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The influence of CBR parameters of low-frost-susceptible soils on the process of airport pavement design

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Abstract. The paper presents the issue of layer thickness selection in designing of concrete airport pavements depending on the values of soil substrate calculation parameters. This analysis is based on laboratory testing of low-frost-susceptible soils, specifically silty sands of various silt content, for which the California Bearing Ratio values were determined [1, 2]. Dimensioning methods used in airport pavement design are presented, together with their brief descriptions. Comparative calculations of surface layer thickness depending on the interpretation of the obtained CBR laboratory test results are performed. Differences in airport pavement layer thickness resulting from the assumed CBR values are presented. A correction of the results of pavement calculations based on the California bearing ratio is proposed.
Keywords: airport pavement, CBR test, pavement dimensioning, soil subtrate, low-frost-susceptible soil
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1. Introduction

Recently, both in Poland and worldwide, a dynamic growth of civilian aviation can be observed, airport development in particlar. This is related to the expansion of basic airport infrastructure, among others construction of new taxiways and aprons, and extension or construction of new runways. The planned investments are increasingly located in areas disadvantageous from the perspective of soil and water conditions. This is caused by the fact that airports cover significant areas and it is not possible to guarantee the same soil substrate parameters for the entire facility.

If areas of reduced soil substrate load-bearing capacity are encountered, it is attempted to improve its properties by various technical means. Substrate load-bearing capacity increase may at times necessitate the employment of specialist geotechnical works that can generate substantial costs and constitute a large proportion of the construction work costs. The authors are familiar with a case (at a civiliar airport in Poland) of native soil, specifically silt, being replaced with cement-stabilised all--in aggregate of almost 2.5 m thickness. A brief analysis demonstrated that there was no need for replacement on this scale, but the pavement designer, wary of the test results, adopted a highly conservative variant.

Assumption of the correct soil parameters is of great importance when dimensioning the pavement and therefore directly translates to investment costs. It is crucial to identify the full scope of possible soil substrate testing, the possible resulting parameters that may be useful for calculations, and most importantly — to select the right test method.

Assumption of incorrect geotechnical parameters (for various reasons) may result in overdimensioning of the structure or pavement damage during its operation. Even a correctly built pavement may be damaged if the soil substrate load-bearing capacity is overestimated.

2. Dimensioning of airport pavements

An airport pavement is a complex structural system — simple in terms of its constituent elements, but highly complicated in terms of calculations during the design phase. There are numerous methods for calculating airport pavements, which have been successfully used for many years. Classic dimensioning methods based on certain calculation simplifications have been known for over 90 years, yet they continue to be developed and perfected [3, 4]. Thus new methods, based on the finite element method (FEM), emerge, enabling accurate modelling of the pavement structural system's behaviour under load. Fundamental (classic) methods include:

— Westergaard method,
— Pickett and Ray method,
— methods based on CBR parameters.

A certain development of the above is the FAA (Federal Aviation Administration) method and the ACN-PCN (Aircraft Classification Number — Pavement Classification Number) pavement load-bearing capacity determination method [6]. State of the art methods are based on numerical calculations utilising the FEM.

This paper focuses on presenting airport pavement dimensioning based on CBR (California Bearing Ratio) parameter testing results. Soil substrate testing based on the CBR parameter was pioneered by the United States Army Corps of Engineers in the 1930s. Over the years, this testing method continued to be developed and efforts were made to adapt to local conditions. Similar work was also conducted in Poland, with the aim of adapting this testing methodology to Polish soil and climate conditions. CBR testing is based on comparing the value of force necessary to penetrate with a standard plunger to the force required to penetrate the reference crushed rock material with the same plunger. These tests can be performed in a laboratory (on samples prepared for this purpose) or as field tests measuring the soil parameters at the specific location and time.

The CBR-based pavement dimensioning method relies on direct results of laboratory or field tests. Based on the data obtained from the analysis (percentage CBR result) and using the available nomograms, one can determine the subgrade reaction coefficient „k" or determine the required pavement thickness directly. If the „k" coefficient is determined, it can be used in the Estergaard or Pickett and Ray methods. Additionally, using common correlation relationships, CBR can be utilised to determine, for example, the subgrade deformation modulus or load-bearing capacity expressed as acceptable unit pressure [7].

Various modifications of CBR-based dimensioning methods enable annual precipitation levels, the effects of frost or the expected (also predicted future) scale of traffic load, to be taken into account.

