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LANDFILL IN JASŁO – SLOPE STABILITY ANALYSIS WITH VARIABLE COHESION VALUES FOR MUNICIPAL WASTE

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ABSTRACT

Aim of the study
The paper presents results of tests and calculations aiming at the determination of the influence of changes in the values of municipal waste cohesion on the values of safety factor calculated with the Fellenius method. The works in questions were performed for the landfill for waste other than hazardous and inert waste located in Jasło.

Material and methods
The analysis was based on our own research, calculations and the existing landfill documentation. The computational part of our work included checking the stability of slopes in two selected cross-sections, assuming municipal waste cohesion values in the range of 0–30 kPa. Depending on the assumed cross-section and the calculation scheme, we concluded that even for cohesion equal to 23 kPa the calculated safety factor is indicative of stability deficiencies.

Results and conclusions
On the basis of geotechnical parameters compliant with the standard, we checked the stability of the slope in a selected cross-section. For the analysed cross-section we obtained safety factor values in the range of 0.70–1.38, thus proving the dominance of retention forces

Keywords: landfills, slope stability, cohesion, safety factor

INTRODUCTION

Landfills, like most earthworks, have a problem with landslides. A slope is stable when there is no mass movement such as landslides or slides. Its measure is the ratio of forces, moments striving to maintain equilibrium, and forces, moments striving for a landslide. The evaluation of the stability of slopes and slopes consists in determining the minimum stability index F and comparing it with the index permissible for a given structure. The slope is considered stable when $F > 1$, i.e., the forces resisting the displacement, are greater than the forces causing the displacement of the soil masses, however, the required indicators for different structures usually range from 1.2–1.5. The problem of assessing the stability of slopes and slopes includes the analysis of the static and dynamic stability of the influence of atmospheric factors and anthropogenic factors.

A landfill is a facility for organised waste disposal located and arranged in accordance with the applicable regulations, where selection and partial recovery of recycling materials are also carried out (d'Obyrn and Szalińska, 2005; Dixon et al., 2005; Gomes and

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Lopes, 2012; Handy and Spangler, 2006). Waste may be stored only in a designated place usually owned by the local government.

In the 1990s, problems related to the recultivation of existing municipal landfills started attracting some attention. In the case of the so-called above-ground landfills, the most critical issue includes maintaining the stability of the slopes and protecting soil and groundwater in the waste storage place (Bray et al., 2009; Rosik-Dulewska et al., 2007; Zadroga and Olańczuk-Neyman, 2001; Zydroń and Baran, 2011; Zydroń and Demczuk, 2013). In Poland, landfilling is still the most common method of waste disposal. About forty-five million cubic meters of municipal waste is disposed of yearly; the quantity is growing every year. Old landfills are usually badly located, they lack appropriate equipment, are poorly operated and managed, they lack sanitary protection zones and green belts around them. Proper location, structure and operation of a landfill depend on the type and quantity of waste to be landfilled, as well as on local hydrological and geological conditions (Wysokiński, 2009). Regulation of the Minister of Environment of 30 April 2013 precisely defines the areas in which hazardous, and non-hazardous and non-inert waste can be landfilled, and it also provides for the minimum distance between the landfill from the buildings i.e., the distance determined in accordance with the landfill environmental impact report.

Currently, when designing new landfills, special attention is paid to protecting the environment from the adverse effects of the accumulated waste and reducing its nuisance to the environment. According to the Waste Act of 27 April 2001 at the end of landfill life, the surface area of stored waste and slopes should be secured, relevant recultivation cover should be made, and slope stability should be assessed using geotechnical methods (Caicedo et al., 2002; Cholewa, 2012; Gharabaghi et al., 2008; Stark et al., 2009; Zhan et al., 2008; Zheng et al., 2006). If there are existing slopes, the probability of damage caused by landslide should be determined (Gitirana et al., 2008; Krishnamoorthy, 2007; Oh, and Vanapalli, 2010; Pham and Fredlung, 2003).

