# LIMITATIONS OF CLASSICAL ANALYTICAL METHODS IN THE DESIGN OF DSM-PILLARS

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***Abstract.*** *The classic analytical methods used in calculating the bearing capacity and settlement of DSM columns in soil cement mortar - the SP 24.13330.2021 standard, the Broms-Kitazume method, and the Poulos-Davis elastic solution - were compared with the results of natural tests conducted in the Andijan region. The analysis shows that these methods, originally developed for bored piles and elastic half-space, cannot fully reflect the characteristics of DSM piles: SP 24.13330.2021 overestimates the bearing capacity by 405%, the Broms-Kitazume method by 153%, and the Poulos-Davis method underestimates settlement by 90%. The article analyzes the reasons for these results in detail and identifies the limitations of applying classical methods in the design of DSM columns. The numerical method in PLAXIS 3D software is recommended as an alternative.*

***Keywords****: DSM-column, SP 24.13330, Broms-Kitazume method, Poulos-Davis method, classical analytical methods, load-bearing capacity, settlement, numerical modeling, loess soil.*

## Introduction

In the last decade, the Deep Soil Mixing (DSM) technology has been widely used in Uzbekistan for structures built on weak loessic and saturated, dusty sandy soils. The advantages of this technology include the fact that the soil is not removed from its original location, minimal impact of vibrations and noise on the surroundings, and the speed of the foundation construction process [1, 2].

However, an important question arises in the design of DSM columns: which method can more accurately determine their load-bearing capacity and settlement? In current design practice, classical analytical methods are often used—the SP 24.13330.2021 standard (for helical piles), the Broms-Kitazume method (for soft loess piles), and the Poulos-Davis elastic solution (for calculating the settlement of flexible piles) [3, 4, 5]. These methods have been developed over a long history and are widely used by designers.

At the same time, DSM piles are a unique type of structure whose properties differ from those of conventional reinforced concrete piles (≈30 MPa). Their uniaxial strength (qu = 5–10 MPa) is several times lower than that of conventional reinforced concrete piles (≈30 MPa), and the soil-pile interface has a different character. Therefore, it is necessary to objectively assess the suitability of classic methods for DSM piles.

The purpose of this work is to determine the applicability of three classical analytical methods to DSM columns using a construction site in the Andijan region as an example, and to scientifically define the limitations of these methods.

## Research methodology

The study is based on natural static test data obtained at the construction site of the agro-logistics center located in the Andijan region. The DSM column No. 3 selected for testing has the following characteristics: diameter D = 0.6 m, length L = 7 m, M40 grade soil-cement mortar (qu = 5.57 MPa). The test was conducted in February-March 2026 in accordance with the requirements of ASTM D1143 and GOST 5686-2020.

The engineering-geological classification of the area was compiled based on data from 161 wells. At a depth of 8.5 m, layers of loess-like silt and saturated dusty sandy loam are present; below that are layers of hard silt and medium-density sand. The groundwater table is located at depths of 1.1–2.8 m. The soil parameters are presented in Table 1.

***Table 1. Properties of the soil layers in the field***

| Qatlam | H, m | Soil type | γ, kN/m³ | c, kPa | φ, ° | E, MPa | $e_0$ |
|---|---|---|---|---|---|---|---|
| I | 0.0–2.0 | Loam / clay loam | 18.1 | 12 | 18 | 4.0 | 0.82 |
| II | 2.0–8.5 | Soft loam / soft clay loam | 18.9 | 18 | 20 | 7.0 | 0.78 |
| III | 8.5–10.5 | Hard / stiff loam | 19.3 | 24 | 22 | 11.5 | 0.71 |
| IV | 10.5–13.0 | Sandy loam | 19.6 | 5 | 28 | 18.5 | 0.64 |
| V | 13.0–15.0 | Sand | 20.1 | 1 | 33 | 22.0 | 0.58 |

The study analyzed the following three classical analytical methods:

1. SP 24.13330.2021 - Russian standard method for calculating the load-bearing capacity of screw piles, formula:

$$F_d = \gamma_c \cdot \left(\gamma_{cr} \cdot R \cdot A + u \cdot \sum \gamma_{cf} \cdot f_i \cdot h_i\right)$$

Here, $F_d$ is the calculated bearing capacity of the pile, R is the calculated resistance of the subgrade under the pile tip, A is the area of the pile tip, u is the pile perimeter, and fi is the lateral friction coefficient of the i-th layer.

