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Comparison of field methods for evaluating subgrade bearing capacity based on the CBR index: analysis of test results obtained using the Panda penetrometer and the Dynamic Cone Penetrometer

Abstract: The article presents a comprehensive analysis of two field methods for determining the California Bearing Ratio (CBR), namely the Panda cone penetrometer and the Dynamic Cone Penetrometer (DCP). The tests were carried out at an airport facility, covering 10 measurement points, and the data obtained was subjected to statistical and comparative evaluation. Due to formal restrictions, it was not possible to collect soil samples, which made it impossible to perform laboratory tests as a reference method. However, a strong correlation was found between the CBR values obtained by the field methods (Pearson r = 0.895), which confirms the possibility of using them interchangeably under certain conditions. The advantages and limitations of dynamic methods in the context of airport and road infrastructure testing were also discussed.

Keywords: bearing capacity, California Bearing Ratio (CBR), field tests, subgrade soils.

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1. INTRODUCTION

The bearing capacity of the subgrade is the ability of the soil to transfer loads applied above it without excessive settlement or damage. The bearing capacity of the ground is expressed using the California Bearing Ratio (CBR), which is used, among other things, in road and airport engineering.

The CBR can be tested in the laboratory and in the field. The laboratory method is accurate and repeatable, but it is also time-consuming and requires the collection and proper preparation of samples. Field methods, on the other hand, are quick and practical. Each method, whether laboratory or field, has its advantages and disadvantages, but also its specific purpose.

The research program, the results of which will be described in the article, included testing the CBR index using the laboratory method, but it was not possible to collect soil samples at the site where the field tests were performed. Due to this fact, the analyses focus on two field methods, i.e., testing with a Dynamic Cone Penetrometer (DCP) and a Panda cone penetrometer. Both methods are dynamic methods.

The field tests were carried out in August 2025 at one of the airport facilities in Poland, at 10 test points, to a depth of 0.85 m below ground level. The distance between the Panda probe and the DCP probe was approximately 1 m.

2. METHODOLOGY OF SELECTED FIELD METHODS

2.1. DETERMINATION OF THE CBR INDEX USING THE PANDA CONE PENETROMETER

The Panda dynamic cone penetrometer was designed and developed in France in 1989 [1]. Testing with the Panda penetrometer involves driving a rod equipped with a cone tip into the ground. During the test, the impact energy is measured for each hammer blow on the anvil using strain gauges. It should be noted that in this test, the driving energy is variable, which allows it to be adjusted to the density of the soil being tested. The depth of the cone-shaped rod is measured using a depth measuring cable, which transmits the data to the appropriate sensor. All information from various sensors is transmitted to the CAU measurement data collection system, where it is processed and forwarded to the recorder [2]. The Panda probe diagram is shown in Fig. 1.

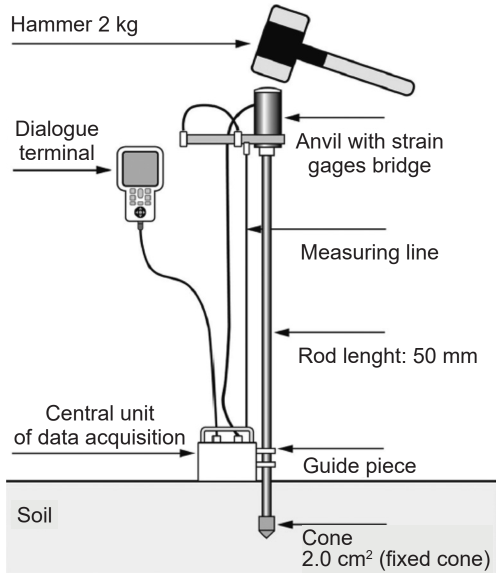

Fig. 1. Panda probe diagram [3]

Based on the measured data, the dynamic cone penetration resistance q_d is calculated, and based on the q_d value, it is possible to calculate the CBR soil bearing capacity index. The dynamic cone penetration resistance is calculated according to the "Dutch" formula (1) [4]:

$$q_d = \left(\frac{1}{A}\right)\cdot\left(\frac{E}{e}\right)\cdot\left(\frac{1}{1+\frac{P}{M}}\right), \tag{1}$$

where:

A – area of a cone [cm^2],
E – variable energy of each impact [J],
e – cone indentation after each impact [mm],
P – weight of the driven-in system (anvil, rods, cone) [kg],
M – hammer weight [kg].