THE SCOPE AND PURPOSE OF THIS PAPER

The aim of this paper was first of all to assess the stability of the selected overground municipal waste landfill in Jasło. Based on the documentation of the examined landfill (Sigma, 2011), we conducted field and laboratory tests in the Department of Hydraulic Engineering and Geotechnics of the University of Agriculture in Kraków. Then, we performed relevant slope stability calculations. The scope and methods of research were based on an in-depth analysis of the literature on waste storage (Castelli and Maugeri, 2014; Dixon et al., 2005) and landfill recultivation, as well as selected issues related to the geotechnical aspects of civil engineering (PN-EN ISO 14688-1:2006 Część 1: Oznaczanie i opis, Część 2: Zasady klasyfikowania, PN-EN ISO 22475-1:2006 – Część 1: Techniczne zasady wykonania)

THE MUNICIPAL LANDFILL IN JASŁO

The landfill is located in the Jasło Poviat (Podkarpackie Province), which occupies a highland and mountainous area of 831 km^2 and has 116,000 inhabitants.

Jasło lies in a valley of three rivers: Wisłoka, Jasiołka and Ropa, at an altitude height of 280–350 m above sea level, 50 km from the border with Slovakia, near the Magurski National Park. The town is an important industrial centre focusing on chemical, glass, food, and wood industries. The landfill in question is located in the eastern part of the town, in the Sobniów district (see: Fig. 1). From the north, it neighbours the Hankówka – 4 borehole, the Roztoka PGNiG Mine. The Jasiołka River is ca. 100 m away. On the other sides, there are farming fields. The nearest residential buildings are over 150 m south-east from the landfill.

In addition to the described landfill, there are also industrial waste landfills in the town which belong to the LOTOS Jasło S.A. refinery, where the used oils are regenerated, and to the ZTS Gamrat S.A. company.

Waste is collected in a selective manner in the town by deploying more than seventy sets of user-friendly 1.5–2.5 m^3 bins. The bins differ in terms of type of waste to be collected in them. Plastics, wastepaper, white glass and coloured glass are collected in this way.

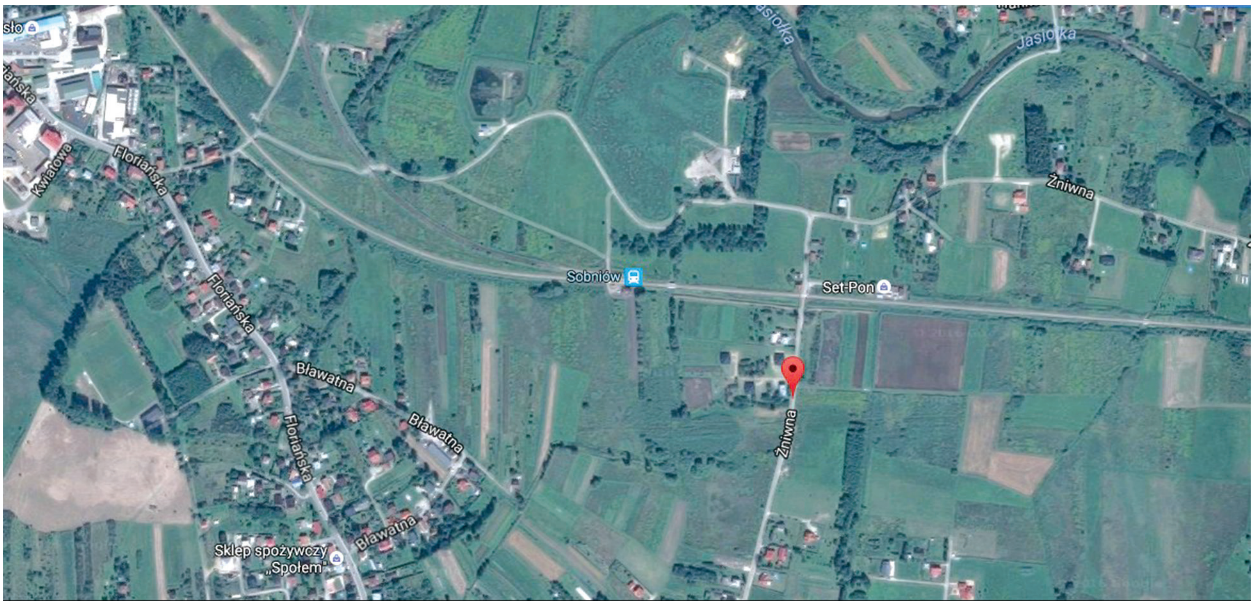

Fig. 1. Location of the landfill (*Source*: maps.google.pl)

