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Ground improvement in road construction: time and implementation challenges based on a survey study

Abstract: The article explores stakeholder perceptions of time intensity and execution challenges associated with ground improvement methods in road construction. Based on survey data from 214 respondents representing both employers and contractors, the analysis highlights differences in how various technologies are assessed in terms of implementation feasibility. Geosynthetics and grain size improvement with compaction are viewed as the least time-consuming methods, while preloading embankments are considered the most time-intensive. It should be noted, that despite their longer implementation period, preloading are usually the cheapest and most reliable solution, and reducing the duration of their load on the soil may limit the effectiveness of the improvement. Employers generally perceive higher time demands than industry professionals. Execution-related difficulties were rated as moderate overall, with the highest risks linked to equipment operations, design, and preparatory tasks. Employers expressed more concern about procurement and documentation stages. The results underscore the importance of including practitioner perspectives in planning and risk assessment processes. By identifying where stakeholder views converge or diverge, the study supports more realistic method selection and improved coordination in road infrastructure projects.

Keywords: construction time, execution difficulties, ground improvement, road construction, survey-based study.

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1. INTRODUCTION

Selecting the appropriate ground improvement method is a fundamental decision in any road construction project. This choice affects not only structural safety and long-term durability but also has implications for material use, environmental impact, and overall construction costs [1-5]. Employers often choose methods that are quick and straightforward to implement, as they can accelerate project timelines and limit expenditures. However, determining which method is most suitable requires consideration of several context-specific factors. These include the site's geological complexity, groundwater conditions, potential anthropogenic disturbances (such as legacy mining activity), and the functional demands of the planned infrastructure [6-10].

The present study investigates how various ground improvement techniques are perceived in terms of execution time and implementation challenges. What distinguishes this research is its dual-perspective approach, drawing on the experiences of both employers and contractors (including designers, and site supervisors). By contrasting these viewpoints, the study aims to uncover where evaluations differ and what that means for project feasibility and coordination.

While technical parameters can define project feasibility, the empirical experience of project stakeholders helps determine what is practical. Surprisingly little attention has been paid in previous studies to how practitioners assess the workability of these methods on actual job sites. The goal of this paper is to provide practical evaluation of various ground improvement methods based on the experience of project stakeholders.

In order to set the stage for the empirical findings, the next section offers a brief overview of the most common ground improvement methods used in contemporary road construction. This background is intended to support interpretation of the survey results and clarify the types of implementation challenges faced in the field.

2. CHOICE OF RIGHT GROUND IMPROVEMENT METHOD AND *ITS* PROPER IMPLEMENTATION

2.1. GENERAL REMARKS

Modern road construction distinguishes several major ground improvement methods such as stone and gravel columns, concrete columns, cement-soil columns, deep drainage, dynamic and impulse compaction, piles, chemical stabilization and stabilization with hydraulic binders, grain size improvement and ground consolidation, geosynthetics, soil replacement, and preloading embankments. These methods have already been comprehensively characterized in the literature, therefore, a detailed description is not repeated here. Readers may refer to, among others in [6-14].

The choice and implementation of proper ground improvement method for a specific project is often based on the experience gathered in previous enterprises. It is also crucial to perform proper site investigation of ground properties before starting the project [9]. The results determine whether ground improvement is needed at all and what kind of method is the most suitable to safely position the structure with lowest risk, with relatively low price and time span, and with little impact on the environment [6]. Site investigation of ground properties also allows to determine the scope of the project [13]. Therefore, all necessary tests and measurements should be conducted thoroughly and take into account all necessary aspects of project development [11]. Several recent research projects are conducted in order to improve the test quality of such ground improvement methods as vibro-compaction and vibro-stone columns [15].

Geotechnical supervision of the ongoing project consists of drilling, coring, taking soil samples, in-situ measurements of various ground properties, and laboratory analysis of soil and fluids [6, 9]. It is also important to periodically control the correctness and effectiveness of implemented ground improvement method by geodetic monitoring [12].