A very important issue is performing the CBR test correctly, based on tried methodology, because the unaccounted for variability of geotechnical parameters may affect the pavement's behaviour during its operation. This particularly applies to field tests, which must be performed at times when the subgrade load-bearing capacity is the lowest (high groundwater levels, no water drain available).

3. California Bearing Ratio (CBR) tests for low-frost-susceptible soils

According to the *Rigid pavement catalogue* [8], soils forming airport subgrades can be classified according to their frost susceptibility. That document divides soils as not susceptible to the effects of water and low temperature (non-frost-susceptible soils), to low-frost susceptible soils or ones that can under certain conditions change their parameters during adverse weather conditions, to highly frost-susceptible soils that are unsuitable as pavement subgrade.

This paper focuses on CBR tests for one of the low-frost-susceptible soils — silty sands, which if watered, have some water accumulation ability and are thus susceptible to low temperatures.

In accordance with the *Catalogue...* [8], the CBR laboratory tests were performed using the methodology described in standard [9]. Soils with a silty content between 4% and 23% were used to determine the CBR value; Figure 1 below shows a sample grain size distribution curve for soil sample no. 4.

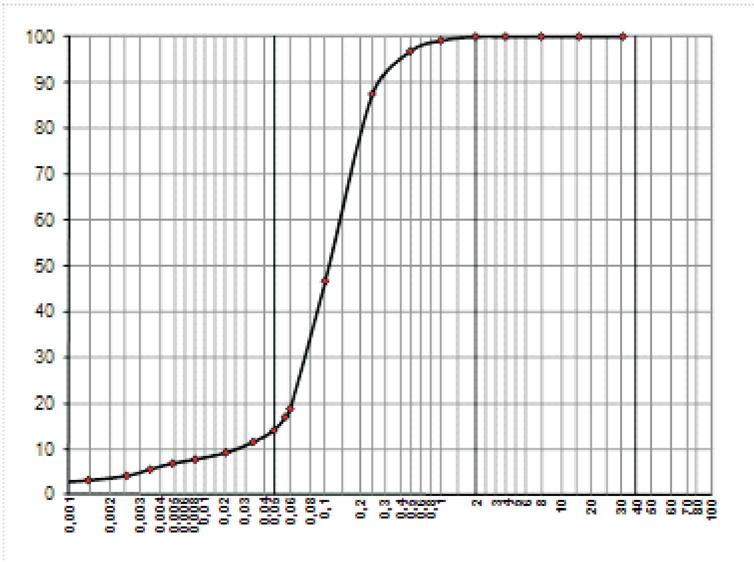

Fig. 1. Sample grain size distribution curve for sample no. 4

For all tested soils, their basic physical properties were determined, such as: silty fraction content; optimum moisture content; maximum bulk density of the soil skeleton. The tests were performed in accordance with standard [10], which — although withdrawn — is the standard designed for such tests according to the *Catalogue...* [8]. Table 1 below summarises the parameters determined for all soil samples.

Table 1

Summary of physical characteristics of the test samples

Sample no.	Silty fraction content [%]	Optimum moisture content [%]	Maximum bulk density of soil skeleton [kN/m^3]	Porosity index
1	4.0	8.1	1.789	0.481
2	7.3	9.3	1.828	0.450
3	9.0	9.9	1.852	0.431
4	13.5	9.6	1.859	0.425
5	18.4	10.1	1.830	0.448
6	23.0	9.5	1.863	0.422

After the basic tests, the CBR tests proper were performed, during which a changing of the shape of penetration plot curve was observed, which phenomenon was described as plot "bulging" away from the standard line (Fig. 2). The curve changes were observed for all silty sand test samples. It was possible to note for every analysed sample that there is an area where the CBR parameter read increased by as much as several per cent compared to the end value.