CHARACTERISTICS OF LANDFILLED WASTE

The landfill in Jasło occupies an area of 6.84 ha, including 4.5 ha of storage area (see: Fig. 1). It accepts non-hazardous and inert waste, which includes unsorted municipal waste, waste from cleaning squares and streets, waste from industrial plants, as well as stabilized sludge from the sewage treatment plant in Jasło. The landfill receives waste from Jasło and from the municipalities: Brzyska, Dębowiec, Kołczyce, Krempna, Nowy Żmigród, Skołoszyn and Tarnowiec.

The waste brought to the landfill is weighed and stored on a plot of land with occupancy permit, and then transported with appropriate equipment to its final destination.

CURRENT CONDITION OF THE FACILITY

The landfill site includes a section for landfilling, limited by embankments, and a section with back-up facilities of the landfill. There are also facilities necessary for the proper operation of the landfill:

- social and storage building,
- garage for mechanical equipment,
- equipment washing station,
- disinfectant paddling pool,
- sanitary and car wash wastewater settling tanks connected to the municipal sewage system,
- leachate containment system connected to the existing municipal sewage system,
- car scale,
- waste reloading station with access roads and manoeuvre yards,
- entrance gate with a fragment of a fence,
- water supply, municipal sewage system, and power supply systems.

The landfill area is crossed by a rainwater collector which divides it into two parts. It drains rainwater from an open drainage ditch to the Jasiołka River. After profiling, the existing landfill slopes were planted with willows and elderberry trees.

GEOLOGICAL STRUCTURE OF THE LANDFILL GROUND

The Jaslo Poviat is located in the Outer Carpathians (Flysch), which are built of sandstone and shale rocks from the Cretaceous and Oligocene periods. The Flysch Carpathians are made up of many nappes, folds, thrust slices, furrow slices overlapping to the north. This surface is built from three main units overlapping each other from the south to the north. The Magurian nappe is the southernmost one, whereas the northernmost ones are the Dukla and Silesian nappes.

ASSUMPTIONS CONCERNING LANDFILL RELIEF

The landfill quarters of about four hectares are made up of a lump of waste, which was created stepwise by depositing waste in subsequent sectors. Ordinates of the waste lump edges vary from 233 m on the east side to 235.15 m on the west side, and the slope is about 1:2. In the central part of the quarters, waste is stored up the ordinate of 236.5 m, thus achieving the required 2–3% slope, whereas in the eastern direction the slope increases to an average value of about 3.2%. The maximum ordinate of the tops parts of the quarters after recultivation was designed at 237.5 m, i.e., 1 m above the levelling layer.

FIELD RESEARCH

Carried field tests allowed to get acquainted with the landfill infrastructure, take samples, and perform a visual inspection. With the help of a window Edelman auger, drilled eight boreholes (see: Fig. 2) with a depth of 2.25–3.25 m. The soil found at the appropriate depth was silt clay.

STABILITY CALCULATIONS

The Fellenius method was used for stability calculations (considering the vertical and horizontal influence of adjacent strips). In this method, assuming a circular-cylindrical slip surface, the analysis includes the ratio of forces resulting from the division and properties of the ground blocks presented.

The calculations were made with the Intersoft program. Stability of slopes and slopes is intended for calculations related to checking the stability of newly designed embankments and slopes, as well as checking the already existing slopes. The calculations performed by the program are based on block methods (Bishop and Fellenius).

Slope stability was examined on the example of two most characteristic cross-sections, whose location is shown in Fig. 2. The A-A cross-section is the facility's least advantageous from the point of view