2.2. CHALLENGES AND LIMITATIONS OF CHOSEN GROUND IMPROVEMENT METHODS

Even after choosing an appropriate ground improvement method for a given construction project, it is hard to avoid some challenges and limitations during its implementation. Such challenges are mostly related to the high costs of the method, its long-time span, the difficult location and complex geological structure of the project area, and local environmental restrictions [6, 13].

For instance, CFA- and prefabricated piles as well as stone columns enable relatively quick and good stabilization of soft ground. However, prefabricated piles are quite expensive [7, 16].

Vibrations performed during dynamic compaction may damage the existing adjacent structures. This method often cannot be us ed in environmental protected areas due to high noise it is producing [7].

Achieving proper ground improvement using stone and gravel columns needs tests to verify the parameters for their correct design, which is time -and cost consuming [17].

Preloading embankments method often guarantees a good ground consolidation and effectively reduces ground settlement but does not fully control it and is time consuming [18].

In case of high ground water level, only partial removal of soft soil is not a proper method of ground improvement to choose [14]. It can lead to insufficient load-bearing capacity and post-construction settlement, especially in road or embankment projects.

Consolidation of thick clay layers without measures accelerating consolidation is very time consuming [18].

Chapters 3 and 4 further explain the time and implementation challenges of ground improvement methods based on the feedback given by employers and contractors.

3. METHODOLOGY OF SURVEY – BASED STUDY

The research was carried out in 2024 through two online surveys targeting stakeholders involved in road infrastructure projects. The sample included 131 representatives of public sector entities (referred to in this paper as "employers, in line with FIDIC terminology, meaning the commissioning authorities" [19-20]) and 83 professionals working in design and construction companies (referred as contractors). Participants were selected using purposive sampling to ensure representation from both public and private sectors.

The employer group was dominated by public institutions, which accounted for more than 90% of respondents. Only a small proportion represented public-private partnerships, corporate investors, or individual stakeholders. Roughly half of the participants worked in small organizations, 29% in medium-sized entities, and 17% in large enterprises. Most operated locally (63.4%), and a significant share (34.4%) had been involved in more than 20 road construction projects. Respondents typically held mid- to senior-level management roles, including positions such as project supervisor or investment inspector.

The second group included professionals from companies active in road design and construction. Design firms made up the largest share (41%), with nearly one-quarter also engaged in construction work. Contractors accounted for 26.5% of the sample, and project supervision companies made up 24.1%. The remainder represented laboratories and quality control service providers. Over 61% of all respondents in this group had more than a decade of industry experience. While most were involved in expressway and motorway projects (80.4%), some also worked on regional, county, and municipal roads.

In terms of company size in the second group, 57.8% of respondents represented large enterprises. Small and medium-sized enterprises (SMEs) accounted for 32%, including 9.6% micro-enterprises. Most companies operated on a national scale (55.4%), with smaller proportions working regionally (10.8%), internationally (27.7%), or globally (3.6%). Common job roles among respondents included contract managers, site managers, designers, project directors, and inspectors.

The questionnaires included both nominal and ordinal variables. The core focus of the research was on implementation-related aspects of ground improvement, specifically, the perceived time requirements and the challenges associated with executing these methods at different stages of project delivery. These two dimensions, time requirements and implementation challenges, were analyzed jointly due to their interdependent nature.

Complex ground improvement methods often require longer execution times and are more prone to coordination issues and implementation risks. Examining both aspects in tandem provides a more complete picture of a method's practicality, considering not just technical feasibility but also organizational constraints and field conditions.

The time-related assessment covered a broad spectrum of techniques, including: stone columns, concrete columns, cement-soil columns, deep drainage systems, dynamic and impulse compaction, prefabricated piles, grain size improvement with compaction, geosynthetics, chemical- and hydraulic binders stabilization, soil replacement, and preloading embankments.

