Geotechnical and environmental aspects of landfill reclamation: a case study of an old municipal solid waste landfill in Poland

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ABSTRACT

Reclamation of landfills requires solutions to many unusual issues in the field of geotechnics and environmental engineering. The aim of the paper was to present some examples of reclamation works aimed at reducing the impact of an old municipal solid waste landfill on the soil-water environment and ensuring geotechnical safety. The article discusses several technical solutions applied in shaping the landfill body and strengthening the stability of the slopes. Moreover, some methods of reducing the spread of pollutants within the landfill site were presented. The article presents an example of a landfill located in difficult hydrogeological conditions, which for many years of operation did not have any systems applied for the purpose of protection from contamination. Based on the results of monitoring and numerical modeling, a beneficial effects of reclamation works on the improvement of groundwater quality and conditions of landfill slope stability were demonstrated. It was also shown that the application of a vertical barrier and a leachate drainage system have a positive effect on the improvement of the condition of plant communities in the landfill surroundings. It was concluded that reclamation works do not essentially change the function of the landfill but reduce its negative impact on the environment, in particular by limiting the spread of pollutants into the soil-water environment, protecting the slopes from erosion, reducing dust, increasing evapotranspiration and improving landscape value.

Keywords: reclamation, vertical barrier, environment, geotechnics, geotechnical safety

1 INTRODUCTION

The problem of reclamation works at landfills in Poland has been reliably recognized only from the 90s (Koda, 1999). Earlier, the “ordering” of landfills usually consisted of covering the wastes with a random soil, built-in without taking into consideration any earthworks rules and standards. Hence, that approach resulted in no required protection of the soil-water environment. Currently, landfill reclamation is treated as a set of formal, legal, technical and environmental activities aiming at full elimination of threats to the environment. The need of reclamation works also results from the Polish law and European Union directives.

The main purpose of reclamation works is to eliminate or reduce the impact of the landfill on the soil-water environment and the atmosphere (Jain et al., 2013; Camerini and Groppali, 2014). For this purpose, isolation barriers, cover layers and vegetation are used (Vaverková and Adamcová, 2018). In the case of above-ground landfills, a very important issue is the shaping of the landfill body with respect to stability protection, taking into account the final development of the area (Ma et al., 2019; Koda et al., 2020).

Technical reclamation of landfills is a long-term process and requires the implementation of unusual engineering structures and the use of sometimes scarce materials (Praveen and Sunil, 2016). Therefore, various types of anthropogenic materials can be used to carry out reclamation works at landfills. For example, ballast wastes and construction debris can be applied for shaping slopes and stabilizing roads. Moreover, waste debris and aggregates can be used as filtration backfill and materials for drainage layers. Horizontal reinforcements improving slope stability and enhancing anti-erosion protection are frequently developed with the use of tires. Diluted leachate can be applied for watering plants and technological roads, whereas waste compost, fly ash and sewage sludge are used to create a reclamation layer on the landfill surface. Stachowski et al. (2019) stated that irrigation should be treated as necessary during the biological reclamation and management of the municipal waste landfill.

With regards to closing and reclamation of landfills, two cases differing in planning and scope of reclamation works should be distinguished. The first case is related to closing the landfill designed and operated in accordance with environmental protection standards and legal requirements, whereas the second case concerns closing and reclamation of disordered, old landfills established without any protection systems.

In the first case, reclamation works are related to the shaping of the landfill body, installation of degassing system, sealing the surface, drainage installation and application of reclamation layer and vegetation. In the second case, reclamation works should be supplemented with solutions protecting against progressive degradation of the natural environment and removing the effects of the degradation that has been developing for many years. It must be also highlighted that properly reclaimed landfill site can be adapted for agricultural, forest, construction or recreational purposes (Hoefer et al., 2016; Kwiatkowska-Malina and Dybowska, 2016).

As indicated by Weng et al. (2015), for enhancing the proper landfill management and seeking effective reclamation methods, the ex-post monitoring, supported by impact assessments, and cost-benefit analysis should be performed, taking into consideration the reclamation type as well as local conditions.

The idea of presented study was to show some practical solutions, concerning technical and environmental aspects, adopted within the reclamation project of an old municipal solid waste landfill located in central Poland.

