erosion they do not appear, and if are, it is marginal form, even at the applying into embankments of mixtures ash-of slag (Rahardio, Hartizuk, Leong & Rezaur, 2003). Traditional ways of the preparation of the surface of slopes in excavations and embankments one showed on Figure 10.

ANALYSIS OF RESULTS

Material used to compaction in embankment construction was identified as a clayey sand (continuous line on Fig. 11), additionally the slopes were covered with organic soil (dashed line on Fig. 11).

As a result of compaction and reclamation slope surface some parameters has improved.

Slope surface was compacted and covered with organic soil (organic matter content exceed 5%) and hydroseeding mixture (various seeds of grass species).

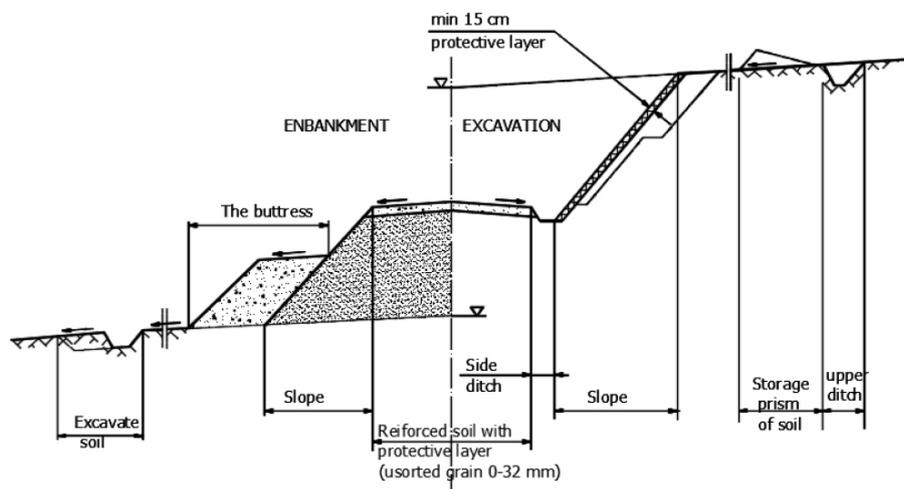


Fig. 10. The collected layer of the ground (in case of humus applying, not necessary in case of the hydroseeding)

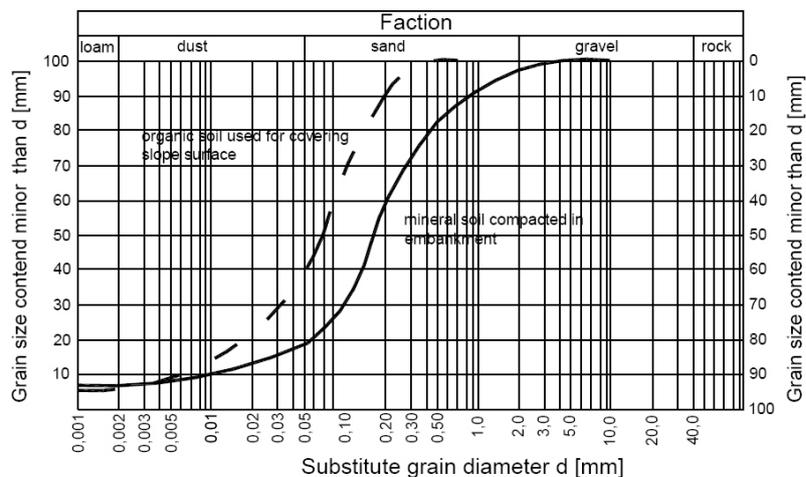


Fig. 11. Diagram of the grain size curve of the soils used for compaction of the embankment