Statistical analysis was conducted using SPSS software. Descriptive statistics and frequency distributions were used alongside the Mann-Whitney *U* test to evaluate differences between respondent groups. A significance level of $p < 0.05$ was applied in all tests.

4. STUDY RESULTS

4.1. TIME INTENSITY OF GROUND IMPROVEMENT METHODS

Fig. 1 illustrates the responses of all survey participants to the question concerning the estimated time required to implement selected ground improvement methods. The data are presented in the form of a bar chart with a 95% confidence interval for the mean, indicating that there is a 95% probability that the estimated parameter falls within the given range. Respondents rated the duration of each method on a 7-point scale, where 1 indicated a very short execution time, and 7 indicated a very long execution time.

The results show that respondents tended to assign ratings suggesting an average or rather short implementation time for most ground improvement techniques. An exception is the preloading embankments, for which the average score exceeds 5, suggesting that this method generally takes longer to complete than the others. It is noteworthy that the confidence interval for this method does not overlap with those of the other methods, indicating a statistically significant difference in execution time for preloading embankments compared to the remaining techniques.

The study indicates that the greatest time savings in ground improvement works can be achieved through grain size improvement and compaction, as well as the use of geosynthetics. In both cases, the mean rating slightly exceeds the value of 3, which suggests that these methods require less time than the average duration typically needed for ground improvement in road construction projects.

It is important to note that the confidence intervals for these two methods do not overlap with those of the other techniques, except for chemical- and hydraulic binders stabilization and dynamic and impulse compaction. This indicates a statistically significant difference in execution time compared to most other ground reinforcement methods.

Table 1 presents the distribution of responses, showing the percentage frequency of each rating. The results confirm that respondents were more likely to associate short execution times with the use of geosynthetics (56.1%) and grain size improvement and compaction (54.2%). Respondents were four times more likely to perceive these methods as quick to implement rather than time-consuming.

