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Causes and mitigation of delay and cost overrun in deep excavations supported by soil nailing and ground anchoring: a mixed-methods study from Iran

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Abstract

Purpose – Deep excavation projects supported by soil nailing and ground anchoring systems are increasingly prevalent in densely urbanized metropolitan areas, yet remain understudied in construction management research. This study investigates the primary causes of delay and cost overrun in such projects, drawing on empirical data from Iran.

Design/methodology/approach – A mixed-methods approach was adopted, combining a PRISMA-guided systematic review of 431 international publications with expert interviews and consultations involving 25 industry professionals and structured questionnaires administered to contractors, consultants and owners. Delay factors were evaluated using impact indices, likelihood of occurrence, and overall significance, with root cause analysis pursued to the fourth causal level in key cases.

Findings – Constraints related to neighboring structures and underground facilities emerged as the most critical drivers, followed by inadequacies in geotechnical investigation. Stakeholder responsibility analysis attributed approximately 38.0% of factors to owners, 37.7% to contractors and 15.9% to consultants. A practical mitigation framework was developed, integrating insights from the systematic review, prior case studies and expert judgement. Regional conditions and sample size constraints may limit transferability.

Originality/value – This is the first study to apply a PRISMA-guided systematic review of 431 publications specifically to soil nailing and ground anchoring systems, combined with multi-level root cause analysis and structured stakeholder attribution, offering targeted guidance for Iranian urban deep excavation projects and transferable implications for similarly urbanizing economies.

Keywords Delay and cost overrun, Deep excavation, Soil nailing and ground anchoring, Construction risk management, Systematic literature review

Paper type Research article

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Introduction

The construction industry is a fundamental driver of economic development worldwide, playing a pivotal role in national growth and infrastructure delivery. The infrastructure now recognized as the fastest-growing segment of the global construction industry, projected to grow at around 4% per annum through to 2030 (Harrison and Leonard, 2021).

Failing to consider deep excavation project risks significantly impairs the ability to accurately estimate project costs and durations, leading to substantial delays and overruns (Heravi *et al.*, 2021). Delay is a frequent phenomenon in construction projects, affecting between 70% and 100% of projects in different regions (Marzouk and El-Rasas, 2014). Underground construction projects commonly experience cost escalations averaging 30% (Flyvbjerg *et al.*, 2003). In addition, notable incidents such as the collapse of neighboring structures highlight the serious consequences of inadequate risk management and implementation in deep excavation projects (Talebi, 2013, Ale Davood, 2022).

Deep excavations are commonly supported by single or combined techniques such as soil nailing, ground anchoring, truss retaining structures and bracing struts, which act as support of excavation (SOE) systems that are crucial for minimizing soil failure risks. This paper focuses on factors contributing to delay and cost overrun in projects using soil nailing and ground anchoring (SN/GA), among the most widely used SOE systems.

While extensive research has examined delay and cost overrun in building construction (Abbasi *et al.*, 2020; Ammar *et al.*, 2022; Abdallah *et al.*, 2024) and tunnelling (Wang *et al.*, 2012; Koohathongsumrit and Meethom, 2024; Mahmoodzadeh *et al.*, 2021), a clear knowledge gap remains regarding deep excavation projects, particularly across different SOE methods. This gap is especially evident in the Iranian construction industry, where these methods are increasingly utilized in dense urban contexts. The primary objectives of this research are to identify and analyze the key factors contributing to delays and cost overruns in SN/GA systems, incorporating the perspectives of contractors, consultants and project owners. Employing a methodology aligned with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Page *et al.*, 2021), the study combines a systematic literature review with a questionnaire survey and expert consultation.

Beyond identifying and ranking these factors, the study advances a proposition that the literature has not been tested directly: that delay causation in deep excavation is contingent on the SOE technique employed, and not solely on national or economic context. Ranked factors are best understood as symptoms rather than as basic causes, and treating a symptom without reaching its origin allows the problem to recur (Rosenfeld, 2014). A further limitation of ranking is that it treats each factor as independent, whereas the significance of any single cause is conditioned by its relationships with others (Arantes and Ferreira, 2024). Accordingly, factor ranking is coupled here with multi-level root cause analysis and normalized stakeholder attribution, so that each cause is traced to its origin and matched to the party holding the authority to address it.

Literature review

Delay in construction projects, commonly defined as a time overrun beyond the project's contractual completion date or agreed delivery date (Assaf and Al-Hejji, 2006), significantly affects project success and stakeholder satisfaction. In Iranian public construction projects, delay-related direct costs were estimated at about 575 million USD in the year 2000, excluding lost opportunity costs (Shakeri and Ghorbani, 2005). The Statistical Centre of Iran subsequently reported approximately 21 billion USD in direct delay costs for government construction projects executed between 2002 and 2012, again excluding opportunity costs (Samarghandi *et al.*, 2016).

Origins of project delay and cost overrun

Financial problems consistently rank among the leading causes of time overruns in construction projects across multiple international contexts (Kullaya *et al.*, 2022; Larsen *et al.*, 2016; Sambasivan and Soon, 2007). Recent studies have identified owner-initiated change orders as one of the primary causes of schedule delay and cost overrun in constructing projects across a range of international contexts (Alenazi *et al.*, 2022; Umar *et al.*, 2020). The structure of the contract itself conditions the incidence of delay, since the allocation of responsibilities between parties, together with warranty and penalty provisions, bears directly on project timelines and on the returns realized from infrastructure investment (Alshboul and Shehadeh, 2024). Poor planning and scheduling are key contributors to construction delays as demonstrated across multiple contexts (Arantes and Ferreira, 2020; Yap *et al.*, 2021).

Recent research also highlights the impact of rework (Hassan *et al.*, 2023) as well as miscommunication on project delays and work quality (Abdallah *et al.*, 2024). Regression analysis of Iranian construction projects shows that the average delay per year is 5.9 months, with overall cost overruns reaching 15.4% (Samarghandi *et al.*, 2016).

Unexpected ground conditions pose constant threats to project continuity (Yazdani-Chamzini, 2014), and a global analysis of 206 tunnelling incidents confirms them as the dominant trigger of construction accidents and delays (Sousa and Einstein, 2021). Since delay and safety incidents frequently share an origin in unforeseen site conditions, predictive analytics trained on historical injury records offer a means of anticipating hazardous exposures before they materialize on site (Alshboul and Shehadeh, 2025). Subsurface unpredictability translates directly into time extension and budget overrun in Iranian deep excavation projects (Mahmoodzadeh *et al.*, 2021), with one documented case experiencing a 50% cost overrun (Heravi *et al.*, 2021).

Research methodology

The research methodology employed a two-phase design, comprising a systematic literature review followed by empirical data collection and analysis.