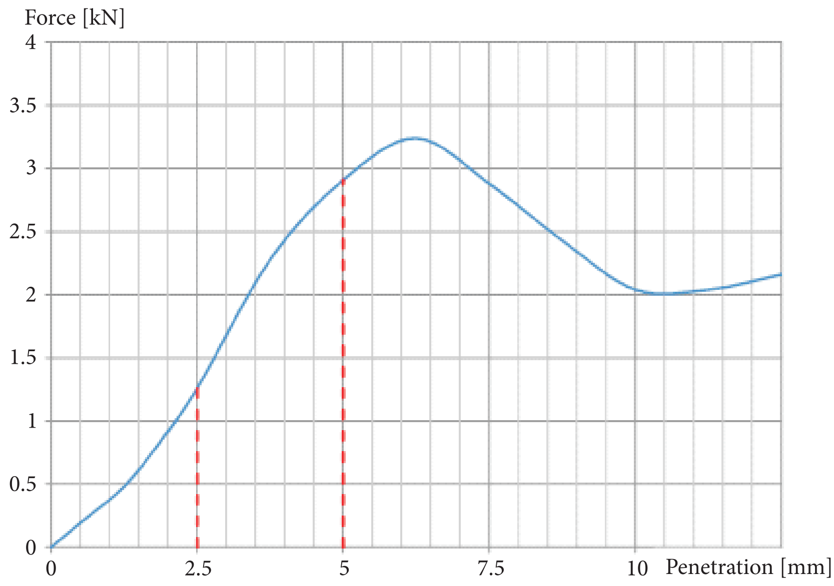

Fig. 2. Penetration plot for sample no. 4 with reference reading points marked

According to the test methodology, CBR values are read at the penetration depth of 2.5 mm to 5.0 mm (the parameter value is determined using the higher value read, regardless of depth). As can be seen, the bulging phenomenon encompasses both reference penetration depths. The phenomenon of CBR value increase occurs at various plunger penetration depths and there is a clearly visible relation between silty fraction content and the depth where the phenomenon occurs. When determining the method for correcting the plot, involving a removal of the "bulge", standard curve approximation was used and the curve was approximated using a fourth degree polynomial. The polynomial was determined for the standard curve, which at later steps was fitted to the test results. The polynomial takes the following form:

$$y = -0.0034x^4 + 0.1038x^3 - 1.1561x^2 + 7.6661x$$

where: y — force in [kN],
x — plunger penetration depth in [mm].

Figure 3 shows corrected penetration curve plots for sample no. 4. The blue line is the measurement plot, while the red line is the plot with the adopted polynomial taken into account.

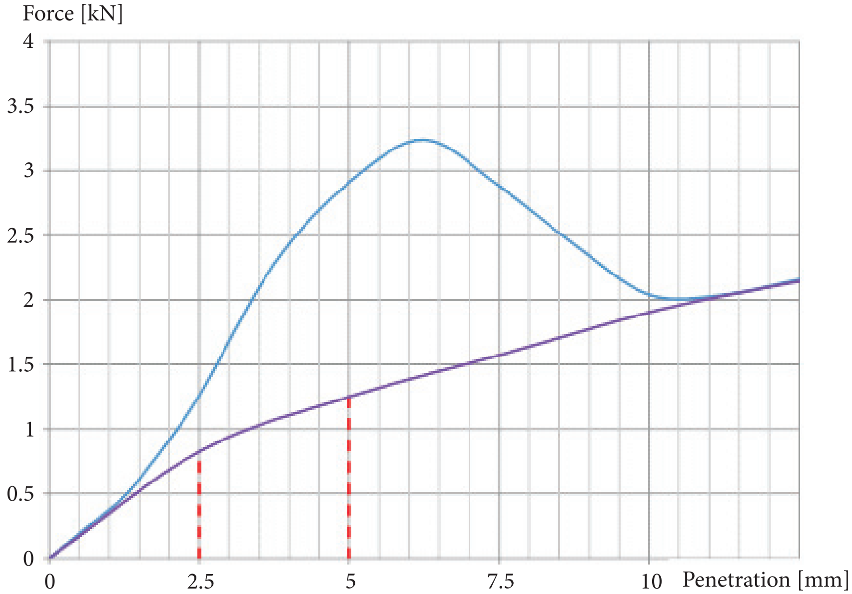

Fig. 3. Corrected penetration plot for sample no. 4

Due to the emergence of the "bulging" phenomenon, after performing a series of tests, the results were analysed and Table 2 compares the obtained CBR values for the 6 analysed samples with the parameter values read from the proposed correction curves.

Analysing the obtained and compared test results, it can be stated that the differences in CBR values are significant and reach as much as 11%. Moreover, it is visible that after reaching the full "deflection", the plot returns to the standard curve shape at penetration beyond 11 mm. This phenomenon was also observed for all test samples.