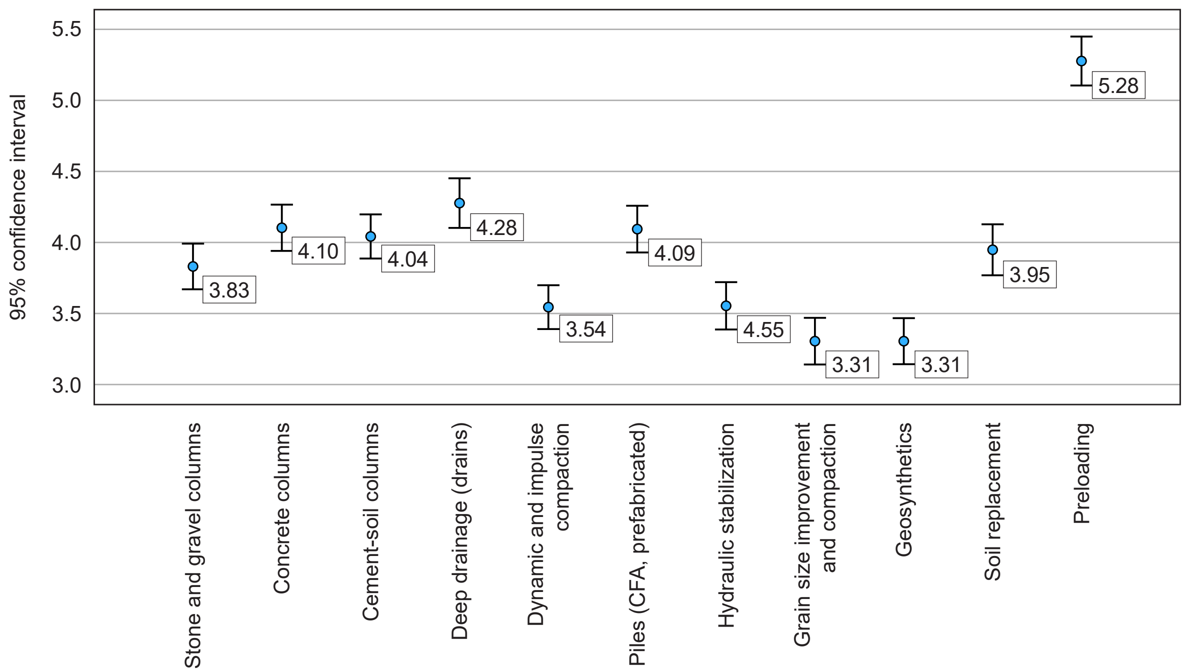

Fig. 1. Execution time of ground improvement methods according to respondents' opinions

Table 1. Distribution of respondents' ratings on the execution time of ground improvement methods

No.	Method	Scale [%]						
		Very short	Short	Rather short	Neither short nor long	Rather long	Long	Very long
1	Stone and gravel columns	1.4	14.0	20.1	36.9	20.1	6.5	0.9
2	Concrete columns	0.9	8.9	20.1	31.8	27.1	9.3	1.9
3	Cement-soil columns	0.9	8.4	20.6	36.9	22.0	10.7	0.5
4	Deep drainage (drains)	1.9	7.0	18.7	23.8	35.0	9.3	4.2
5	Dynamic and impulse compaction	5.1	11.7	27.6	38.8	14.0	1.9	0.9
6	Piles (CFA, prefabricated)	0.9	9.8	19.6	30.8	27.1	10.3	1.4
7	Chemical- and hydraulic binders stabilization	2.3	20.6	23.4	35.0	11.7	6.1	0.9
8	Grain size improvement and compaction	5.1	23.4	25.7	32.7	8.4	4.2	0.5
9	Geosynthetics	5.1	22.0	29.0	29.4	10.7	3.3	0.5
10	Soil replacement	1.9	11.7	23.4	33.2	17.3	8.4	4.2
11	Preloading embankments	0.5	0.9	4.7	25.4	22.5	24.9	21.1

A significant proportion of participants also indicated relatively low time requirements for chemical- and hydraulic binders stabilization (46.3%) and dynamic/impulse compaction (44.4%), while the proportion of opposing responses in these cases was 18.7% and 16.8%, respectively.

Among the methods that received the highest proportion of responses indicating long execution times, the following were identified: preloading embankments (68.5%), deep drainage (48.5%), piles (38.8%), concrete columns (38.3%), and cement-soil columns (33.2%). In all these cases, high ratings ("rather long", "long", or "very long execution time") clearly outnumbered low ratings ("rather short", "short", or "very short"), with respective differences of: 62.4%, 20.9%, 8.5%, 8.4%, and 3.3% in favor of the longer time assessments.

Table 2 presents the results of a comparative analysis between two groups of respondents: employers and contractors. The last two columns show the results of the Mann-Whitney U test, indicating for which methods the respondents' opinions differ in a statistically significant way.

Table 2. Comparative analysis of execution time ratings for ground improvement methods between two respondent groups

No.	Method	Employers		Contractors		Statistical test	
		Mean	Standard deviation	Mean	Standard deviation	U	p
1	Stone and gravel columns	4.03	1.123	3.53	1.233	4139.000	0.002$^{*)}$
2	Concrete columns	4.27	1.108	3.86	1.308	4395.000	0.015$^{*)}$
3	Cement-soil columns	4.19	1.031	3.82	1.289	4529.500	0.033$^{*)}$
4	Deep drainage (drains)	4.13	1.160	4.52	1.451	4521.500	0.032$^{*)}$
5	Dynamic and impulse compaction	3.87	0.980	3.02	1.189	3122.000	0.001$^{**)}$
6	Piles (CFA, prefabricated)	4.23	1.085	3.89	1.379	4644.000	0.064
7	Chemical- and hydraulic binders stabilization	3.63	1.084	3.43	1.433	4766.000	0.116
8	Grain size improvement and compaction	3.64	1.089	2.77	1.213	3052.000	0.001$^{**)}$
9	Geosynthetics	3.56	1.082	2.90	1.265	3522.000	0.001$^{**)}$
10	Soil replacement	4.15	1.304	3.61	1.305	4041.500	0.001$^{**)}$
11	Preloading embankments	4.82	1.223	5.99	1.006	2552.000	0.001$^{**)}$