Systematic literature review using PRISMA framework

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework guided the identification, screening and selection process to ensure transparency and reproducibility. Scopus and Google Scholar were searched for peer-reviewed publications across civil engineering, construction management and geotechnical engineering. The search was systematically limited to peer-reviewed articles published between 2008 and 2026, a timeframe selected to prioritize contemporary research where relevant studies are more abundant and methodologically stronger, while remaining sufficiently broad to capture the growth of deep excavation and underground construction research over the past two decades. The Scopus query was executed in January 2026 across title, abstract and keyword fields using the following string:

TITLE-ABS-KEY((“delay” OR “construction delay*” OR “project delay*” OR “cost overrun*” OR “time overrun*” OR “schedule delay*”) AND (“construction project*” OR “infrastructure project*” OR “building project*”) AND (“delay factor*” OR “delay cause*” OR “risk factor*” OR “root cause*”)) AND PUBYEAR >2007 AND PUBYEAR <2027.

Supplementary queries were run for spelling and hyphenation variants, with retrieved records entering the same screening process; the string reported above is the primary query. A supplementary Google Scholar search using equivalent terms was conducted to identify publications not indexed in Scopus; records retrieved from this source entered the same screening process. Truncation was applied throughout to capture singular, plural and derivative forms. Restriction to peer-reviewed journal articles within the relevant subject areas was applied at the screening stage rather than within the query itself.

A complementary technique-specific query was executed under identical parameters, combining deep excavation terminology (“deep excavation*”, “support of excavation”, “earth retention”, “retaining system*”) with support-system terminology (“soil nail*”, “ground anchor*", "tieback*", "anchored wall*") and delay and cost overrun terms. The limited yield of this query confirms that delay and cost overrun in excavations supported by soil nailing and ground anchoring remain substantially unexamined, and it is this gap that the present study addresses. The broader corpus was therefore retained as the evidentiary base, and interrogated for its applicability to the SN/GA context.

Systematic screening was performed using predefined inclusion and exclusion criteria. Inclusion criteria comprised: (1) peer-reviewed journal articles published between 2008 and 2026, with exceptions for foundational studies on underground construction, (2) articles written in English, (3) studies focusing on delay and cost overrun in construction projects, particularly those addressing deep excavation contexts and (4) full-text accessibility through institutional databases. Exclusion criteria comprised: conference papers, non-peer-reviewed literature, publications outside construction management and civil engineering, and cross-database duplicates. These criteria govern the corpus subjected to systematic extraction; foundational and contextual works cited elsewhere in this paper fall outside the review protocol.

The PRISMA-guided selection process involved multiple stages: initial database search, duplicate removal using reference management software, title and abstract screening, full-text review for eligibility and final inclusion based on relevance and quality assessment. After removing duplicates, 431 publications were analyzed for relevance to construction delay and cost overrun. Independent dual-reviewer screening was applied throughout to minimize bias, with discrepancies resolved through discussion until consensus was reached. To enhance comprehensiveness, backward snowballing was conducted on key included articles by systematically examining their reference lists to identify additional pertinent publications not captured through initial database searches.

Empirical data collection and analysis

The data collection methodology comprised three distinct phases. In the first phase, critical factors contributing to schedule extensions were identified through the systematic literature review and in-depth consultations with 25 industry professionals, each with more than ten years of experience in deep excavation projects across the owner, contractor and consulting domains.

The second phase involved administering a structured survey instrument. Respondents evaluated delay and cost escalation factors using a five-point Likert scale (Joshi *et al.*, 2015), ranging from very low (1) to very high (5), with separate ratings for importance, probability of occurrence and impact severity. The questionnaire categorized 20 primary delay factors into four domains: owner-related, consultant-related, contractor-related and miscellaneous. The survey was distributed electronically and through 65 physical copies to Iranian construction firms specializing in deep excavation, yielding 37 completed responses.

The sampling strategy sought representation across all three contractual positions, comprising contractors, consultants and owners. The adequacy of the sample size was verified using Levy and Lemeshow (2013) formulae (Equations (1) and (2)), incorporating population size $N = 150$, coefficient of variation VX = 0.24, standard deviation SX = 0.66, mean value $\overline{X} = 2.77$, reliability confidence $Z = 1.96$, and error coefficient $\varepsilon = 0.08$.

$$n \geq \frac{Z^2 N V_X^2}{(N-1)\varepsilon^2 + Z^2 V_X^2} \tag{1}$$

$$V_X = \frac{S_X}{\overline{X}} \tag{2}$$

The calculated minimum sample requirement of 29.03 was satisfied, with population parameters derived from public report of Iran's National Organization for Planning and

Budget (2023). Confidence intervals were employed to assess the reliability and precision of parameter estimates (Oosterwijk *et al.*, 2019). Survey reliability was evaluated using Cronbach's alpha, with values between 0.70 and 0.90 considered acceptable (Adeniran, 2019). The 37 responses obtained represent approximately 25% of the estimated specialist population of 150, and exceed the calculated minimum requirement by 27%. Representativeness was pursued through stratification rather than volume, with all three contractual positions represented, so that no single perspective dominates the weightings reported in Table 2. Eligibility was further restricted to respondents holding at least a bachelor's degree and three years' deep excavation experience, and the Friedman test was selected in part because it imposes no distributional assumptions on samples of this size (Riffenburgh, 2012).

Agreement among respondents on the resulting hierarchy was assessed through Kendall's coefficient of concordance, a normalization of the Friedman statistic ranging from zero to unity (Kendall and Smith, 1939). The analysis returned $W = 0.260$ ($\chi^2 = 182.77$, df = 19, $p < 0.001$), indicating a statistically significant degree of concordance among respondents. A coefficient of this order is characteristic of studies in which a substantial factor set is ranked by a professionally diverse sample, where consensus is strongest at the extremes of the ranking and disperses through the intermediate positions. Stability of the hierarchy across contractual positions was examined through Spearman rank correlation between the mean orderings produced by each stakeholder group (Spearman, 1904). All three pairings were positive and statistically significant, with $\rho = 0.569$ between owners and contractors ($p = 0.009$), $\rho = 0.516$ between owners and consultants ($p = 0.020$), and $\rho = 0.710$ between contractors and consultants ($p < 0.001$), against a critical value of 0.45 at the 5% level with 18 degrees of freedom. A Kruskal–Wallis one-way analysis of variance by ranks applied to the overall respondent scores found no significant difference between owners, contractors and consultants ($H = 5.273$, df $= 2$, $p = 0.072$), indicating that no stakeholder group systematically assigned higher ratings across the factor set as a whole (Kruskal and Wallis, 1952). Taken together, these results indicate that the ranking reported in Table 1 reflects a shared professional assessment rather than the perspective of any one group.

The third phase employed the Friedman test to prioritize cost overrun sources based on impact, occurrence probability and significance. This nonparametric approach enables the comparison of critical factor rankings (Riffenburgh, 2012). Performance indicators were calculated by normalizing Likert scores against the maximum possible values, with overall rankings determined through factor multiplication. Root cause analysis extended to the fourth level of causation.