TABLE 2

Summary of differences in CBR values

Sample no.	CBR [%] (test plot)	CBR [%] (corrected plot)	Difference
1	10.6	4.8	5.8
2	15.3	5.6	9.7
3	15.6	4.5	11.1
4	14.3	6.1	8.2
5	10.1	6.1	4.0
6	8.5	6.1	2.4

4. Analysis of the effects of CBR parameter changes on pavement dimensioning

Currently, airport pavement dimensioning methods are based on the following calculation methods, which depend on the geotechnical parameters:

- — determination of total pavement thickness based on the CBR parameter (CBR, Wyoming methods),
- — determination of the subgrade reaction coefficient „k" (Westergaard method),
- — determination of the ground deformation modulus based on the subgrade reaction coefficient „k" (FEMs).

This paper focused on the comparison of total pavement thickness values determined using the CBR parameter. For each sample and its corresponding CBR value, a total airport pavement thickness was determined. The following input data were assumed for dimensioning:

— infrastructure element	runway
— subgrade	silty sand
— single wheel load	311 kN (70 000 pounds)
— no. of operations per day	N = 50
— groundwater	2 m b.g.l.

Using the available nomogram (Fig. 4), total airport pavement thickness and subgrade reaction coefficient „k" were determined for the parameters obtained during testing, as well as for CBR parameters determined using the standard curves.

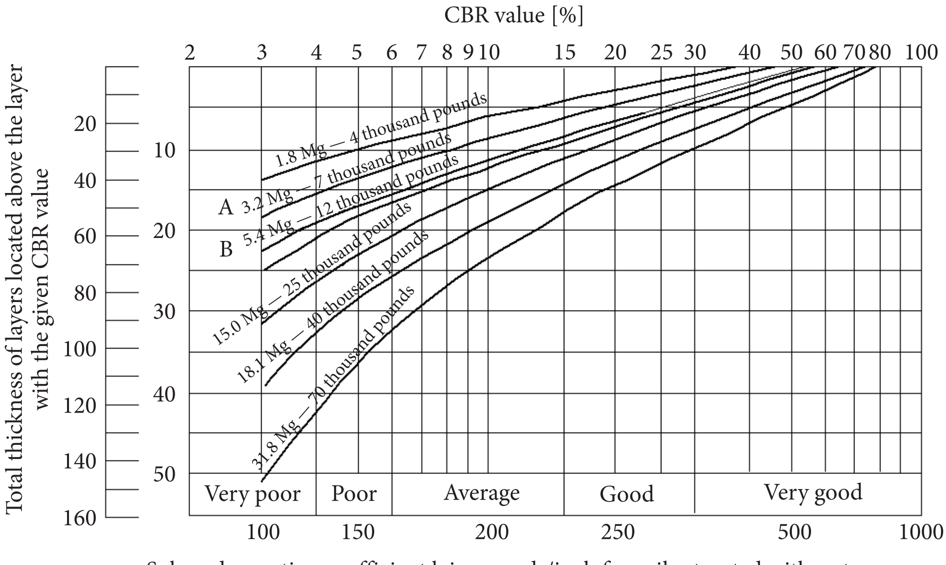

Fig. 4. Nomogram for determining pavement thickness based on CBR [5]

The nomogram for calculating pavement thickness based on the CBR parameter was developed in the USA and is used by the United States Army Corps of Engineers as an official method for dimensioning airport pavements.

Table 3 below shows a summary of the obtained results

TABLE 3

Results of CBR comparative analysis for the coefficient „k" and total pavement thickness

Sample no.	CBR [%] (test plot)	CBR [%] (corrected plot)	Coefficient "k" [MPa/m] (test plot)	Coefficient "k" [MPa/m] (corrected plot)	Total pavement thickness [cm] (test plot)	Total pavement thickness [cm] (corrected plot)	Thickness difference [cm]
1	10.6	4.8	56	40	93	62	+31
2	15.3	5.6	64	42	87	45	+42
3	15.6	4.5	64	38	98	44	+54
4	14.3	6.1	62	43	84	48	+36
5	10.1	6.1	54	43	84	63	+21
6	8.5	6.1	52	43	84	70	+14