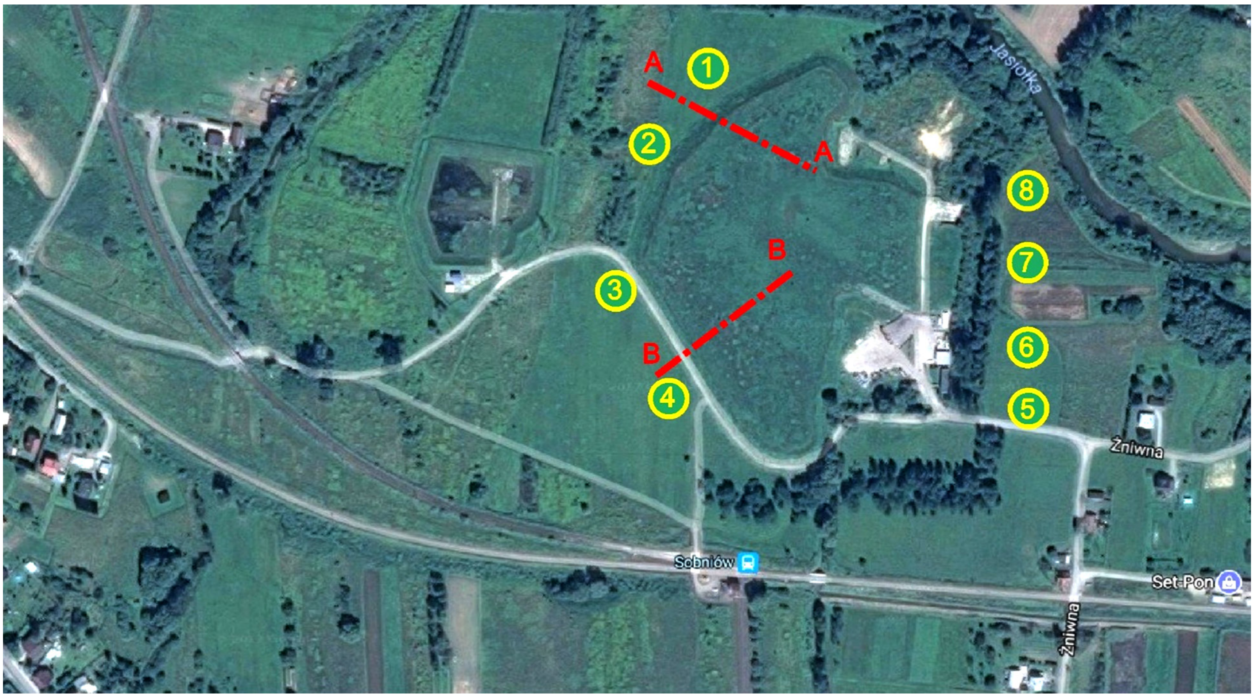

Fig. 2. Location of bores and cross-sections (*Source*: www.google.pl/maps)

of stability. The slope is 1:1.40, with a height of 8.8 m. The slope has no bench. The B-B section has an inclination typical for most slopes in the lower part of the landfill. The above-ground height is 6.7 m, with the height to length ratio of 1:2.28. Stability calculations have been carried out for these two inclinations to check how changes in the cohesion value affect the safety factor. The cohesion values were found in the range of 0–30 kPa. The calculations for each of the cross-sections were carried out in the following variants:

The basic soil physical parameters were determined in laboratories in accordance with PN-EN ISO 14688-1:2006, PN-EN ISO 14688-2:2006 and PN-EN ISO 22475-1:2006 (see: Table 1). Mechanical parameters of soil and the recultivation layer were assumed according to PN-03020, while parameters of the municipal waste were taken from (Wysokiński, 2009).

DESIGN A-A CROSS-SECTION

The calculation scheme (see: Fig.3) considers geotechnical parameters (see: Table 1) the levelling layer (1, 2), the ground (5) and the parameters of municipal waste assumed from the literature (3, 4). For the slope inclination most unfavourable for the whole facility (1:1.40), assuming cohesion value for waste close being to zero, the calculated safety factor is 0.88 (see: Fig. 4).

B-B DESIGN CROSS-SECTION

The calculation scheme considers geotechnical layers and parameters given in Table 1. The B-B cross-section (see: Fig. 5) is characterised by its slope (1:2.28) being gentler than the slope in A-A cross-section.

In the scheme under consideration, there is no risk of stability loss even with minimum cohesion values assumed for municipal waste. The calculated safety factor is 1.38 and is higher than the limit value given for facilities of this type (1.30).

Once the surface load is considered in the calculation scheme, the value of the safety factor decreases twice (see: Fig. 6). With a cohesion value assumed as being close to zero, it was 0.75. The slip curve covers the upper part of the analysed slope, the ground is 1.7 m below. In order for the assumed scheme to have a safety factor of more than 1.3, the cohesion should have values above 10.8 (see: Fig. 6).