The fishbone diagram methodology was selected for its comprehensive analytical capabilities in addressing the study's objectives and bridging identified knowledge gaps. This technique facilitates the systematic organization of causal factors and their interrelationships, enabling detailed examination of both direct and indirect contributors to project delays. As developed by Ishikawa and Loftus (1990), this approach provides a standardized framework for root cause analysis and comparison with existing literature. The mitigation strategies derived through this process were subsequently submitted to expert validation, in which senior practitioners with direct experience of soil nailing and ground anchoring projects reviewed each proposed measure for technical soundness and practical feasibility within the Iranian construction context. Measures identified as impractical or insufficiently specific were revised or removed, and the framework presented in Figure 4 reflects the outcome of this review. Figure 1 presents a structured flowchart summarizing the three-phase research methodology used in this study.

Research limitations

Factors affecting project duration inherently impact costs, as established by Akaiku *et al.* (2021), while construction industry stakeholders view time and cost as equally crucial project parameters (Flyvbjerg *et al.*, 2018). Given this strong reciprocal correlation between time and

Table 1. Ranking of top 20 delays and cost overrun factors in SN/GA SOE applications

Total rating	Stakeholder category	Factors	Importance Indicator	Rank	Probability of occurrence Indicator	Rank	Impact Indicator	Rank	Importance× possibility × influence	Normalized magnitude
1	Owner	Problems with neighbors, neighboring structures and underground facilities	92.43	1	83.24	1	87.57	3	673777.74	0.0755
2	Owner	Inefficient geotechnical report	92.43	1	74.05	6	90.81	1	621599.67	0.0696
3	Contractor	Inefficient monitoring of wall displacement	90.81	3	74.05	6	88.11	2	592518.98	0.0664
4	Owner	Awarding the bid to the contractor with the lowest bid, irrespective of their technical capabilities	81.62	7	82.16	2	83.78	5	561871.56	0.0629
5	Owner	Unclear scope of work and change orders	80.00	9	81.08	3	85.95	4	557487.22	0.0624
6	Consultant	Inadequate examination and oversight of the project	82.70	5	80.00	5	81.08	9	536449.96	0.0601
7	Contractor	Inadequate experience of the contractor	84.86	4	73.51	9	82.16	8	512586.26	0.0574
8	Consultant	Designers' limited knowledge of the implementation issues	82.16	6	74.05	6	82.70	6	503199.73	0.0564
9	Miscellaneous	Inflation and fluctuation of exchange rates	77.84	10	80.54	4	75.14	11	471029.79	0.0528
10	Contractor	Controlling underground water and Isolation system	80.54	8	70.27	14	82.70	6	468064.68	0.0524
11	Contractor	Lack of adequate project coordination	75.68	11	73.51	9	74.59	12	414983.52	0.0465
12	Contractor	Poor subcontractor performance	75.68	11	72.97	11	73.51	15	405962.13	0.0455
13	Owner	Unrealistic contract duration	73.51	14	71.35	13	74.59	12	391270.17	0.0438
14	Consultant	Delay in submission of design or shop drawings and concurrent design	75.14	13	69.19	15	73.51	15	382162.87	0.0428
15	Contractor	Insufficient knowledge of experts in planning and project controls	70.81	15	71.89	12	69.19	17	352223.01	0.0395
16	Contractor	Financial challenges encountered by the contractor	67.57	18	67.03	16	76.22	10	345172.05	0.0387
17	Owner	Challenges related to securing funding and ensuring adequate financing	70.81	15	60.54	19	74.59	12	319781.41	0.0358
18	Contractor	Reworks due to errors during construction	63.78	20	62.70	17	69.19	17	276716.32	0.0310
19	Miscellaneous	Adverse weather conditions, air pollution and social crisis	68.65	17	58.92	20	67.57	19	273290.82	0.0306
20	Owner	Delay in decision-making by owner	65.95	19	61.08	18	66.49	20	267810.87	0.0300

Source(s): Authors' own work

Table 2. Weighted contributions across stakeholders' categories

Row	Stakeholder category	Weighted contribution (%)
1	Owner	38.0
2	Contractor	37.7
3	Consultant	15.9
4	Miscellaneous	8.3

Source(s): Authors' own work

cost factors, the study does not attempt to differentiate their impacts. While centered on Tehran, it encompassed respondents from deep excavation projects throughout Iran, extending beyond a single region. However, Iran-specific market conditions and regional characteristics may limit generalizability to other contexts. Despite potential differences among respondents, broad agreement emerged regarding the significance of identified delay causes.

The systematic review revealed limited studies specifically addressing deep excavation and underground construction delays. The evidence base for this specific application is therefore narrower than for general construction, and the synthesis draws in part on findings developed in adjacent contexts. A significant methodological limitation concerned the availability of qualified expert participants. Previous research models typically suggest sample sizes between 150–200 participants (Liu *et al.*, 2016); however, such numbers are challenging to achieve given the limited pool of deep excavation experts. Consequently, researchers have prioritized sample accuracy over volume, as demonstrated in multiple studies (Ozorhon *et al.*, 2018). Three sources of potential bias warrant acknowledgement. Self-selection may favor practitioners with stronger engagement in professional networks and, by extension, greater exposure to well-documented projects, which could understate difficulties encountered on smaller or less formally managed works. Non-response bias could not be tested directly, since characteristics of non-respondents were not recorded. Respondent concentration in Tehran, notwithstanding participation from projects elsewhere in Iran, may weigh the findings toward dense urban conditions where adjacent-structure constraints are most acute. Convergence across the three evidence streams – the systematic review, expert consultations and the questionnaire – provides partial mitigation, as does the consistency of the instrument when previously applied to alternative support systems in the same national context (Bayandor *et al.*, 2025). The study population was evenly distributed among three key project stakeholders (including owners, contractors and consultants), each comprising 33% of the sample. Notably, SN/GA systems were analyzed together as a single category due to their methodological similarities.

The sample was not stratified by excavation depth, project size or procurement route, and these characteristics were not recorded. Since retained height governs the load transferred to soil nails and ground anchors, and since procurement route determines how risk is allocated between parties, the reported rankings should be understood as an aggregate across the range of conditions represented rather than as applicable uniformly to projects of any depth, scale or delivery method.

Findings

Analysis of survey responses yielded a Cronbach's alpha coefficient of 0.88 for the SN/GA systems, confirming strong internal consistency. Survey participants held at least a bachelor's degree and a minimum of three years' deep excavation experience. Participant demographics are illustrated in Figure 2.