2. The Broms-Kitazume method - an approach that accounts for the possibility of the column itself breaking due to material weakness [4]:

$$Q_{ult} = \min\left(Q_{col}, Q_{soil}\right),\ Q_{col} = q_u \cdot A_p \cdot \eta$$

Here, $Q_{col}$ is the limit load resulting from the failure of the column material, and η = 0.4 is the variability coefficient.

3. The Poulos-Davis method - the classical elastic solution [5] for calculating the sinking of a soft spring in an elastic half-space:

$$s = \frac{P \cdot I_0 \cdot R_k \cdot R_h \cdot R_v}{\bar{E}_s \cdot D}$$

Here, $I_0 = 0.045, R_k, R_h, R_v$ are the influence coefficients, and Ēs is the weighted average modulus of the soil with respect to depth.

The calculation results were compared with the natural test results of column No. 3. In addition, a numerical calculation was performed in PLAXIS 3D using the calibrated Hardening Soil Small model, and the degree of agreement was evaluated for the conclusion.

**Results and Discussion**

The calculation results and their comparison with natural testing are presented in Table 2 and Figure 1. The experimental result in column 3 is the lifting capacity. $Q_{ult}$ = 249 kN, maximum displacement speake = 8.19 mm. The calculation results obtained using classical methods and the numerical model are as follows:

***Table 2. Comparison of the results of classical analytical methods and the numerical model with experimental data.***

| Calculation method | Q, kN | ΔQ, % | s, mm | Δs, % |
|---|---|---|---|---|
| Experiment / Test (Pile No. 3) | 249 | - | 8.19 | - |
| SP 24.13330.2021 | 1 257 | +405 | - | - |
| Broms–Kitazume | 630 | +153 | - | - |
| Poulos - Davis (elastic) | - | - | 0.79 | −90 |
| PLAXIS HSsmall (calibrated) | 245 | −1.6 | 8.88 | +8.4 |

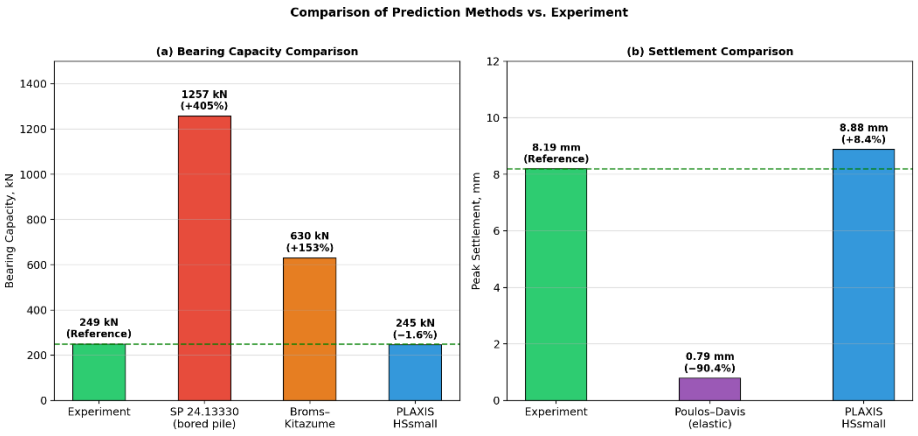



***Figure 1. Comparison of calculation results: (a) lifting capacity; (b) maximum deflection***

**Analysis of the results of the SP 24.13330.2021 standard**

The bearing capacity calculated according to the SP 24.13330.2021 standard, Fd = 1,257 kN, is 5 times higher than the experimental value. The reason for such a large difference can be seen in the fact that the SP standard is intended for reinforced concrete piles. The concrete strength of a reinforced pile is typically around 30 MPa, while the soil-cement grout material of the DSM column has a qu of 5.57 MPa. This difference is nearly 5.4-fold. For this reason, although both the R (tensile resistance) and fi (lateral friction) values in the formula are selected based on the soil test results, the calculation is performed under the assumption that the pile itself will not fail. In the DSM column, however, the material fails before lateral surface friction can be fully mobilized.