SUMMARY

Spherical slip zones may develop on slopes made of municipal waste. The probability of this event can be predicted with simple two-dimensional analysis packets. The main difficulty in the analysis of the slope stability is the location of the most probable displacement surfaces and the knowledge of water and ground conditions. Many landslides can only be analyzed after accidents that occur when the forces leading to displacement exceed the stabilizing forces.

Table 1. Geotechnical characteristics of subsoil layers

Parameter	Unit	Value
Name according to PN-B-02481:1998	–	Gπ
Name according to PKN-CEN ISO/TS 17892-4:2009	–	sasiCl
Uniformity coefficient	–	7
Specific density	$Mg \cdot m^{-3}$	2.67
Optimum moisture content	%	16.2
Maximum dry density by Proctor's method	$Mg \cdot m^{-3}$	1.82

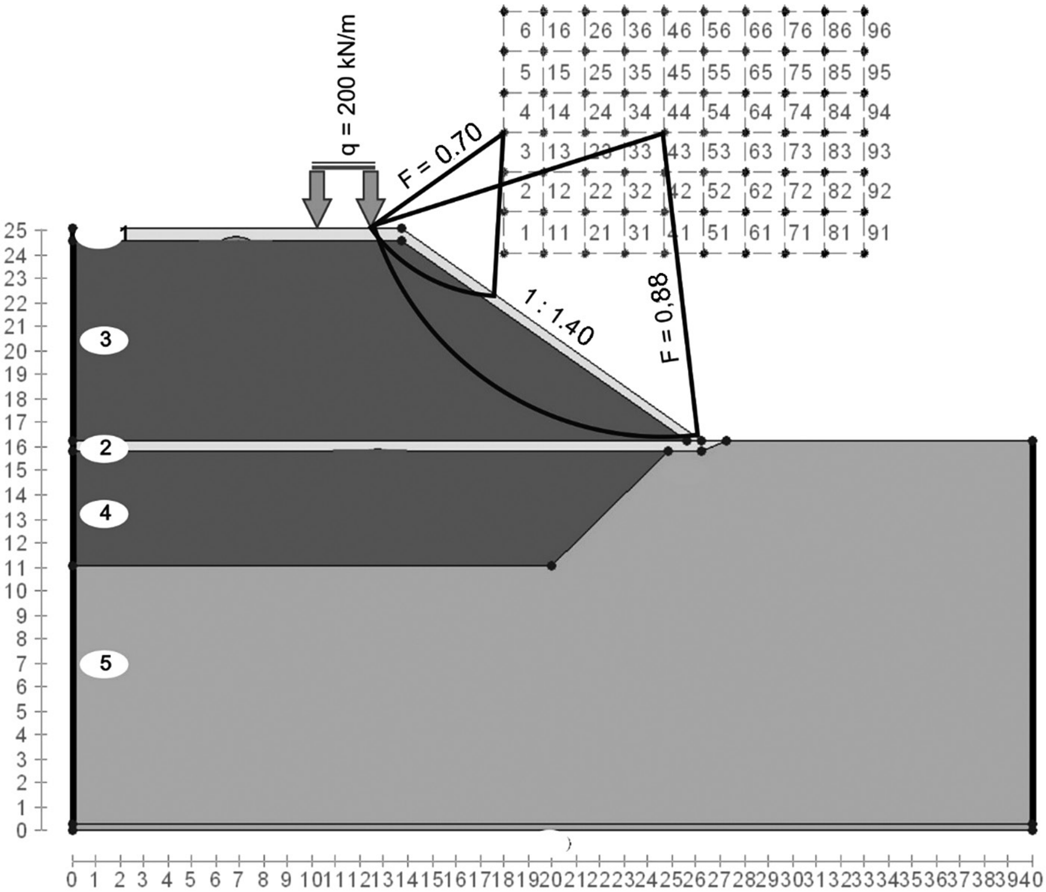

Fig. 3. Stability calculation scheme – A–A cross-section

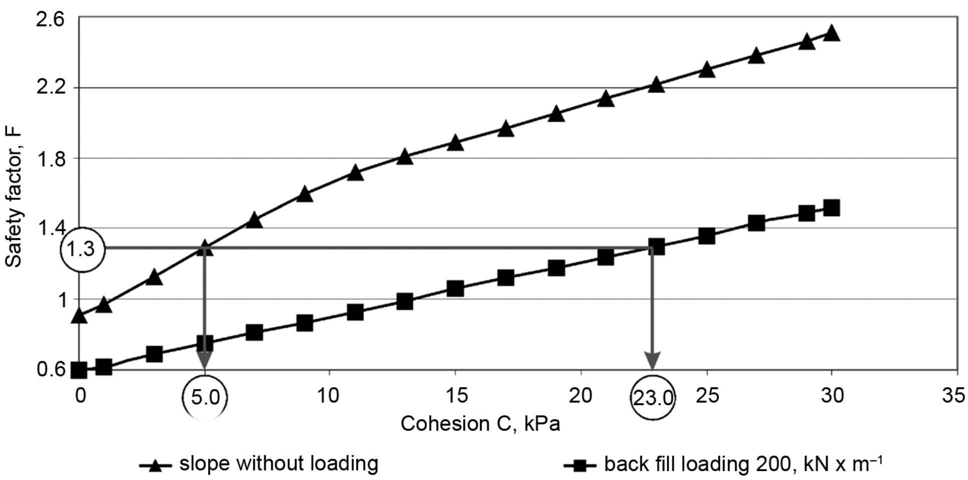

Fig. 4. Relationship between the safety factor and waste cohesion in the A-A cross-section