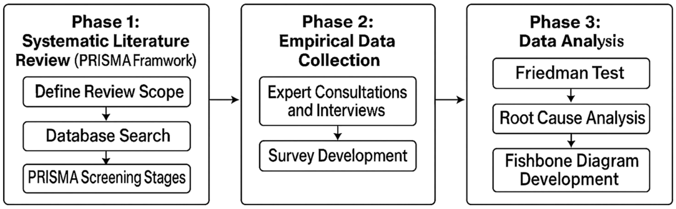

Figure 1. Flowchart of the three-phase research methodology of the study. Source: Authors' own work

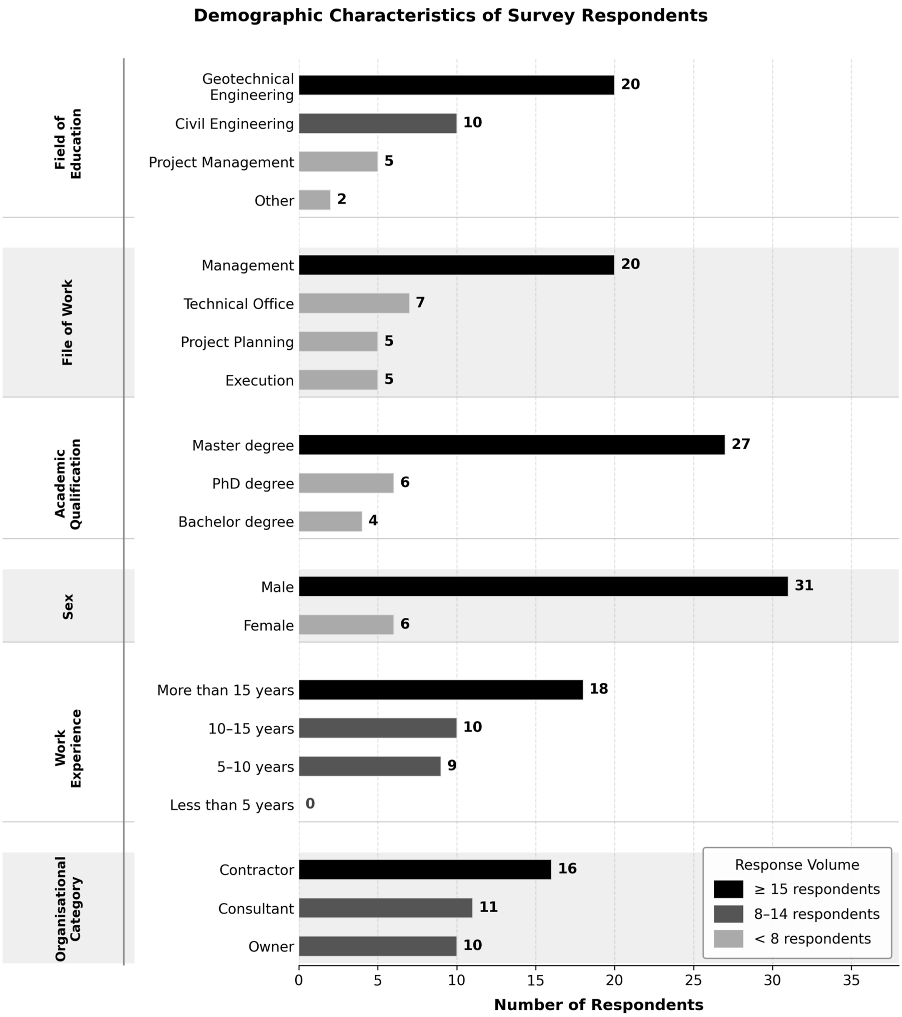

Figure 2. Participants' characteristics. Source: Authors' own work

Table 1 presents the hierarchical ranking of the top 20 factors contributing to delays and cost overruns in SN/GA deep excavation projects, based on normalized weightings.

Interference with adjacent structures, neighboring properties and subsurface utilities emerged as the primary driver of cost overruns. The second most significant factor was inadequacies in geotechnical investigation and reporting. Wall displacement monitoring deficiencies emerged as the third most significant contributor to project delays and cost overruns.

Table 2 presents weighted contributions across stakeholders' relevant factors in SN/GA SOE applications. Owner-related factors carry the highest weighting (38.0%), aligning with findings by Ahmad *et al.* (2020) on public infrastructure delays in Jordan. Contractor-related factors follow at 37.7%, and consultant-related factors at 15.9%. Miscellaneous factors – including price inflation, exchange rate fluctuations, adverse weather conditions, air pollution and social disruptions – collectively account for 8.34% of delay causes. Table 3 presents a hierarchical analysis of delays and cost overrun factors, derived from the systematic literature review, case studies and expert consultations. These relationships are visually represented in the fishbone diagram (Figure 3), with corresponding mitigation strategies outlined in Figure 4, where the measures are organized by stakeholder category so that each is matched to the party holding the authority to implement it, having been confirmed by experienced practitioners as technically sound and applicable in practice. It should be noted that certain root causes recur across multiple factors, reflecting their status as common underlying drivers rather than duplicate entries.

Discussion

Owner-originated factors and potential mitigations

The pattern emerging across owner-originated factors invites comparison with an earlier application of the same instrument, in the same country and with the same balanced stakeholder structure, to bracing strut and top-down construction, where inflation and exchange rate fluctuation ranked first (Bayandor *et al.*, 2025). In SN/GA systems, financial factors are displaced from the leading positions by interference with adjacent structures and by inadequate geotechnical investigation. Since national context, period, sampling frame and instrument are held constant across the two studies, the divergence is attributable to the support method itself, which transmits load beyond the site boundary and depends on soil–structure interaction in the bond zone for its stability.

Within owner-related factors, interference with adjacent structures, neighboring properties and subsurface utilities emerge as the primary concern. SN/GA systems installation introduces complex geotechnical interactions extending beyond property boundaries, creating challenges related to structural integrity, property rights and legal implications. Where parties hold divergent objectives, the resulting disputes translate into schedule extension and cost escalation, and structured negotiation frameworks offer a predictive means of resolving them before they mature into formal claims (Alshboul and Shehadeh, 2026). Mitigation requires thorough pre-construction surveys, clear stakeholder communication, advanced geotechnical tools and collaborative planning to ensure legal compliance and prevent disputes.

The second-ranked factor – inadequate geotechnical investigation and reporting (Table 2) – demonstrates how subsurface condition uncertainties significantly impact deep excavation projects employing SN/GA systems. This aligns with tunnelling projects, where ground investigation consistently ranks among primary cost drivers (Mahmoodzadeh *et al.*, 2021; Paraskevopoulou and Boutsis, 2020). Construction cost analyzes show excavation and support costs ranging from 30.2 €/m^3 for favorable rock masses to 138.3 €/m^3 for poor soil conditions, underscoring economic significance of accurate geotechnical investigation (Paraskevopoulou and Benardos, 2013). Global analysis of 206 tunnel construction accidents confirms unexpected ground conditions as the primary cause of delays and safety incidents, with 69% attributed to collapses from unforeseen subsurface conditions (Sousa and Einstein, 2021).

Comprehensive pre-contract investigation should include detailed site surveys, historical construction records and advanced geophysical investigations where necessary.