This situation is not a deficiency of the standard, but rather indicates its scope of application: the SP 24.13330.2021 standard is not intended for DSM columns, and it cannot be directly applied to this type of structure. This conclusion is not a criticism of the SP standard, but rather an acknowledgment of its actual scope of application.

**Analysis of the Broms-Kitazume method**

The Broms-Kitazume method accounts for the possibility of the column itself breaking, thereby eliminating the limitation of the SP 24.13330.2021 standard. Calculation result: $Q_{col}$

= 5.57 × 0.283 × 0.4 = 630 kN. The difference from the experiment is +153% – a significant improvement over the SP standard, but it still overestimates the experiment by 2.5 times.

This is because the coefficient η = 0.4 is assumed to be global in nature and cannot reflect the variability in local construction quality. International literature has noted that the coefficient of variation for the strength of DSM columns can reach up to 40% within a single field. [6]. Such a large variability cannot be captured by a single η value. Furthermore, the method only provides load-bearing capacity and is not suitable for assessing settlement.

**Analysis of the Poulos-Davis method**

The Poulos-Davis method is a classical solution based on the theory of elastic half-space. P = 240 kN, L/D = 11.7, $\bar{E}s$ = 18.1 MPa, and the calculated penetration s = 0.79 mm. The difference with the experiment is −90%, meaning the penetration was underestimated by a factor of 10.

Such a large error is the result of the method considering only elastic deformations. In a real DSM column, the main part of the settlement arises from plastic slips at the interface between the soil and the column face. Sensitivity analysis shows that in slender DSM columns (L/D ≥ 10), the interface coefficient $R_{\text{inter}}$ is the most important parameter for settlement, and the elastic solution that ignores it differs sharply from the actual behavior.

**The Limits of Classical Methods and Alternative Approaches**

The results of the analysis make it possible to identify the following limitations of classical analytical methods:

1) The SP 24.13330.2021 standard was developed for threaded reinforced concrete piles and does not take into account the low strength of DSM columns.

2) The Broms-Kitazume method takes into account the material's ultimate strength, but it cannot reflect variations in the quality of local construction.

3) The Poulos-Davis elastic solution does not take into account the soil's plastic deformations and interface slip.

The calibrated Hardening Soil Small model in PLAXIS 3D allows for an accurate assessment of both bearing capacity and settlement within ±10% of the classical methods (−1.6% and +8.4% in the table). This corresponds to the accepted tolerance range according to the European Code and SP 24.13330.2021 requirements.

It should be noted that the numerical method must also be calibrated with local monitoring tests. Otherwise, the accuracy of the numerical method may not differ from that of classical methods. Therefore, in every project using DSM columns, it is necessary to conduct at least one physical test and calibrate the numerical model based on it.

**Conclusion**

In this work, three classic analytical methods used in the design of DSM-columns—the SP 24.13330.2021 standard, the Broms-Kitazume method, and the Poulos-Davis elastic solution—were compared with the results of natural tests in the Andijan region. The main results are as follows:

SP 24.13330.2021 incorrectly assesses the load-bearing capacity of the DSM column by 405%, because the standard was developed for reinforced concrete piles and does not account for the low strength of the soil-cement grout material.

2. The Broms-Kitazume method accounts for the possibility of column failure and reduces error by up to 153%, but it cannot fully reflect the variability in local construction quality.

3. The Poulos-Davis elastic solution underestimates settlement by 90% because plastic deformations of the soil and interface slip are not taken into account.

4. In the PLAXIS 3D software, the Hardening Soil Small model, calibrated based on natural tests, accurately estimates both bearing capacity and settlement within ±10% and is recommended as the preferred method for designing DSM columns.

5. On every construction site using DSM columns, it is necessary to conduct at least one natural control test and calibrate the numerical model accordingly. Classical analytical methods are useful for preliminary estimation, but not as the final design calculation.

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