The relationship between the CBR index and resistance on the q_d cone is described by the formula (2) [2]:

$$CBR = \alpha\cdot\left(\frac{q_d}{p_a}\right)^{\beta}, \tag{2}$$

where:

q_d – dynamic cone resistance [MPa],
p_a – atmospheric pressure (standard value assumed as 101,325 Pa),
α, β – empirical coefficients depending on soil type [–].

The Panda probe test is not standardized in Poland. It is performed according to the manufacturer's instructions. In France, where the Panda probe originates and is one of the basic tests for determining the CBR bearing capacity index, it is a standardized test performed in accordance with the provisions of standard NF P94-105:2025 "Soils: investigation and testing – Inspection of compaction quality – Method using a variable energy dynamic penetrometer – Principle and method for calibrating the penetrometer – Exploitation of results – Interpretation" [5].

The road engineering guidelines in force in Poland allow the use of the PANDA probe testing method, as confirmed, among others, in the following documents: Guidelines for soil testing for road construction purposes. Part 1: Guidelines for testing construction soil in road engineering [6], Catalog of typical rigid pavement structures [7], Catalog of typical flexible and semi-rigid pavement structures [8].

2.2. TESTING THE CBR INDEX USING AN DYNAMIC CONE PENETROMETER DCP

The *CBR* bearing capacity index test using a DCP (Fig. 2) involves measuring the penetration of the probe tip per impact of a weight falling from a specified height [9]. The direct parameter obtained during the test is the *DCP* index [mm], i.e., the penetration of the probe cone per impact. In the case of the DCP, the impact energy is constant.

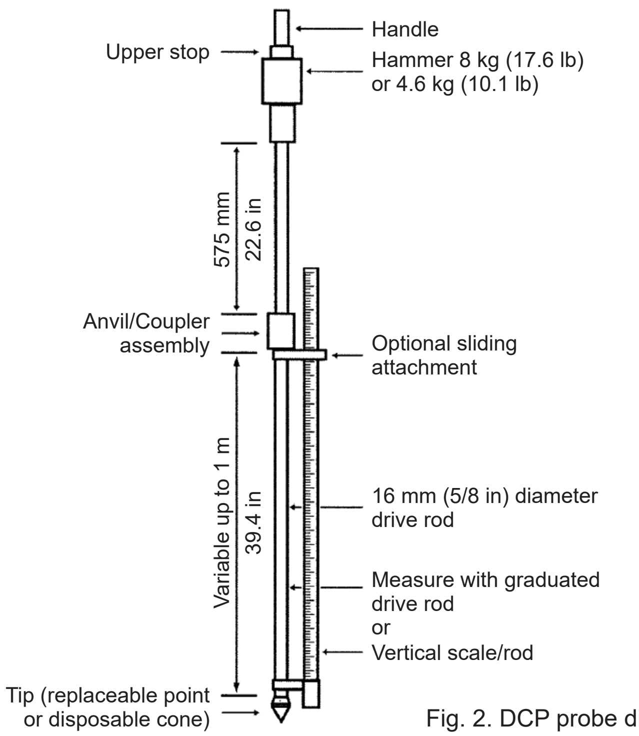

Fig. 2. DCP probe diagram [11]

The literature describes many correlations between the *CBR* and *DCP* indices. Based on the results of previous studies and observations, it has been assumed that the most functional relationship between the *CBR* and *DCP* indices is the formula (3) [10]:

$$CBR = \frac{292}{DCP^{1.12}}, \tag{3}$$

where:

CBR – California bearing ratio CBR [%],

DCP – cone penetration per blow [mm].

The Fig. 3 shows a correlation chart of the *CBR* index in relation to the *DCP* index, which is described by formula (3).

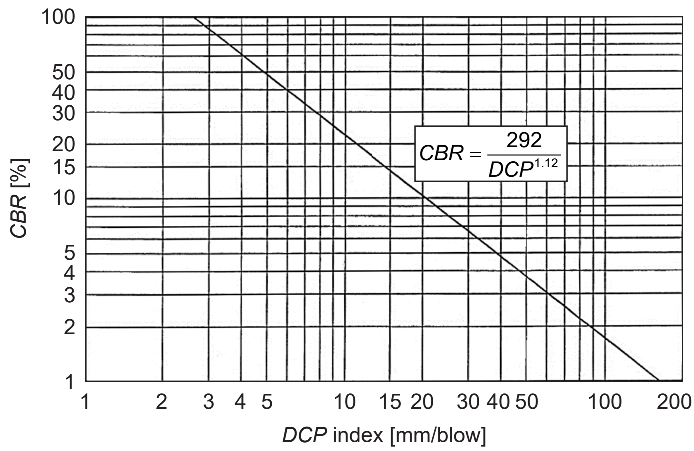

Fig. 3. Correlation between the *CBR* indicator and the *DCP* index [12]