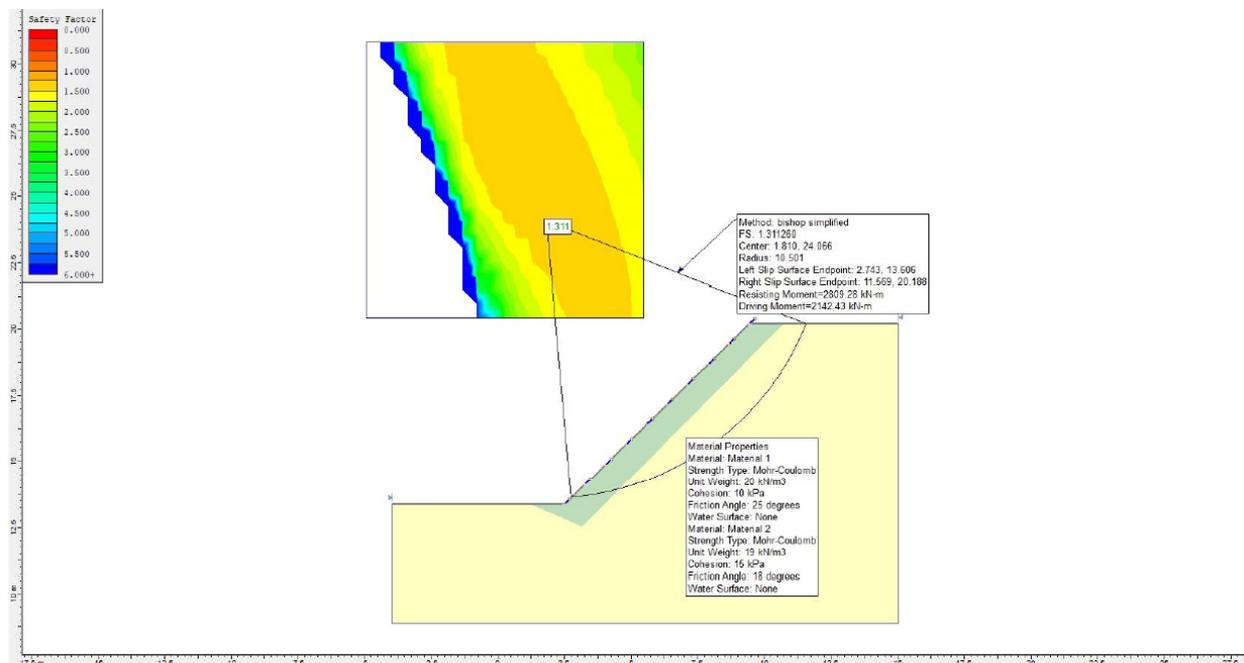


Fig. 12. Analysis of stability of compacted and reinforced slope with Slide application

Three month later, once green cover on the slope was shaped as a natural protection against wind rain waterflow. Additionally root structure settled deeply under surface improved tensile strength of green cover, protect slope against mudflow. Safety factor (F) has increase from 1.05 to 1.31 (Fig. 12). Other improved parameters are mentioned in the table.

Table. Values of improved parameters as a result of reclamation on the slope surface

Parameter	Compaction and reclamation work		
	symbol	before	after
Safety factor	F	1.05	1.31
Compaction ratio	I_s	0.67	0.95
Tensile strength of green cover [kPa]	R_f	0.00	35.00

CONCLUSIONS

The adverse effect of water on road-earthen structures undoubtedly exists since building of first ways, but became an essential problem, when one began to build a road the quick traffic (motorways and express ways).

Earthen structures, especially road-slopes, are exposed on the superficial erosion of flute, during their construction and the later exploitation. Therefore, essential is, effectively to protect surfaces of slopes against the erosion. Suitably assorted to the earthen structure and correctly performed anti-erosive reinforcement reduce (and even the eliminate) costs related to the removal of results of the superficial (ephemeral flutes and erosive furrows) erosion.

The proper technology of the slope formation (with the required compaction) and the way of the putting of individual protective films (hydro-mixtures and other reinforcement) about suitable properties guarantee the effectiveness of the hydro-seeding as a method of the protections anti-erosive surface sloping from anthropogenic compositions (Zhengwei & Longbin, 2020). The inobservance of these rules, seized hitherto partly in binding standards, specifications and instructions, is effective with the need for the increase of investment outlays on the removal of destructions on slopes, roadsides and ditches through the concentrated run-off of water (Beatistula, 2020).