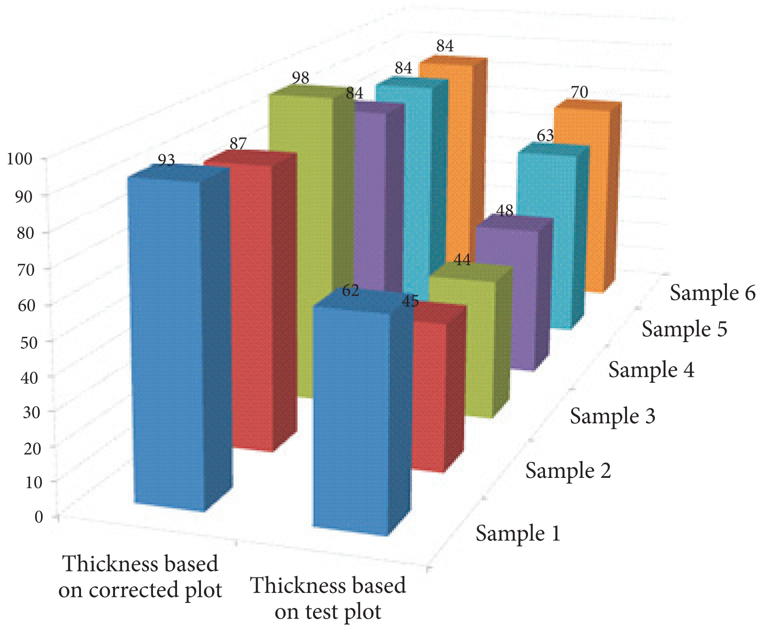

Fig. 5. Visualisation of differences in the calculated pavement thicknesses

The airport pavement calculations performed demonstrate that differences in the results obtained are significant and they increase the lower the subgrade load-bearing capacity determined using the CBR parameter is. For soils of medium load-bearing capacity (at CBR = 15%), the differences in thickness are minor, but when subgrade load-bearing capacity lowers (CBR = 8.5%), the differences are noticeable and reach values exceeding 50 cm. It must be noted that the tests performed only concern natural non-reinforced subgrades.

5. Summary and conclusions

The need to adapt airport infrastructure to increasing air traffic loads necessitates an expansion of airport pavements. Today, there are numerous pavement dimensioning methods known, based on various parameters. The basic element responsible for correct pavement dimensioning is the assumption of correct geotechnical parameters of the subgrade. One method of determining subgrade load-bearing capacity is the CBR — California Bearing Ratio — test, which can be determined for samples taken from the investment site (laboratory testing) or directly on site (field testing). The laboratory CBR tests performed for low-frost-susceptible soils, specifically silty sands, demonstrated that these soils do not exhibit a classic load-bearing capacity profile, unlike other soils subjected to CBR tests. This applies in particular to the load — penetration curve. For silty sands, it can be seen that at a certain depth, the penetration plot deviates from the standard plot. Additionally, the possibility of major errors during result interpretation that may occur when using PN-EN standards must be noted [11, 12, 13]. According to the provision in section 10.1.3 it is recommended to correct the concave part upwards with a line tangent to the inflexion point, which is shown in Figures no. 1 of these standards [12, 13]. This figure is a clear over-interpretation, the plot curve may have its break in the initial section, which is usually due to an instrument error or a result of uneven surface [4]. It is fairly controversial that the standard in Polish [12], corrected in 2007 and valid until 2017, was replaced with an almost identical 2012 standard in English with an incorrect key under Figure 1.

Based on the test results, pavement thickness was calculated using the modified CBR method — the Wyoming method. The calculations were performed for CBRs directly from the test curve and for CBRs determined based on the standard curve. For soils of low load-bearing capacity, the differences are significant and for identical operating loads, they reach as much as 50 cm. The better the soil parameters, the lower the differences were.

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Wpływ parametrów CBR gruntów wątpliwych na wymiarowanie nawierzchni lotniskowych

Streszczenie. W artykule przedstawiono zagadnienie dotyczące doboru grubości warstw dla projektowanych betonowych nawierzchni lotniskowych w zależności od wartości wyznaczonych parametrów obliczeniowych podłoża gruntowego. Analiza ta bazuje na badaniach laboratoryjnych gruntów wątpliwych, jakimi były piaski pylaste o różnej zawartości frakcji pylastych, dla których określano wartość kalifornijskiego wskaźnika nośności CBR [1, 2]. Przedstawiono stosowane w projektowaniu metody wymiarowania nawierzchni lotniskowych wraz z ich krótką charakterystyką. Wykonano obliczenia porównawcze grubości warstw nawierzchniowych w zależności od interpretacji otrzymanych wyników badań laboratoryjnych CBR. Zaprezentowano różnice w grubości warstw nawierzchni lotniskowych wynikające z przyjmowanych wartości wskaźnika CBR. Zaproponowano korektę wyników obliczeń nawierzchni opartych na kalifornijskim wskaźniku nośności.

Słowa kluczowe: nawierzchnie lotniskowe, badania CBR, wymiarowanie nawierzchni, podłoże gruntowe, grunty wątpliwe

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