Table 3. Roots of delay and cost overrun in four layers for top 20 factors

Rank	1st bone	2nd bone code	2nd bone	3rd bone code	3rd bone	4th bone code	4th bone
1	Owner	1-1	Problems with neighbors, neighboring structures and underground facilities	1-1-1	Lack of knowledge about the importance of project surroundings	1-1-1-1	Delay in the inquiry of the surrounding facility
						1-1-1-2	Ambiguity in surrounding facility documents
				1-1-2	Unstable structure of neighbors	–	–
2	Owner	2-1	Inefficient geotechnical report	2-1-1	Lack of technical knowledge	–	–
				2-1-2	Inefficient number of soil tests	2-1-2-1	Lack of *in situ* tests
				2-1-3	Delay in presenting the full report	–	–
				2-1-4	Low efficiency of testing equipment	–	–
3	Contractor	3-1	Inefficient monitoring of wall displacement	3-1-1	Delay in the monitoring of the wall	3-1-1-1	The long duration between monitoring reports
				3-1-2	Inadequate experience of the surveyor	–	–
				3-1-3	Low efficiency of the equipment	–	–
				3-1-4	Lack of technical knowledge about wall movement	–	–
4	Owner	4-1	Awarding the bid to the contractor with the lowest bid, irrespective of their technical capabilities	4-1-1	Inefficient bidding process	4-1-1-1	The nonstandard evaluation process of contractors
				4-1-2	Discrepancies in a contract document	4-1-2-1	Following a non-systematic approach
				4-1-3	Corruption in the tender process	4-1-3-1	Preferring relationships to standard rules
						4-1-3-2	Insufficient supervision in the bidding process
				4-1-4	Complications in the tendering process	–	–
				4-1-5	Preferring low cost over quality	–	–

(*continued*)

Table 3. Continued

Rank	1st bone	2nd bone code	2nd bone	3rd bone code	3rd bone	4th bone code	4th bone
5	Owner	5-1	Unclear scope of work and change orders	5-1-1	Accepting inadequate design drawings	–	–
				5-1-2	Poor management of the contract	–	–
				5-1-3	Lack of knowledge about the importance of project surroundings	–	–
				5-1-4	Changing stabilization method	–	–
				5-1-5	Unrealistic contract price	–	–
				5-1-6	Simultaneous design and implementation	5-1-6-1	Sending numerous drafts to the project site
				5-1-7	Discrepancies among departments	5-1-7-1	Following non-systematic approach
6	Consultant	6-1	Inadequate examination and oversight of the project	6-1-1	Inadequate QC procedure	–	–
				6-1-2	Insufficient number of inspections	–	–
				6-1-3	Employing insufficient consultant	6-1-3-1	Inadequate experience as a consultant
					–	6-1-3-2	Lack of technical knowledge of the consultant
7	Contractor	7-1	Inadequate experience of the contractor	7-1-1	Inappropriate construction methods implemented by the contractor	–	–
				7-1-2	Lack of technical knowledge	–	–
				7-1-3	Frequent changes of managers	–	–
				7-1-4	Lack of supervision of the project	–	–
				7-1-5	Late order of materials and equipment	–	–
				7-1-6	Delay in the estimation of materials	7-1-6-1	Lack of risk management of the project
						7-1-6-2	Lack of storage space
						7-1-6-3	Lack of funding

(*continued*)

Table 3. Continued

Rank	1st bone	2nd bone code	2nd bone	3rd bone code	3rd bone	4th bone code	4th bone
8	Consultant	8-1	Designers’ limited knowledge of implementation issues	8-1-1	Design errors	–	–
				8-1-2	Inadequate experience of the designers	–	–
				8-1-3	lack of periodic site inspections	–	–
9	Miscellaneous	9-1	Inflation and fluctuation of exchange rates	9-1-1	Economic instability	9-1-1-1	Lack of risk management of the project
				9-1-2	Delay in ordering the project’s material	9-1-2-1	Lack of storage space
						9-1-2-2	Lack of funding
10	Contractor	10-1	Controlling underground water and Isolation system	10-1-1	Inadequate experience of the contractor	10-1-1-1	Employing inexperienced workforce
				10-1-2	Not following the standard sequence	–	–
				10-1-3	Lack of academic knowledge	–	–
				10-1-4	Depending on the specific subcontractor or supplier	–	–
				10-1-5	Poor quality of materials	10-1-5-1	Inadequate QC procedure
				10-1-6	Preferring low cost over quality	–	–
11	Contractor	11-1	Lack of adequate project coordination	11-1-1	Poor site management	11-1-1-1	Lack of charisma and managerial power
				11-1-2	Frequent changes in client managers	–	–
				11-1-3	Inappropriate construction methods implemented by the contractor	–	–
				11-1-4	Depending on the specific subcontractor or supplier	11-1-4-1	Contractor’s reluctance to pay adequate wages
				11-1-5	Lack of periodic meetings	–	–
				11-1-6	Delay in material fabrication	11-1-6-1	Delay in the estimation of materials
				11-1-7	Discrepancies among departments	–	–

(*continued*)

Table 3. Continued

Rank	1st bone	2nd bone code	2nd bone	3rd bone code	3rd bone	4th bone code	4th bone
12	Contractor	12-1	Poor subcontractor performance	12-1-1	Poor labor productivity	12-1-1-1	Contractor's reluctance to pay adequate wages
						12-1-1-2	Lack of charisma and managerial power
						12-1-1-3	Poor working conditions for laborers
				12-1-2	Delay in payment to subcontractors	12-1-2-1	Poor handling of financial documents
				12-1-3	Problems with providing equipment	–	–
				12-1-4	Low efficiency of the equipment	–	–
				12-1-5	Not following the standard sequence	–	–
				12-1-6	Lack of periodic meetings	–	–
13	Owner	13-1	Unrealistic contract duration	13-1-1	Lack of professional point of view	–	–
				13-1-2	Unclear definition of the project	–	–
14	Consultant	14-1	Delay in the submission of design or shop drawing and Concurrent design	14-1-1	Unforeseen complexity of the project	–	–
				14-1-2	Slow drafting and approval process	–	–
				14-1-3	Employing inadequate consultants	–	–
				14-1-4	Lack of periodic meetings	–	–
15	Contractor	15-1	Lack of adequate project coordination	15-1-1	Poor site management	15-1-1-1	Lack of charisma and managerial power
				15-1-2	Frequent changes in client managers	–	–
				15-1-3	Inappropriate construction methods implemented by the contractor	–	–
				15-1-4	Depending on the specific subcontractor or supplier	15-1-4-1	Contractor's reluctance to pay adequate wages
				15-1-5	Lack of periodic meetings	–	–
				15-1-6	Delay in material fabrication	15-1-6-1	Delay in the estimation of materials
				15-1-7	Discrepancies among departments	–	–

(*continued*)