2 STUDY AREA

The Łubna landfill is located within distance of approximately 30 km from the city of Warsaw, Poland. The nearest western surrounding area of the landfill are wasteland with grassland plants. Further from the landfill, there are forest, grasslands and arable fields. The woodland is a legally protected landscape. The landfill was established in 1978, with no protection system applied against the possible contamination (Fig. 1). The landfill was closed on 31 March 2011. It covers an area of approximately 22 ha, and its height is almost 60 m. Reclamation works have been carried out since 1996 and included: construction of the vertical barrier, installation of the leachate drainage system, construction of berms as well as degassing and mineral capping system. Until 2014, reclamation works consisted of the formation and capping of the landfill surface and its biological remediation. In 2015, the final plan of the construction and remediation works was accepted. So far, it has been stated that the aquifer was contaminated by the landfill leachate and contaminants washed out from rainfall water, coming from infiltration through the wastes stored on the landfill from 1978 to 1998. After the closure of the vertical barrier, a systematic improvement of groundwater quality has been observed within the landfill area.

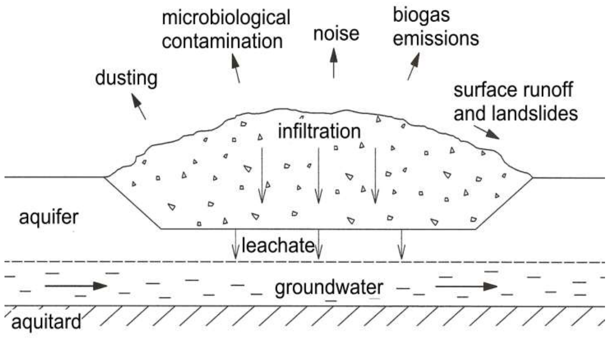

Fig. 1. Impact of the Łubna landfill on the surrounding environment before reclamation works.

3 GEOTECHNICAL ASPECTS

As a part of reclamation works the bentonite vertical barrier was constructed. The application of the vertical barrier is especially important for old landfills, for which the base of the landfill has not been sealed. The vertical barrier of 0.6 m thickness and length of c.a. 2000 m was installed approximately 2.0 m below impermeable soil layers. Its depth ranged from 5.5 to 17 m (depending on hydrogeological conditions). The hydraulic conductivity of the vertical barrier was below 10^{-9} m/s (Lipiński et al., 2007). The initial hydraulic gradient for the bentonite was ca. i_0=50, while existing gradient in the field was i=2-3. In fact, the constructed vertical barrier was practically impermeable.

Technical solutions adapted for the Łubna landfill reclamation (Fig. 2) allowed for the reduction of the extent of contaminant migration in the area.

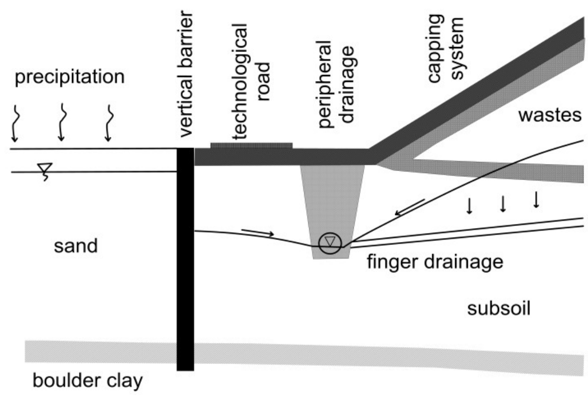

Fig. 2. The scheme of remedial solutions adapted at the Łubna landfill site.

Local water monitoring allowed tracking of changes in surface and groundwater quality in the landfill area during and after the reclamation works (post-operational phase), and also allowed assessing the quality of the effectiveness of conducted reclamation works.

By the example of piezometer located within the zone of groundwater discharge from the landfill it was revealed that the progressing improvement of groundwater quality is observed after the installation of the vertical barrier (Fig. 3).

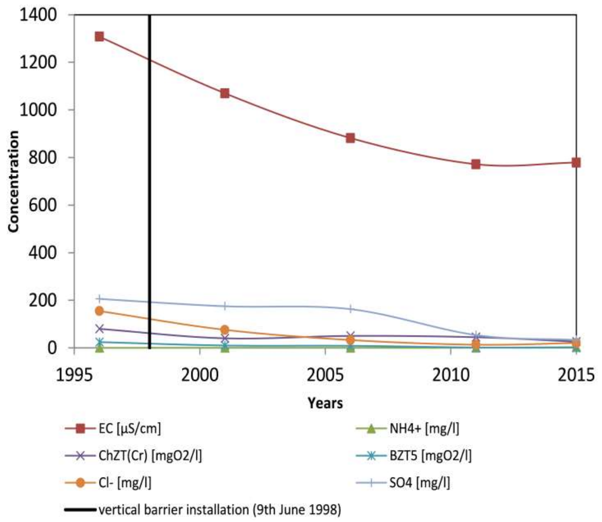

Fig. 3. Changes of groundwater quality indicators within the Łubna landfill site after the installation of the vertical barrier.