The method of testing the CBR bearing capacity index using an DCP probe is required in Poland for natural airfield pavements. The test is performed in accordance with ASTM D6951M-09 "Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications" [11] and Defense Standard NO-17-A503:2017 "Airport pavements. Natural airport pavements. Load-bearing capacity tests" [9]. In terms of CBR testing in road construction, this method is approved in the following documents: Guidelines for testing soil subgrade for road construction purposes. Part 1: Guidelines for testing construction subgrade in road construction. [6], Catalog of typical rigid pavement structures [7], Catalog of typical flexible and semi-rigid pavement structures [8].

3. ANALYSIS OF THE RESULTS OBTAINED

3.1. CBR BEARING CAPACITY VALUES OBTAINED FROM INDIVIDUAL TESTS

Fig. 4 shows graphs from Panda and DCP probe conducted at test point No. 1, while all the results obtained are presented in Table 1.

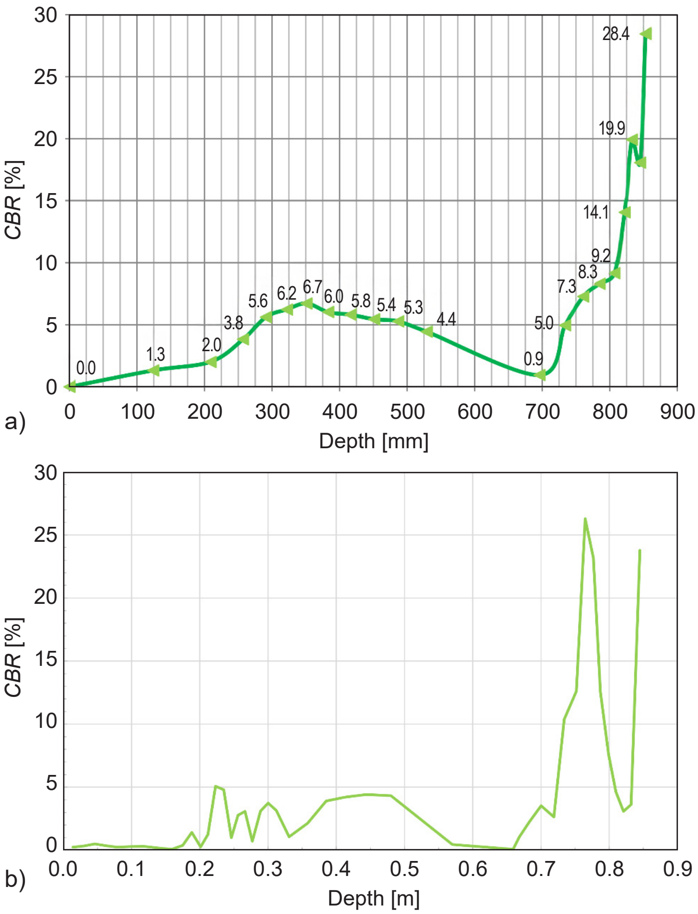

Fig. 4. Charts from Panda and DCP surveys – survey point no. 1: a) Dynamic Cone Penetrometer DCP, b) Panda probe

Table 1. Results of the *CBR* index obtained using two field methods

Test point No.	Average CBR value	
	Panda probe [%]	DCP probe [%]
8	8.3	6.5
7	24.2	25.4
3	5.6	7.4
5	12.0	10.5
4	4.3	10.1
23	11.6	7.4
21	1.4	2.5
19	1.6	3.8
18	2.9	7.7
1	4.3	7.8

3.2. ANALYSIS OF THE RESULTS OBTAINED

The CBR bearing capacity values obtained during field tests using the Panda probe and the DCP probe were analyzed to determine whether the two methods are correlated. Fig. 5 shows a graph of the results obtained, together with the regression line and the equation of the linear regression. The slope of 0.811 means that with a 1% increase in *CBR* (Panda), *CBR* (DCP) will increase by an average of approximately 0.81%. The intercept of 2.728 indicates that the SDS method has a certain initial value – DCP may give slightly higher values at very low *CBR* values.