Table 3. Continued

Rank	1st bone	2nd bone code	2nd bone	3rd bone code	3rd bone	4th bone code	4th bone
16	Contractor	16-1	Financial challenges encountered by the contractor	16-1-1	The contractor’s poor management of cash flow	–	–
				16-1-2	Inappropriate allocation of budgets	16-1-2-1	Poor management of monetary assets
				16-1-3	Misallocation of fiscal resources	16-1-3-1	The owner’s poor financial outcomes
				16-1-4	Postponement in handling the financial records of the contractor	–	–
				16-1-5	Considerable waste of materials	–	–
				16-1-6	Insufficient contract price	–	–
17	Owner	17-1	Challenges related to securing funding and ensuring adequate finance	17-1-1	Poor distribution of cash flow	–	–
				17-1-2	Poor financial performance of the owner	–	–
				17-1-3	Decisions based on political views, not professional view	–	–
				17-1-4	Ownership of various projects	–	–
				17-1-5	Inconsistency in the objectives of project participants	–	–
18	Contractor	18-1	Reworks due to errors during construction	18-1-1	Poor quality of materials	–	–
				18-1-2	Lack of periodic meetings	–	–
				18-1-3	Discrepancies among departments	–	–
19	Miscellaneous	19-1	Adverse weather conditions, air pollution and social crisis		–	–	–
20	Owner	20-1	Delay in decision-making by the owner	20-1-1	Slow inspection of completed works	–	–
				20-1-2	Lack of supervision of the project	–	–

Source(s): Authors’ own work

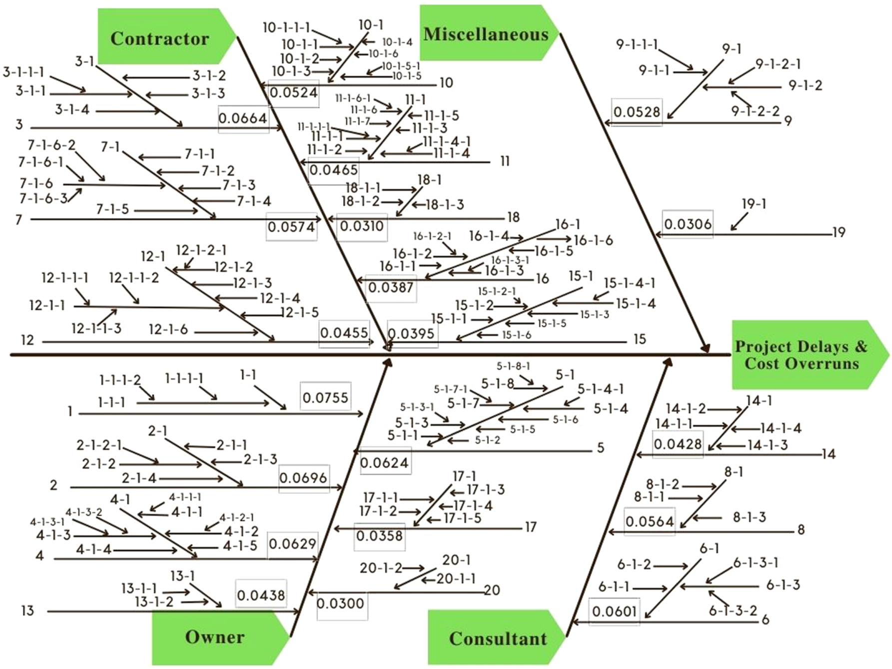

Figure 3. Cause and effect diagram of delay and cost overrun for top 20 factors. Source: Authors' own work

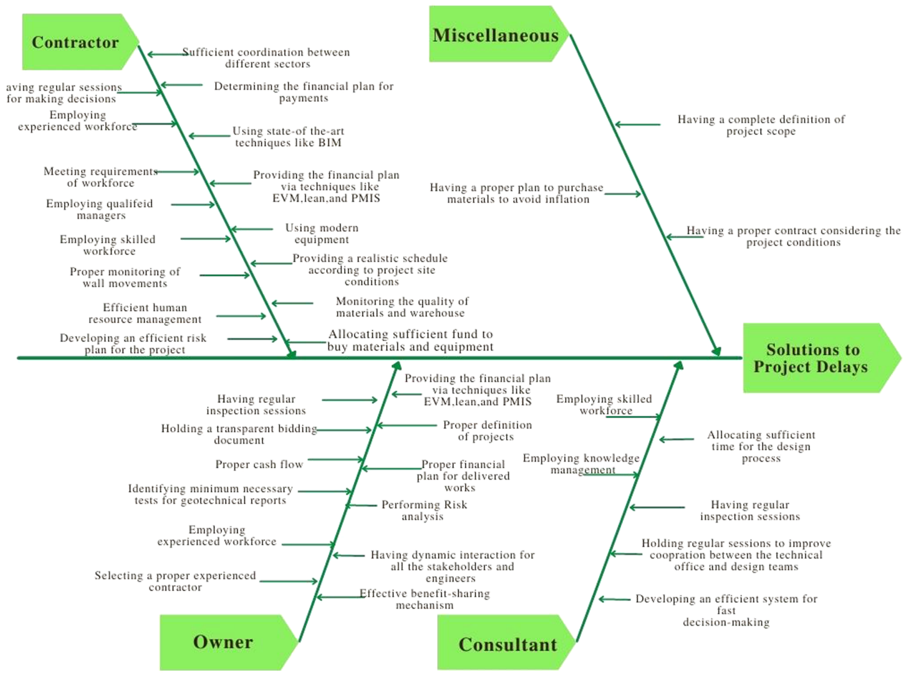

Figure 4. Proposed diagram of mitigation strategies for each stakeholder category. Source: Authors' own work

Recommended mitigation tools include geological uncertainty simulation (Qi *et al.*, 2016), multi-objective optimization of excavation sequencing and construction parameters (Meng *et al.*, 2024), and Deep Neural Networks for settlement prediction (Mahmoodzadeh *et al.*, 2020). Probabilistic classifiers producing calibrated exceedance probabilities, developed for seismic fragility assessment in structural engineering, extend this line of work and offer a means of representing geotechnical uncertainty explicitly rather than as a single deterministic estimate (Alshboul *et al.*, 2026b). Figure 4 proposes mitigation strategies including minimum testing requirements for soil mechanics analysis and engagement of experienced geotechnical consultants.

Project delays frequently stem from procurement practices favoring lowest-bid contractors without adequate technical capability assessment, coupled with ambiguous scope definitions and regular change orders. International evidence consistently identifies contracting with incompetent contractors as a top owner-related delay factor (Al-Attabi, 2025; Bayandor *et al.*, 2025). Owner-initiated change orders, often stemming from incomplete scope definition at tender stage, are consistently identified as a primary global delay cause (Alenazi *et al.*, 2022; Umar *et al.*, 2020). Recommended mitigation includes contractor selection based on demonstrated technical expertise and financial stability, alongside comprehensive pre-contract risk management, complete design development and thorough site analysis prior to tender.

Unrealistic schedule constraints, owner financial limitations and delayed decision-making represent additional significant challenges in SN/GA SOE applications. International research in construction industry confirms slow decision-making ranks among top predictive factors (coefficient = 0.368), while delayed approvals emerge consistently as critical constraints (Doloi *et al.*, 2012).

Payment processing delays by owners represent a primary constraint in public infrastructure (Ahmad *et al.*, 2020). Vietnamese and Egyptian research confirm payment delays as a leading cause, ranking highest overall (mean = 4.34) and with severity reaching 90.9% respectively (Toan *et al.*, 2025; Marzouk and El-Rasas, 2014).