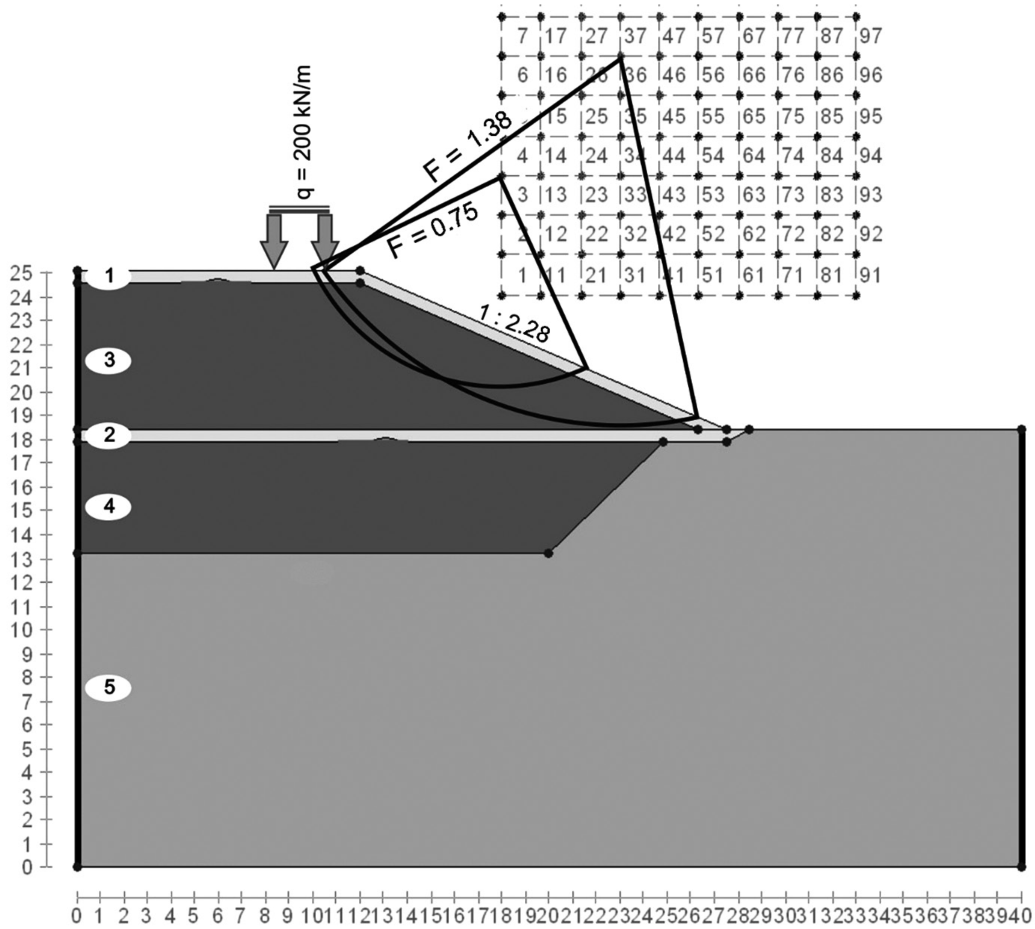

Fig. 5. Stability calculation scheme – B–B cross-section

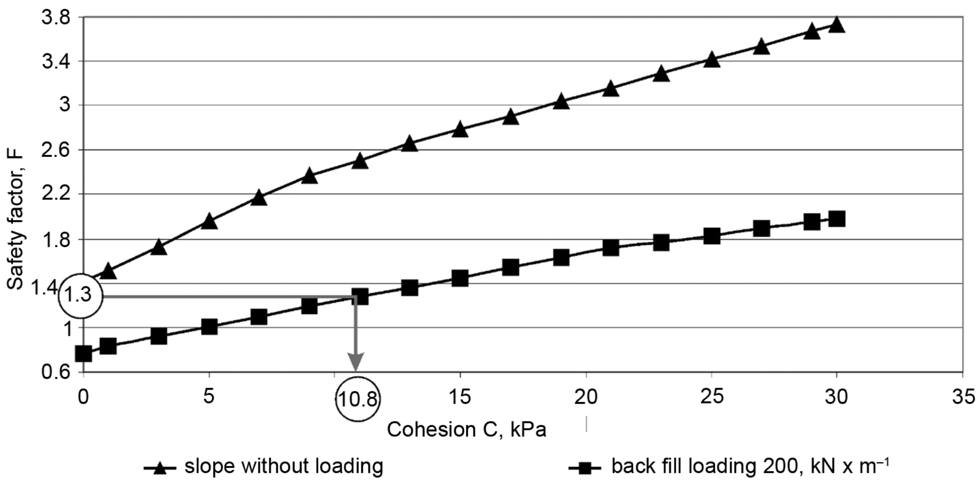

Fig. 6. Relationship between the safety factor and the cohesion of the waste in the B-B cross-section

Solving the slope stability of a landfill is a task that can be solved by various methods. Often with very simple methods that give good results. The most important thing is to correctly estimate the geotechnical parameters of waste and subsoil. Due to the homogeneity of the waste mass and similar strength characteristics of the soil building the landfill, the stability analysis is carried out assuming circular-cylindrical slip surfaces.

The assumed geotechnical parameters of waste were adopted on the basis of the data available in the literature, however, in reality, they vary depending on the type of waste and its age (Cholewa and Mankiewicz, 2011; Cholewa, 2017).

Stability analysis of the selected cross-sections in the Jasło landfill is based on the assumed range of changes of cohesion values, assuming that other geotechnical parameters remain constant. For the A-A design cross-section, the results indicated a risk of stability loss when adopting cohesion values for municipal waste below 5 kPa or 23.0 kPa when the overburden is loaded. The surface slope load contributes to the reduction of the stability coefficient by 40%.

For the B-B cross-section, with its inclination being much safer in terms of stability, the minimum safety factor values obtained in the calculation all exceeded 1.4. It can be assumed that for the most typical slope inclinations in the Jasło landfill, the risk of slope stability loss is negligible. This is even applicable to the minimum cohesion values for municipal waste building the slope in question. The slope surface load in the B-B cross-section resulting from the operation compaction machine or the machine making the recultivation layer results in safety coefficients being about 50% lower

If there are surface loads coming from compaction equipment, in addition to the weight of the machine, the vibrations of the drive unit must be considered. Municipal waste is not the type of ground, which is in danger of liquefaction, but certainly, some reduction in strength parameters will be observed.

It can be stated that the landfill in Jasło is a facility where the risk of stability loss may occur on the steepest embankment slopes with unfavourably low cohesion values.