$^{*)}$ statistically significant results at $p < 0.05$, $^{**)}$ statistically significant results at $p < 0.001$

Analysis of the data reveals that significant differences in responses were observed for several methods, with the most notable discrepancies found in the evaluation of dynamic and impulse compaction, grain size improvement and compaction, use of geosynthetics, and preloading embankments. It is evident that for the first three methods, employers rated the execution time as longer compared to the assessments provided by contractors. This pattern is also observed in other cases where statistically significant differences were identified.

In contrast, an opposite tendency was observed for preloading embankments, respondents representing contracting companies were more likely to consider this method time-consuming than employers. No statistically significant differences between the two groups were observed in the case of piling and chemical- and hydraulic binders stabilization. For these methods, respondents, regardless of their role in the investment process, generally assessed the execution time as average or slightly shorter than average.

4.2. ASSESSMENT OF EXECUTION CHALLENGES DURING GROUND IMPROVEMENT WORKS

Fig. 2 presents the responses of all study participants to the question regarding the stages of ground improvement implementation where execution-related difficulties may arise. The data are shown in a bar chart with a 95% confidence interval for the mean, indicating that the estimated value lies within this range with 95% probability.

Respondents provided their assessments using a 7-point scale, where 1 represented a very low risk of difficulties, and 7 indicated a very high risk. The findings show that the average ratings are generally low, mostly falling within the range corresponding to rather low or neutral levels of risk. This suggests that, overall, execution difficulties are not perceived as a major issue during ground improvement works.

The variation in ratings across different project stages is also moderate, ranging from 3.16 for administrative and documentation tasks to 4.02 for machinery and equipment-related work. This indicates a moderately diverse degree of execution challenges, with higher risks identified in physical and design-related activities, and lower risks in procurement and administrative processes.

It is worth noting that the confidence intervals for the evaluated task groups do not overlap, which confirms that the differences in perceived difficulty between stages are statistically significant.

Table 3 presents the distribution of respondents' ratings regarding the occurrence of execution difficulties at various stages of ground improvement works, expressed as percentages for each stage. The findings indicate that, across all stages analyzed, ratings suggesting moderate risk dominate, meaning the difficulties are perceived as neither particularly low nor high. This may imply that problems can arise but are typically minor in scale and relatively easy to manage in practice.