BIM and Project Management Information Systems (PMIS) further enhance these efforts through precise scope definition, payment documentation, and dynamic stakeholder communication to improve coordination and minimize conflicts (Pérez *et al.*, 2024).

Contractor-originated factors and potential mitigations

The present analysis reveals that contractor-related factors rank second to owner-related issues in contributing to timeline extensions and budget overruns in deep excavation projects. In Iraqi projects, all 14 identified contractor factors were classified as major causes (Al-Attabi, 2025).

Inadequate wall displacement monitoring emerges as the most critical contractor-related delay factor in SN/GA systems, necessitating experienced personnel and regular reporting by engineers to ensure safety compliance. Inadequate displacement monitoring in deep excavations can lead to catastrophic failures and significant project delays (Ding *et al.*, 2018). The catastrophic consequences of inadequate monitoring are illustrated by five major collapses on Seoul subway Line 5 (1991–1993), caused by poor construction management and neglect of groundwater impacts (Shin *et al.*, 2006). Where monitoring is continuous rather than periodic, digital twin approaches offer a route to integrating real-time site data into excavation control, an application already demonstrated in the design of climate-resilient housing across contrasting national settings (Shehadeh *et al.*, 2025b).

Insufficient contractor experience, groundwater management challenges and inadequate planning have been consistently identified as primary delay factors in construction projects (Sambasivan and Soon, 2007). Inadequate contractor experience is particularly recognized as a critical driver globally, ranking as the leading cause among 83 identified delay factors in Turkish construction projects (Gündüz *et al.*, 2013).

Research indicates that the implementation of Project Management Information Systems (PMIS), Earned Value Management (EVM) and lean construction methodologies can significantly reduce contractor-related delays (Urgilés *et al.*, 2019). Figure 4 outlines practical solutions in this regard, including regular coordination meetings, workforce planning and systematic inter-departmental communication protocols. Coordination failures among parties operating under uncertainty are amenable to formal treatment, with cooperative allocation models reported to yield cost savings of up to 15% relative to non-cooperative arrangements (Shehadeh and Alshboul, 2025b). A comprehensive analysis of 206 worldwide tunnel accidents demonstrates that contractor-related deficiencies – including poor site management and supervision, inexperienced site management teams, inadequate construction sequences and procedures, and failure to follow standard construction procedures – represent primary contributors to catastrophic failures, with such incidents resulting in average project delays of six months (Sousa and Einstein, 2021).

Consistent with previous research, suboptimal subcontractor performance and payment management have been identified as significant delay contributors (Fallahnejad, 2013; Sambasivan and Soon, 2007). Equipment inefficiency is tractable through optimization, with algorithmic selection models reported to reduce project duration by 53% and cost by 30.8% against conventional practice (Alshboul *et al.*, 2026a). Contractor financial difficulties rank consistently among top delay causes across multiple countries (Al-Attabi, 2025). Key mitigation measures include comprehensive and precise contract documentation, timely progress payment to subcontractor and ensuring that subcontractors possess adequate skilled labor and technical capabilities (Kshaf *et al.*, 2022).

While rework emerges as a relatively minor factor among the 20 identified delay causes in deep excavation projects, its impact aligns with previous research identifying it as a significant contributor to cost overruns, schedule delays and resource waste (Love *et al.*, 2011). Rework is attributed primarily to coordination deficiencies, technical oversights and stakeholder-initiated modifications, indicating that addressing these factors could optimize project timelines (Hassan *et al.*, 2023). Project delay and reduced work quality are identified as the primary consequences of miscommunication on construction sites, with a clear link established between communication breakdowns, rework and schedule impacts (Abdallah *et al.*, 2024).

Consultant-originated factors and potential mitigations

Consultant-related factors account for approximately 16% of the total delay impact in the SOE methods examined in this study. While this proportion ranks below owner and contractor contributions, consultant performance nonetheless significantly influences overall project outcomes. This finding is broadly consistent with Iranian deep excavation research, where consultant-related factors account for 16% of delays (Bayandor *et al.*, 2025).

Inadequate project inspection and supervision rank sixth among the primary delay factors identified in this study. In top-down deep excavation methods, inadequate supervision ranks fifth (importance index: 88.11%, impact index: 84.86%) and appears among the top ten delay causes across multiple developing country contexts (Bayandor *et al.*, 2025; Marzouk and El-Rasas, 2014). Insufficient supervision in deep excavation projects can lead to quality control issues, safety concerns and subsequent delays (Zhang and Deng, 2023). Analysis of tunnel construction accidents confirms that inadequate supervision and quality control contribute to catastrophic failures and major delays (Shin *et al.*, 2006; Sousa and Einstein, 2021). Supervision and quality assurance are complicated by the volume of conflicting and incomplete information generated on active sites, and structured reasoning frameworks have been advanced to reconcile such data and reduce the incidence of error (Alshboul *et al.*, 2026a).

Design team limitations in understanding implementation practicalities emerge as a further significant contributor to project cost escalation. Designers' limited knowledge of implementation issues ranks first overall in top-down deep excavation methods (importance index 93.51%) and second in bracing strut/truss retaining systems (Bayandor *et al.*, 2025).

Incomplete design documents at tender stage represent the leading root cause of cost overruns in the Israeli construction industry, reported by 86.7% of respondents (Rosenfeld, 2014).

Design and planning components are similarly identified as major risk factors in underground metro construction (Karmarkar *et al.*, 2022). Design modification frequency is identified as the primary driver of cost overruns in New Zealand transport infrastructure projects (Atapattu *et al.*, 2023).

Figure 4 outlines proposed solutions for enhancing consultant performance in deep excavation projects. These include robust drawing management systems, sufficient design development periods, experienced designer engagement and advanced tools such as BIM, Augmented Reality and IoT (Banobi and Jung, 2019). Consultant selection based on experience rather than lowest cost, combined with effective variation order management and timely approval of submittals, are critical mitigation strategies (Marzouk and El-Rasas, 2014). Implementing contract award based on the most economically advantageous bid, combined with design contingency provisions and realistic scheduling from tender stage, represents a key integrated mitigation framework (Al-Attabi, 2025).

Miscellaneous factors and potential mitigations

Economic factors, specifically inflation and exchange rate volatility, emerge as the ninth most significant delay contributor in this study. In Iranian deep excavation projects, inflation and exchange rate fluctuations were identified as the primary delay cause (normalized weight: 0.0768, importance index: 89.73%) across both bracing strut and top-down methods (Bayandor *et al.*, 2025), likely reflecting the substantial material quantities required in such projects. Statistical analysis of Iranian construction projects identified lack of attention to inflation as a significant owner-related delay factor, while regression models indicated average delays of 5.9 months per year and overall cost overruns of 15.4% (Samarghandi *et al.*, 2016).

Inflation is further substantiated as a key risk factor in metro construction projects in developing economies (Karmarkar *et al.*, 2022). Price escalation and material cost increases have been identified as cross-cutting financial issues in Turkish construction projects (Gündüz *et al.*, 2013).