Mechanical parameters of municipal waste have a considerable influence on the slope stability. The research on the angle of internal friction and cohesion, conducted by many authors, is shown in Figure 7. The highest values of the angle of friction were obtained by Landv and Clark. Values from 24 to 53 ° concerned multi-year waste. Research by Kogl et al. Has looked

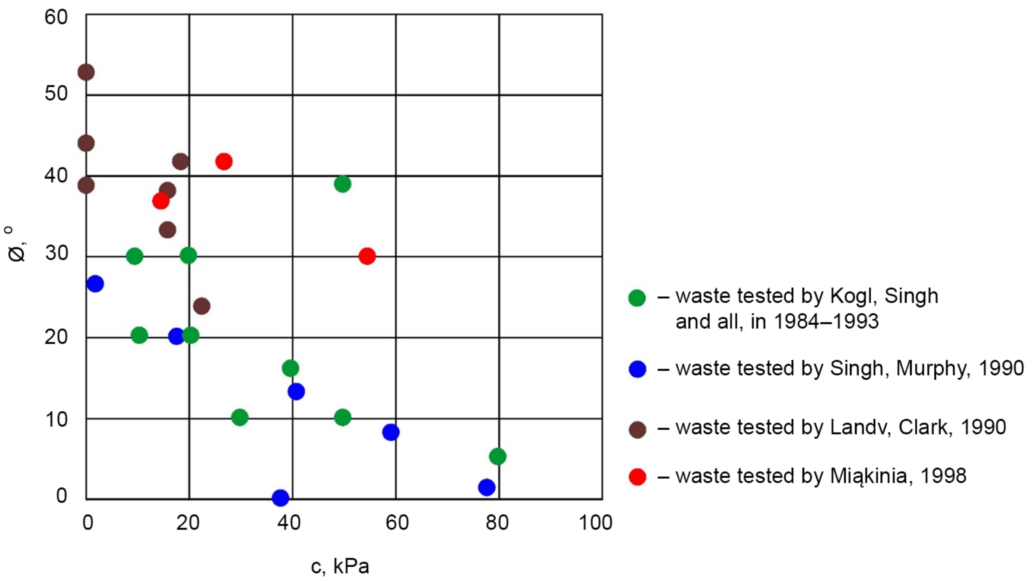

Fig. 7. The values of the angle of internal friction and cohesion for municipal waste (comparison of various tests)

at waste of all ages. The range of the tracia angle is 5–39 °. Singh and Murphy obtained the lowest values for waste older than 10 years. The range of the angle of internal friction is 0–27 °.

The value of cohesion for municipal waste varies greatly. In most studies, the values are in the range from 0 to 20 kPa. The larger results mainly concern the organic fractions of waste. Singh and Kogl achieved a value of up to 80 kPa. There is no systematic research on the geotechnical parameters of waste in Poland. Few publications, e.g., Miąkini, present shear parameters from the landfills in Gdynia and Gdańsk (see: Fig. 7)

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SKŁADOWISKO W JAŚLE – ANALIZA STATECZNOŚCI SKARPY PRZY ZMIENNYCH WARTOŚCIACH SPÓJNOŚCI ODPADÓW KOMUNALNYCH

ABSTRACT

Cel pracy

W artykule przedstawiono wyniki badań i obliczeń mających na celu określenie wpływu zmian wartości spójności odpadów komunalnych na wartości współczynnika bezpieczeństwa obliczanego metodą Felleniusa. Omawiane prace wykonano dla składowiska odpadów innych niż niebezpieczne i obojętne zlokalizowanego w Jaśle.

Materiał i metody

Analizę przeprowadzono, opierając się na własnych badaniach, obliczeniach oraz istniejącej dokumentacji składowiska. Część obliczeniowa pracy obejmowała sprawdzenie stateczności skarp w dwóch wybranych przekrojach, przy założeniu wartości spójności odpadów komunalnych w zakresie 0–30 kPa. W zależności od przyjętego przekroju i schematu obliczeń stwierdzono, że nawet dla kohezji równej 23 kPa obliczony współczynnik bezpieczeństwa wskazuje na braki stateczności.

Wyniki i wnioski

Na podstawie parametrów geotechnicznych zgodnych z normą sprawdzono stateczność skarpy w wybranym przekroju poprzecznym. Dla analizowanego przekroju uzyskano wartości współczynnika bezpieczeństwa w zakresie 0,70–1,38, potwierdzając tym samym dominację sił otrzymujących.

Słowa kluczowe: współczynnik bezpieczeństwa, składowisko odpadów komunalnych, stateczność skarp, kohezja