For the purposes of analyzing the results, Pearson's correlation coefficient was also calculated, which amounted to 0.895, indicating a strong positive correlation between the CBR values obtained with the Panda probe and the DCP probe. In order to verify the statistical significance of Pearson's correlation coefficient, the t-statistic was calculated. For $r = 0.895$ and $n = 10$, $t(8) = 5.67$ was obtained, which corresponds to a value of $p \approx 0.0004$ (two-tailed test). This indicates that the linear relationship between the CBR values obtained using the Panda and SDS probes is statistically significant at the significance level $\alpha = 0.05$.

Based on the results obtained and the statistical analysis performed, it was concluded that the increase in the *CBR* value determined by the Panda probe correlates clearly with the increase in the *CBR* value determined by the DCP probe. Both methods show a similar response to changes in soil bearing capacity, and the observed differences in absolute values (e.g., locally higher values obtained with the DCP method) do not affect the overall nature of the linear relationship.

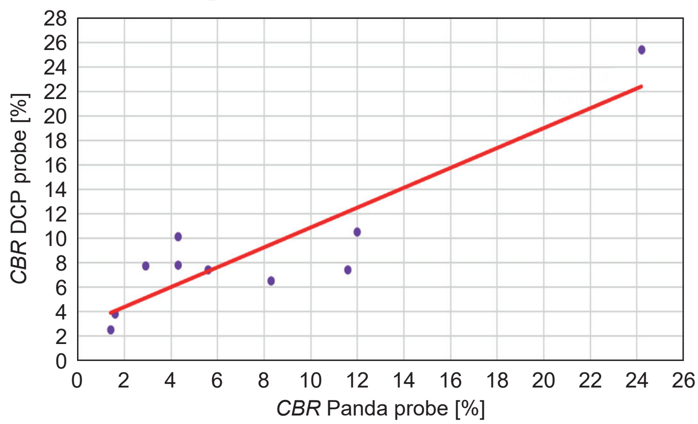

Fig. 5. Correlation of *CBR* results obtained using two research methods: linear regression CBR – Panda probe and CBR – DCP probe

4. CONCLUSIONS

Based on the conducted analysis, the following conclusions were drawn:

1. Both methods used – the Panda probe and DCP – show a correlation, but not strong enough to be used as methods of equal diagnostic value in the spatial assessment of soil bearing capacity variability.
2. Certain differences in the absolute values of the CBR bearing capacity index may result from: variable energy of the Panda probe (greater sensitivity to soil structure), the constant energy of the DCP probe (greater repeatability, less adaptability), local differences in soil conditions even within 1 m, the influence of moisture, which plays a significant role in dynamic methods, or, for example, the use of different empirical correlations. However, these differences in absolute values do not negate their usefulness, as the trend of change remains consistent.
3. Based on the obtained results, it can be preliminarily concluded that both methods demonstrate consistency, which justifies further studies aimed at evaluating their potential interchangeability.
4. Dynamic methods remain irreplaceable in conditions where rapid diagnosis is required (e.g., airports), sampling is impossible, or continuous assessment of the geotechnical profile is necessary.
5. In subsequent stages of the research, it is planned to gradually expand the database of results obtained using the Panda and DCP methods in order to develop local correlations of the CBR index for different soil types. In addition, the scope of the research will be expanded to include laboratory tests, as a comparison of CBR values obtained using field and laboratory methods is a prerequisite for comprehensive analysis and validation of the results.

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Porównanie terenowych metod oceny nośności podłoża gruntowego na podstawie wskaźnika CBR: analiza wyników badań sondą Panda i sondą SDS

Streszczenie: W artykule przedstawiono kompleksową analizę dwóch metod terenowych określania kalifornijskiego wskaźnika nośności CBR, tj. penetrometru stożkowego Panda oraz sondy dynamiczno-stożkowej SDS. Badania przeprowadzono na obiekcie lotniskowym, które obejmowały 10 punktów pomiarowych, a uzyskane dane poddano ocenie statystycznej i porównawczej. Ze względu na ograniczenia formalne niemożliwe było pobranie próbek gruntu, co uniemożliwiło wykonanie badań laboratoryjnych stanowiących metodę odniesienia. Wykazano jednak silną korelację pomiędzy wartościami CBR otrzymanymi metodami terenowymi (Pearson $r = 0{,}895$), co potwierdza możliwość stosowania ich zamiennie w określonych warunkach. Omówiono także zalety i ograniczenia metod dynamicznych w kontekście badań infrastruktury lotniskowej i drogowej.

Słowa kluczowe: badania terenowe, kalifornijski wskaźnik nośności CBR, nośność, podłoże gruntowe.