The six predominant causes of delay in Iran's construction sector are similarly centered on financial challenges affecting contractors and project owners, compounded by inflationary pressures and material cost increases (Abbasi *et al.*, 2020). Contemporary research advocates for the implementation of a dynamic framework encompassing resilient planning, monitoring, response mechanisms and continuous learning to enhance risk management effectiveness (Ning and Gao, 2021). Effective mitigation includes incorporating price forecasts into estimates, early procurement of price-vulnerable materials and fixed-price bulk purchasing agreements (Samarghandi *et al.*, 2016). As illustrated in Figure 4, the development of precise project scope definitions with respect to temporal and financial parameters, coupled with transparent contractual arrangements among stakeholders, can effectively mitigate various sources of delay (Banobi and Jung, 2019).

While environmental factors such as adverse weather conditions, air pollution and social disruptions are classified among miscellaneous delay sources, their relatively low occurrence probability results in a minimal normalized weight impact on the overall findings of this study. This contrasts notably with findings from other geographical contexts, such as Nepal, where Koirala and Shahi (2024) identified severe weather conditions as the principal delay factor. The regulatory environment governing site labor and worker insurance also shapes exposure to disruption, since gaps between labor provisions and insurance cover transfer risk in ways that are not always visible in the contract itself (Alshboul and Shehadeh, 2025).

Although environmental factors register a modest impact in the present sample, evidence from other infrastructure classes indicates that climate exposure carries measurable life-cycle cost consequences, with adaptive material and maintenance strategies shown to extend service life and improve economic performance under projected warming (Shehadeh *et al.*, 2025a).

Across the four stakeholder categories examined above, the identified factors differ markedly in their tractability to digital intervention, and the distinction carries practical consequences for where investment is warranted. Building information modeling addresses factors originating in information rather than in ground behavior, supporting scope definition, coordination and the anticipation of design conflicts before they reach the site. Machine learning and artificial intelligence methods act earlier, at the characterization stage, where neural network forecasting of surface settlement and probabilistic simulation of geological uncertainty convert deterministic estimates into distributions against which contingency can be sized, and where optimization algorithms inform excavation sequencing. Deficient wall displacement monitoring, ranked third overall, is the factor most directly amenable to IoT instrumentation, since continuous sensing coupled with digital twin representation would replace the periodic manual reporting on which current practice depends (Shehadeh *et al.*, 2025b). Predictive analytics extends this logic to hazard anticipation, given the shared origin of delay and safety incidents in unforeseen ground conditions (Shehadeh and Alshboul, 2025a).

Two qualifications temper this assessment. Interference with adjacent structures is only partially tractable despite ranking first, since its resolution depends on property rights, neighbor consent and utility authority approvals that no digital system can accelerate. More broadly, these tools yield benefit only where organizational capability exists to act on the information they generate, and instrumentation reporting displacement to a project lacking authority or expertise to respond relocates the delay rather than preventing it.

Conclusions and future studies

This research investigated the critical factors contributing to delay and cost overrun in deep excavation projects utilizing soil nailing and ground anchoring SOE systems in Iran. Through a two-phase methodology combining a PRISMA-guided systematic review of 431 publications with empirical stakeholder analysis, the study addresses the complex interplay of technical, managerial and economic challenges affecting project performance.

The findings reveal that owner-related factors, particularly constraints related to adjacent structures and inadequate geotechnical investigation, represent the most significant contributors to project delays (38.0%). Contractor-related issues rank second (37.7%), with insufficient wall displacement monitoring emerging as a critical concern. Consultant-related factors, while accounting for a smaller proportion (15.9%), significantly impact project outcomes through design limitations and supervision deficiencies. Economic factors, notably inflation and exchange rate volatility, also emerge as substantial challenges, though environmental factors demonstrate a relatively minor impact due to their low occurrence probability in the Iranian deep excavation context.

For constraints related to adjacent structures, implementing thorough pre-construction surveys, clear communication protocols and advanced geotechnical investigation tools are essential, alongside real-time monitoring systems and collaborative planning among stakeholders. Addressing inadequate geotechnical investigation requires minimum testing standards for soil mechanics and uncertainty risk assessment protocols. Robust pre-contract management, including thorough site investigation and contractor selection based on technical expertise rather than the lowest bid, emerges as crucial for project success. Systematic monitoring, experienced supervision and proactive financial planning are essential across all stakeholder groups. The normalized attribution across stakeholder categories further offers an evidence-based basis for contractual risk allocation, permitting responsibility to be assigned in proportion to demonstrated causal contribution rather than by convention.

Three implications follow from these findings for how delay is theorized in specialized construction settings. Delay factor inventories are not directly transferable between SOE systems, even within a single national context, since the leading causes shift with the technique rather than with the economy. Responsibility is likewise redistributed by that choice, so stakeholder attribution must be established method by method rather than inherited from general construction findings. Mitigation is therefore most effective when matched to the causal tier at which a factor originates, rather than applied uniformly to whichever factors rank highest.

The findings of this research have direct practical applications for stakeholders involved in deep excavation projects, particularly in rapidly urbanizing developing economies facing similar challenges. At the policy level, the prominence of adjacent-structure interference and utility relocation identifies the regulatory interface as a determinant of project performance, with streamlined permitting and clearer statutory frameworks for neighboring-property consent representing measures beyond the reach of any individual project team.

Systems that carry load in other ways, such as diaphragm walls, secant pile walls and hybrid arrangements, remain untested against the pattern of causation reported here, and extending the comparison to them would establish how far technique-specific patterns hold. The same question arises within a single technique, since deeper excavations place greater load on nails and anchors, and different procurement routes place risk with different parties. Analysis grouped by excavation depth, project size and delivery method would show whether the ranking reported here stays the same or changes under those conditions. Repeating the study in other countries would help separate the factors that apply widely from those shaped by local economic and regulatory conditions, and a sample drawn from several countries would be large enough to model how the factors influence one another, and to treat delay and cost overrun as two separate outcomes so that the link between them can be measured rather than assumed. Such a dataset would also support predictive models that combine ground conditions with project management variables, allowing risk to be estimated before contracts are signed. Finally, the emerging technologies discussed in this study should be tested against actual project results, since the benefits of BIM-5D, artificial intelligence and IoT monitoring are widely claimed but rarely measured.

Ethical statement

This study involved the collection of non-sensitive, professional opinion data from construction practitioners through structured questionnaires and expert interviews. All participants were informed of the study's purpose and how their responses would be used. Participation was entirely voluntary, and informed consent was obtained from all respondents prior to data collection. No personal or identifiable information was recorded, and all responses were fully anonymized. In accordance with the Iranian Ethical Framework for Research, formal ethical review was waived for this category of low-risk, non-identifiable survey research. The study was conducted in accordance with the ethical principles of the Belmont Report and relevant national guidelines governing research involving human participants.

Data availability statement

The data supporting the findings of this study were collected through structured questionnaires and expert interviews. The primary results are presented within the article. Raw data are not publicly available due to participant confidentiality, but the aggregated data are available from the corresponding author upon reasonable request.

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