It was revealed that electrical conductivity measured in 1996 (before the installation of the vertical barrier) at the level of 1308 µS/cm was reduced to 779 µS/cm in 2015 (seven years after the installation of the vertical barrier). Values of BZT_5 were reduced up to 30 times, whereas the concentration of chlorides and sulphates were reduced by 8 and 6 times, respectively.

The proposed solutions allowed for the elimination of the possible mixing of unpolluted water in the inflow direction with the leachate in the base of the landfill and stopped the spread of polluted waters to adjacent areas.

Covering the landfill body was one of the basic reclamation works carried out at the Łubna landfill site to protect against uncontrolled emissions to the atmosphere and reduce the amount of the leachate generated. The use of a mineral sealing layer in the cover of the landfill was most advantageous for both the reclaimed landfill and the future use of the area, however it required compliance with criteria for soil selection and principles of material embedding and quality control. Schneider et al. (2017) pointed out that the closure of a landfill should be also supported by an appropriate development of the interim cover which is highly relevant for the remediation, as the settlement processes in the landfill body must be decayed before the final cover application.

Geotechnical aspects of the Łubna landfill reclamation were also strictly related to the stability of slopes. Typically, the stability of landfill slopes is checked for two cases. The first is related to the evaluation of the general stability of the slope, most often using methods based on the analysis of boundary balance or the finite element method. In the second case, the possibility of slipping at the interface of individual cover layers is checked, especially when the geomembrane is applied.

Ensuring landfill stability and anti-erosion protection were key issues to be resolved at the stage of technical reclamation of the Łubna landfill. In Łubna landfill, where the slopes are high and of considerable inclination, the berms (made of cohesive soils and compost) were proposed as the most effective solutions for the slope stability reinforcement. What is more, anthropogenic materials (building debris, mattresses from exploited car tires, grass carpets based on compost from municipal waste) were applied for the purpose of landfill reclamation (Table 1).

Table 1. List of waste materials re-used for reclamation purposes at the Łubna landfill.

Waste	Application	Location
Ballast wastes	Reinforcement	Slopes
Tires	Horizontal mattresses	Slopes
Steel slag and sand from the water treatment plant	Filtration layer, road aggregates	Drainage layers, technological roads
Construction debris, crushed ballast waste	Road aggregates	Technological roads
Fly ash, sewage sludge	Reclamation layer, hydro-seeding	Slopes, top of the landfill
Waste compost	Reclamation layer, grass carpets	Slopes, top of the landfill
Leachate with water	Irrigation, recirculation	Slopes, top of the landfill

Effective solutions for improving the stability consisted of the construction of loading embankments (berms) (Fig. 4) as well as surface strengthening and stabilizing adapted to the height and slope of the landfill.

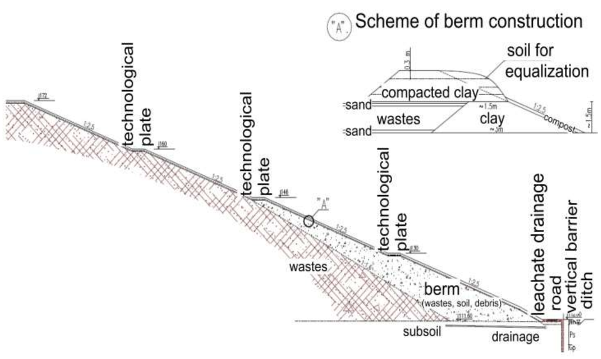

Fig. 4. The scheme of landfill slope stability improvement at the

Łubna landfill.

Additionally, designed berms enabled the achievement of additional capacity for waste disposal. The applied solutions allowed to extend the time of landfill operation by about 10 years. It was also stated by Agarwal et al. (2019) that using reinforced soil berms is better than the other conventional methods of flattening the slope because it requires less space on ground.

It should be highlighted that before reinforcements, almost all slopes of the Łubna landfill were in a state close to the state of equilibrium, as well as numerous landslides and slope blurring were observed. After strengthening, all slopes were considered safe or on the border of safe and warning values (on the eastern slope, factor of safety equal to 1.28) (Table 2).

Table 2. Results of stability analysis at selected slopes of the Łubna landfill using Bishop method.