REFERENCES

- Beatisula, C. H. (2020). *Comprehensive geotechnical site investigation for a high rise building*. Honolulu: Atlantic International University.
- Coppin, N. J. & Richards, I. G. (1990). *Use of Vegetation in Civil Engineering*. Butterworths, London: Construction Industry Research and Information Association.
- Dąbska, A. & Pisarczyk, S. (2017). *Odkształcalność gruntów i osiadanie fundamentów*. Warszawa: Oficyna Wydawnicza Politechniki Warszawskiej.
- Głazewski, M. (1999). Hydrodynamic seeding with use of sewage sludge and fly ash for slope protection. In J.C. Jiang, N. Yagi, T. Yamagami (Eds.) *Slope stability engineering: proceedings of the international symposium on slope stability engineering-IS-Shikoku '99: Matsuyama/Shikoku Japan 8-11 November 1999*. Rotterdam, Brookfield: Balkema.
- Głazewski M. (2007). Skarpy i pobocza w procesach budowy i eksploatacji dróg. *Magazyn Autostrady*, 5, 114–121.
- Głazewski, M., Nowocień, E. & Piechowicz, K. (2011). *Roboty ziemne i rekultywacyjne w budownictwie komunikacyjnym*. Warszawa: Wydawnictwa Komunikacji i Łączności.
- Głazewski, M. & Piechowicz, K. (2009). Budowa i umocnienie przeciwoerozyjne skarp drogowych. *Drogi i Mosty*, 2, 5–31.
- Jodłowski, M. (2000). *Operator maszyn do robót ziemnych*. Krosno: WiHK KaBe s.c.
- Ogundipe, O. M. & Adekani, J. S., Akinkurolere, O. O., Ale, P. O. (2019). Effect of compactive efforts on strength of laterites stabilized with sawdust ash. *Civil Engineering Journal*, 5 (11), 2502–2514. <https://doi.org/10.28991/cej-2019-03091428>
- Pisarczyk, S. (2015). *Grunty nasypowe. Właściwości geotechniczne i metody ich badania*. Warszawa: Oficyna Wydawnicza Politechniki Warszawskiej.
- Pisarczyk, S. (2020). *Geoinżynieria. Metody modyfikacji podłoża gruntowego*. Warszawa: Oficyna Wydawnicza Politechniki Warszawskiej.
- Polski Komitet Normalizacyjny [PKN] (1998). *Drogi samochodowe. Roboty ziemne. Wymagania i badania* (PN-S-02205). Warszawa: Polski Komitet Normalizacyjny.
- Rahardio, H., Haritzuk, K. & Leong, E. C. & Rezaur, R. B. (2003). Effectiveness of horizontal drainage for slope stability. *Engineering Geology*, 69 (3–4), 295–308.
- Rozporządzenie Ministra Infrastruktury z dnia 18 maja 2004 r. w sprawie określenia metod i podstaw sporządzania kosztorysu inwestorskiego, obliczania planowanych kosztów prac projektowych oraz planowanych kosztów robót budowlanych określonych w programie funkcjonalno-użytkowym. Dz.U. 2004 Nr 130 poz. 1389.
- Wiłun, Z. (2007). *Zarys geotechniki*. Warszawa: Wydawnictwa Komunikacji i Łączności.
- Yuyu, Z., Wanyun, Y. & Zouren, W. (2017). Study on the compaction effect factors of lime treated loess highway embankments. *Civil Engineering Journal*, 3 (11), 1008–1019.
- Zhengwei, F. & Longbin, L. (2020). Study on slope treatment and greening construction technology of road engineering. *E3S Web of Conferences*, 165, 04005. <https://doi.org/10.1051/e3sconf/202016504005>
- Ziaja, W. (1993). Dobór traw i roślin do odsiewu pasa drogowego. *Drogownictwo*, 1, 33–41.

WPŁYW ZAGĘSZCZENIA, UMACNIANIA I REKULTYWACJI JAKO ZABEZPIECZENIE ANTYEROZYJNE SKARP W DROGOWYCH ROBOTACH ZIEMNYCH

STRESZCZENIE

Rozwój budownictwa zarówno komunikacyjnego, hydrotechnicznego, jak i przemysłowego charakteryzuje się wzrostem robót ziemnych w realizacji inwestycji. Wymaga to odpowiedniego zabezpieczenia przed destrukcyjnym wpływem wody pochodzącej z opadów atmosferycznych i roztopów. Wzrost robót ziemnych ma bezpośredni wpływ na spływ powierzchniowy i przemieszczanie się mas ziemnych. W niniejszym artykule omówiono roboty ziemne i rekultywacyjne z uwzględnieniem naturalnych metod zabezpieczania pochyłych powierzchni budowli ziemnych.

Słowa kluczowe: budownictwo komunikacyjne, roboty ziemne i rekultywacyjne, skarpy drogowe, prądoteknika