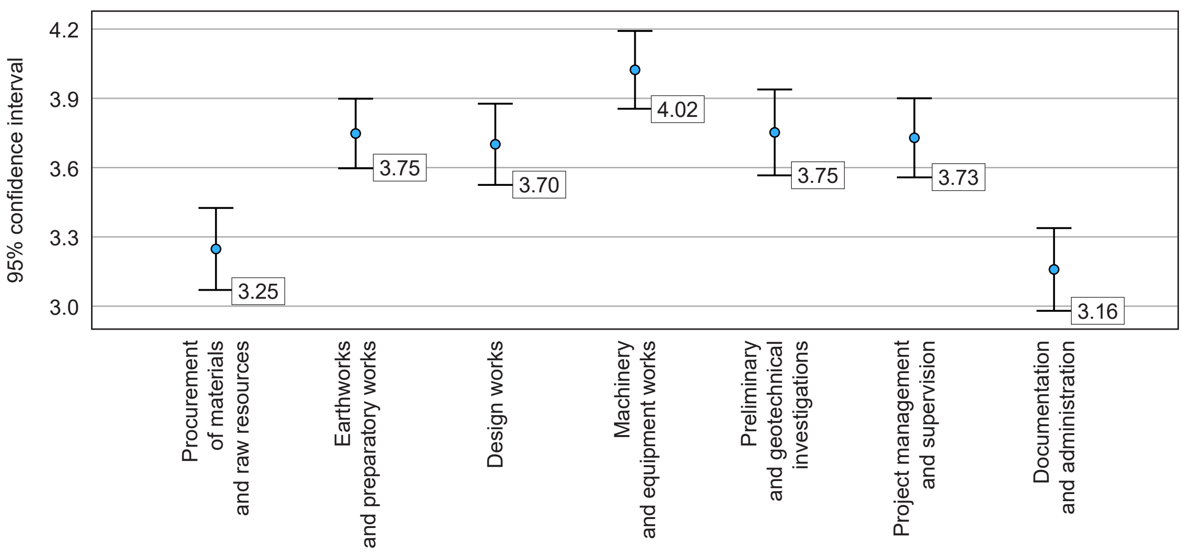

Fig. 2. Assessment of execution difficulties at various stages of ground improvement works

Table 3. Distribution of respondents' ratings regarding execution difficulties during ground improvement works

No.	Stage	Scale [%]						
		Very low risk	Low	Rather low	Neither low nor high	Rather high	High	Very high
1	Procurement of materials and raw resources	10.7	20.1	23.8	27.6	15.0	2.3	0.5
2	Earthworks and preparatory works	1.4	13.6	22.0	41.6	15.4	5.6	0.5
3	Design works	4.2	13.1	25.7	33.2	16.4	4.2	3.3
4	Machinery and equipment works	2.3	8.4	18.2	41.6	18.7	6.5	4.2
5	Preliminar and geotechnical investigations	5.1	13.1	22.9	33.6	13.6	8.9	2.8
6	Project management and supervision	4.7	12.6	20.6	38.3	17.3	4.2	2.3
7	Documentation and administration	12.6	20.1	22.4	34.1	6.5	2.8	1.4

It is worth emphasizing that in every case, low-risk assessments prevailed over high-risk ones, indicating that most respondents perceive execution challenges at individual stages as rather minor. This suggests that potential issues are seen as manageable and unlikely to significantly impact project implementation.

As previously mentioned, the stages associated with slightly higher risk levels include machinery-related work, design tasks, and preparatory activities, which received a greater proportion of responses pointing to an elevated likelihood of execution challenges during implementation.

Table 4 presents the results of a comparative analysis between two groups of respondents: employers and contractors. The last two columns of the table show the results of the Mann-Whitney U test, indicating which stages of project implementation are associated with statistically significant differences in respondents' opinions.

The results show that significant differences in the assessment of execution difficulties occur mainly in areas related to the procurement of materials and raw resources as well as administrative and documentation processes, where employers rated the risk higher than contractors.

In the case of tasks involving the use of machinery and equipment, the differences are close to statistical significance, which may suggest that contractors perceive greater challenges during this stage of implementation.

For the remaining stages, such as earthworks and preparatory activities, design works, preliminary and geotechnical investigations, as well as project management and supervision, the evaluations of both groups are similar, indicating a comparable perception of execution-related difficulties.

Table 4. Comparative analysis of respondents' assessments of execution difficulties during ground improvement works

No.	Stage	Employers		Contractors		Statistical test	
		Mean	Standard deviation	Mean	Standard deviation	U	p
1	Procurement of materials and raw resources	3.47	1.30	2.89	1.27	4032.500	0.001$^{*)}$
2	Earthworks and preparatory works	3.72	1.11	3.80	1.13	5390.000	0.912
3	Design works	3.66	1.21	3.77	1.45	5249.000	0.661
4	Machinery and equipment works	3.89	1.10	4.23	1.44	4692.500	0.078
5	Preliminary and geotechnical investigations	3.63	1.25	3.94	1.55	4909.500	0.219
6	Project management and supervision	3.66	1.17	3.84	1.42	4840.500	0.161
7	Documentation and administration	3.44	1.19	2.71	1.42	3663.500	0.001$^{*)}$
$^{*)}$ statistically significant results at $p < 0.001$							