Slope	Factor of safety	
	Without reinforcement	With reinforcement
Eastern I	1.12	1.32
Eastern II	1.04	1.28
Western III	1.07	1.35
Northern IV	0.99	1.52

4 ENVIRONMENTAL ASPECTS

The plant cover should bind and stabilize the soil on the landfill surface, prevent dusting and spreading odors or aerosols. It is also necessary for high evapotranspiration and slope protection against erosion (Koda et al., 2013). The use of the hydro-seeding method with compositions of grass and legumes in a mixture with sewage sludge and fly ash allows quick greening of the landfill slopes and top without additional expenditure for sodding. The use of vegetation is also found to be a convenient and natural component of landfill restoration (Vaverková et al., 2018). Song (2018) indicated that, when selecting species for landfill reclamation, it is important to choose seeds that are heavy in weight, have wind resistance, and can supply sufficient energy for the initial growth to survive at the harsh environment.

As a part of biological stage of the Łubna landfill reclamation, a plant cover was introduced. Plant species introduced at the landfill had the following predispositions:

a) ecological – i.e. resistance to toxic biogas, expansiveness and competitiveness to existing species,

b) biological – i.e. significant biomass increases and high and intensive transpiration, possibility of creating diverse communities close to natural, ease of propagation and implantation, strongly developed root system and good land cover,

c) economical – i.e. availability of plant material, low costs of obtaining seeds and cuttings and their implantation under the conditions of anticipated constant irrigation as part of leachate recirculation.

It should be noted that environmental effects of the implementation of reclamation works can be assessed not only on the basis of monitoring changes in water relations, but also on the basis of observation of the state of vegetation in areas adjacent to the landfills.

In the area of the Łubna landfill, before the construction of the vertical barrier, the leachate from the landfill contributed to pollution and increased humidity of the meadow and forest areas in the vicinity of the landfill, which caused adverse changes in the state of plant cover. Archival documentation mentions the extinction of meadow vegetation on existing leachate backwaters and the drying out of groups of trees. After the construction of the vertical barrier surrounding the landfill, as well as peripheral and finger drainage catching leachate at the base of the landfill, the water relations within forest and meadow habitats improved significantly (Fig. 5).

Fig. 5. Effects of biological reclamation of the Łubna landfill (view on the northern slope before and after reclamation works).

As a result of closing the vertical barrier, the soil-water conditions stabilized, as well as the gradual purification of surface water and groundwater were observed. The field inspections showed that plant communities in the vicinity of the landfill site have favorable conditions for growth and development, which was indicated by no deadwood, impressive growth, no diseases and pest attacks, as well as abundant flowering. In the area of the northern slope, where before 1998 an extensive backwaters of leachate had been observed, nowadays species diversity of plants developing under favorable habitat conditions is clearly visible.

The implementation of technical solutions, supported by biological reclamation at the Łubna landfill definitely improved the environmental values of the landfill and surrounding areas.

5 CONCLUSIONS

Reclamation of old landfill sites is usually a long-term process, requiring non-conventional and complex technical and biological activities.

After closure of the landfill, it should be ensured that the site is monitored to the extent required for the post-exploitation phase, as well as supervision of leachate collection and degassing systems are provided.

This study confirmed that groundwater protection system, based on the vertical barrier and drainage application, is safe and effective for the reclamation of an old sanitary landfill. Performed study revealed that after the closure of the vertical barrier, the quality of groundwater significantly improved. It was especially expressed by the reduction of electrical conductivity, BZT_5 and concentrations of sulphates and chlorides.

It was also concluded that proper application of waste materials proves the high effectiveness of remedial works and effectively reduces costs of activities undertaken. By the example of the Łubna landfill, it is clearly visible that several kinds of wastes can be effectively used during the reclamation, and their usefulness is predominantly expressed by increasing the factors of safety of reinforced slopes of the landfill (approximately equal or greater than 1.3).