5. SUMMARY AND CONCLUSIONS

This study aimed to explore how ground improvement methods used in road construction are perceived in terms of execution time and implementation challenges. Drawing from the perspectives of both employers and contractors, it goes beyond theoretical evaluations to focus on how these methods are assessed in practice. Key findings include:

1. Geosynthetics and grain size improvement with compaction emerged as the fastest methods to implement, consistently receiving the lowest average ratings for execution time.
2. Preloading embankments were rated as the most time-intensive approach by both groups of respondents.
3. Significant perception gaps were observed: employers generally estimated longer time requirements than contractors. These differences may reflect varying roles, levels of responsibility, or organizational constraints.
4. Implementation difficulties were mostly seen as moderate. The highest risks were linked to machinery and equipment works, whereas the lowest risks were associated with procurement and documentation.
5. The greatest divergence in opinions occurred around procurement and documentation. These phases were considered more problematic by employers, likely due to their closer involvement in administrative and regulatory processes.
6. The results also emphasise the need to select solutions that balance scheduling demands with long-term performance outcomes. In this regard, preloading embankments, although more time-intensive, remain among the most cost-effective and reliable ground improvement methods, provided that sufficient time is allocated for complete soil consolidation.
7. Overall, the findings have practical implications for infrastructure planning and delivery, offering a basis for more accurate method selection, realistic risk forecasting, and improved communication between stakeholders.

Although geotechnical investigations are crucial for successful project delivery, only 25.3% of respondents rated this stage as highly challenging. This suggests a tendency to underestimate the long-term risks associated with inadequate soil investigation, despite its well-documented role in preventing design and construction issues. While based on subjective assessments, the study offers valuable insights into how technical decisions align with project realities. Future research could build on this approach by exploring variations across project scales, geographic regions, or delivery models, and by comparing stakeholder perceptions with actual project performance data.

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Wzmacnianie podłoża w budownictwie drogowym: czasochłonność i trudności wykonawcze na podstawie badania ankietowego

Streszczenie: Artykuł przedstawia wyniki badania ankietowego dotyczącego czasochłonności i trudności wykonawczych wybranych metod wzmacniania podłoża w budownictwie drogowym. Analizie poddano opinie 214 respondentów, obejmujących inwestorów oraz przedstawicieli firm projektowych i wykonawczych. Za najmniej czasochłonne metody uznano zastosowanie geosyntetyków oraz poprawę uziarnienia, natomiast nasypy przeciążające oceniono jako najbardziej czasochłonne. Warto jednak zauważyć, że mimo wydłużonego czasu realizacji nasypy przeciążające pozostają zazwyczaj najtańszym i najbardziej niezawodnym rozwiązaniem, a skrócenie czasu ich oddziaływania na grunt może ograniczać skuteczność wzmocnienia. Inwestorzy częściej wskazywali na wyższe zapotrzebowanie czasowe na realizację danej metody niż przedstawiciele branży wykonawczej. Trudności wykonawcze oceniono ogólnie jako umiarkowane, przy czym największe ryzyko dotyczyło prac sprzętowych, projektowych oraz przygotowawczych. Inwestorzy częściej podkreślali problemy związane z etapami zamówień i przygotowaniem dokumentacji. Wyniki badania akcentują znaczenie uwzględniania perspektywy praktyków w procesie planowania i oceny ryzyka. Zidentyfikowane rozbieżności w postrzeganiu poszczególnych technologii mogą wspierać trafniejszy dobór metod oraz usprawniać koordynację inwestycji drogowych.

Słowa kluczowe: czasochłonność realizacji, trudności wykonawcze, wzmocnienie podłoża, budownictwo drogowe, badania ankietowe.