REFERENCES

1) Agarwal, A., Datta, M., Ramana, G.V., Satyakam, R. (2019): Improving the Slope Stability of Municipal Solid Waste Dumps Using Reinforced Soil Berms: A Case Study. In: Zhan L., Chen Y., Bouazza A. (eds) *Proceedings of the 8th International Congress on Environmental Geotechnics,* Volume 2. ICEG 2018. Environmental Science and Engineering. Springer, Singapore.
2) Camerini, G, Groppali, R. (2014): Landfill restoration and biodiversity: A case of study in Northern Italy. *Waste Management & Research*, 32, 782–790.
3) Hoefer, W., Gallagher, F., Hyslop, T., Wibbelt, T.J., Ravit , B. (2016): Environmental Reviews and Case Studies: Unique Landfill Restoration Designs Increase Opportunities to Create Urban Open Space. *Environmental Practice*, 18, 2, 106-115.
4) Jain, P., Townsend, T.G., Johnson, P. (2013): Case study of landfill reclamation at a Florida landfill site. *Waste Management*, 33(1), 109-116.
5) Koda, E. (1999): Remediation of the old embankment sanitary landfills. *Geoenvironmental Engineering: Ground Contamination*. Thomas Telford ed., London, 29-38.
6) Koda, E., Pachuta, K., Osinski, P. (2013): Potential of plant applications in the initial stage of the landfill reclamation process. *Polish Journal of Environmental Studies,* 22, 1731–1739.
7) Koda, E., Miszkowska A., Sieczka A., Osiński P. (2019): Cut-Off Walls and Dewatering Systems as an Effective Method of Contaminated Sites Reclamation Processes. *IOP Conference Series: Materials Science and Engineering,* 471, 042021.
8) Koda, E., Kiersnowska, A., Kawalec, J., Osiński, P. (2020): Landfill slope stability improvement incorporating reinforcements in reclamation process applying observational method. *Applied Sciences,* 10(5), 1572.
9) Kwiatkowska-Malina, J., Dybowska, S. (2016): The Concept Of Land Use Development Of A Municipal Solid Waste Landfill: The Cegłów Commune Case Study. *Infrastructure and Ecology of Rural Areas*, IV/I, 1229-1241.
10) Lipiński M.J., Koda E., Wdowska M.K. (2007): Assessment of key geotechnical characteristics of a groundwater protective vertical barrier. Millpress Science Publishers, Rotterdam, The Netherlands. *14th European Conference on Soil Mechanics and Geotechnical Engineering* Madrid, 2, 767-772.
11) Ma, P., Lan, J., Ke, H. (2019): Field Monitoring of a Geogrid Reinforced MSW Slope. In: Zhan L., Chen Y., Bouazza A. (Eds.). *Proceedings of the 8th International Congress on Environmental Geotechnics*, vol. 2. Environmental Science and Engineering. Springer, Singapore.
12) Maslikov V., Chusov A., Zhazhkov V., Vasilyeva O. (2018): MSW Landfills Reclamation Based on Monitoring of Biogas Emissions. In: Murgul V., Popovic Z. (eds). International Scientific Conference Energy Management of Municipal Transportation Facilities and Transport EMMFT 2017. EMMFT 2017. *Advances in Intelligent Systems and Computing*, 692. Springer, Cham.
13) Praveen, V., Sunil, B.M. (2016): Potential use of waste rubber shreds in drainage layer of landfills - An experimental study. *Advances in Environmental Research*, 5(3), 201-211.
14) Schneider, P., Oswald, K.D., Weiß, B., Littmann, R. (2017): Assessing Geotechnical Risks in the Frame of Landfill Engineering in Eastern Europe. *Journal of Geological Resource and Engineering*, 1, 1-14.
15) Song, U. (2018): Selecting plant species for landfill revegetation: a test of 10 native species on reclaimed soils. *Journal of Ecology and Environment*, 42, 30.
16) Stachowski, P., Kraczkowska, K., Oliskiewicz-Krzywicka, A., Rolbiecki, S., Rolbiecki, R. (2019): Irrigation in the reclamation of municipal waste landfills. *Annual Set The Environment Protection*, 21, 472-480.
17) Vaverková, M.D., Adamcová, D. (2018): Case study of landfill reclamation at Czech landfill site. *Environmental Engineering and Management Journal,* 17, 641–648.
18) Vaverková, M.D., Radziemska, M., Bartoň, S., Cerdà, A., Koda, E. (2018): The use of vegetation as a natural strategy for landfill restoration. *Land Degradation & Development*, 29 (10), 3674-3680.
19) Vaverková, M.D., Adamcová, D., Winkler, J., Koda, E., Červenková, J., Podlasek, A. (2019). Influence of a Municipal Solid Waste Landfill on the Surrounding Environment: Landfill Vegetation as a Potential Risk of Allergenic Pollen. *International Journal of Environmental Research and Public Health, 16*, 5064.
20) Weng, Y.-C., Fujiwara, T., Houng, H.J., Sun, C.-H. Li, W.-Y., Kuo, Y.-W. (2015): Management of landfill reclamation with regard to biodiversity preservation, global warming mitigation and landfill mining: experiences from the Asia-Pacific region. *Journal of Cleaner Production*, 104, 364-373.