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CAUSES OF DELAYS OCCURRING IN LINEAR PROJECTS-A SURVEY OF PRESTRESSED CONCRETE SHEET PILE RETAINING WALL CONSTRUCTIONS IN TAIWAN

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Abstract

Delays occur in all types of projects, including those featuring linear works. In the hopes of identifying the major causes of delays in prestressed concrete sheet pile retaining wall projects in Taiwan, we conducted a literature review and pilot study to determine causes of potential delays. The study obtained the "causes of actual delays" by analyzing material supply request records from a pile supplier, which covered 113 completed projects executed from 2019 to 2021. Additionally, "causes of perceived delays" were gathered through 49 Analytical Hierarchy Process (AHP) questionnaires from project parties. The sets of the causes of delays identified from the surveys were ranked using the Relative Importance Index (RII), and the correlation between the ranked sets of "causes of actual delays" and "causes of perceived delays" was assessed using the Spearman rank correlation (ρ). The results showed that the top five critical factors were "acts of God or bad weather", "mistakes during the construction stage—wrong jobs", "unrealistic contract durations imposed by clients", "inadequate path design", and "poor procurement management by contractors". The outbreak of the novel coronavirus disease (COVID-19) pandemic did not significantly impact the availability of skilled personnel for the completed projects.

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Key words

- precast concrete sheet pile retaining wall,
- Causes of delays,
- Analytical Hierarchy Process (AHP),
- Relative Importance Index (RII),
- Spearman rank correlation (ρ).

1 INTRODUCTION

Construction delays have been identified as critical, recurring problems (Sweis et al., 2008; Li et al., 2017) and recognized as a worldwide phenomenon (Taha et al., 2016; Upadhyay et al., 2016). These delays occur not only in building construction (Rao & Culas, 2014; Hari & Pandey, 2016; Muhwezi et al., 2014) but also in infrastructure projects, such as pipeline projects (Orangi et al., 2011; Fallahnejad, 2013; Shebob et al., 2011), dam projects (Sohu et al., 2017), and road projects (Ram & Paul, 2015; Alfakhri et al., 2018; Rivera et al., 2020). In Taiwan, precast concrete sheet piles have been used as the primary materials for retaining wall constructions in infrastructures such as riverbanks, road sidewalks, coastline banks, and hill sidewalks for decades. Their construction has also been suffering from delays. Therefore, it is essential to identify the causes to mitigate their negative impacts on the durations of construction projects.

This study adopts the causes of delays identified in a previous study (Fallahnejad, 2013), which focused on determining the major causes of delay in pipeline projects. The rationale for this approach is that precast concrete sheet pile retaining wall constructions share characteristics with pipeline projects, including linear operations, a high demand

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for materials, a large number of repetitive tasks, and common problems and challenges (Orangi et al., 2011; Fallahnejad, 2013). In this study, site material supply request records maintained by a pile supplier, which cover 113 completed precast concrete sheet pile retaining wall construction projects, including riverbank, roadside, coastline, and hillside projects executed between 2019 and 2021, were examined. A total of 49 experts from various project parties, which were organized in groups of piling subcontractors, contractors, consultants, and owners, were involved in the questionnaire surveys.

Figure 1 illustrates the study's methodology, and the major objectives are as follows:

- To learn the causes of delays of linear constructions and the methodologies applied for finding them through a literature review;
- To identify the causes of delays for pilot questionnaires;
- To construct the final questionnaires for the study
- To observe the "causes of actual delays" through studying various site material supply request records of completed constructions;
- To identify the "causes of perceived delays" from the perspectives of project parties such as piling subcontractors, contractors, consultants, and owners through Analytic Hierarchy Process (AHP) questionnaires;
- To rank the "causes of actual delays" and "causes of perceived delays" using a Relative Importance Index (RII);
- To assess the strength of the association between every two ranked sets using a Spearman rank correlation (ρ).

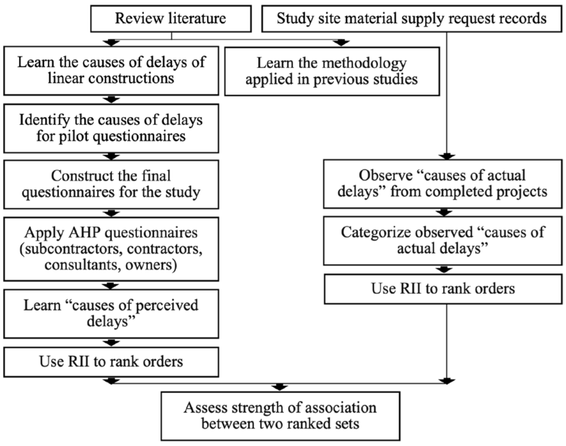

Fig. 1 *Flowchart of the studyinterior of the fortification.*

2 LITERATURE REVIEW

2.1 Causes of delays of projects with features of linear constructions

As stated earlier, precast concrete sheet pile retaining wall constructions share similar features with those of roadway and pipeline constructions. Learning the major causes of delays in roadway and pipeline constructions was essential to our study.

Delays in roadway constructions have occurred in many countries and regions (Mahamid et al., 2012). A study has even indicated that 50% of the causes of delays in roadway constructions were similar in some developing countries (Rivera et al., 2020). As to the pipeline constructions, delay was not only considered a critical factor for the success of a construction but was also identified as the most influential factor for changes in construction designs (Zadeh et al., 2014). The major causes of delays identified in roadway and pipeline constructions are listed in Tables 1 and 2, respectively.

Tab.1 *Causes of delays identified in roadway constructions in this study*

Author	Study area	Major causes of delays
Alfakhri et al. (2018)	Libya	cost overruns; time extensions; disputes, loss of profit; breaches of contract; poor quality of work; company's bad reputation
Akomah & Jackson (2016)	Ghana	delay in honoring payment certificates; bad weather conditions; unfavorable site conditions; consultant-initiated variations; delay in instructions from consultants and difficulty in accessing bank credit
Kayelle et al. (2023)	Brazil	contractor; designer; manager; material/manpower/equipment; external factors
Mahamid et al. (2012)	Palestine	political situation; segmentation and limited movement among areas; award project to the lowest bid price; delay of progress payment by owner; shortage of equipment
Nikjow et al. (2021)	Belt and Road Initiative, strategy adopted by the Chinese government	improper management of the design; unsustainable land acquisition; insufficient use of joint venture in the constructing phase and the leading causes of unsuitable procurement; undervalued procurement cost; inefficient logistics in labour and materials; improper planning; unqualified site supervisors; inefficient technical standard management; inefficient constant payment terms in the procurement phase
Ram & Paul (2015)	India	land acquisition; environmental issues; delay in progress payment; ineffective project planning and scheduling; poor site management and supervision; rework due to errors; delay in approving design documents; poor coordination between owner and the other parties; financial closure and change order

Rivera et al. (2020)	Included 25 developing countries	the lack of experience of the construction manager; inadequate planning/scheduling; effect on people's land alongside the road construction project; frequent changes in the design
Santoso & Soeng (2016)	Cambodia	Rain; flood; land acquisition; award of project to lowest bidder; equipment breakdowns; poor site arrangement; management and supervision; unexpected ground condition and terrain; low quality of the contractor human resources; late progress payments; low productivity of labour
Seboru (2015)	Kenya	payment by client; slow decision making; bureaucracy in client organization; inadequate planning and scheduling; rain
Toriola-Coker et al. (2022)	Nigeria	clients' financial difficulties; cash flow during construction; political influence; government regulations; inclement or bad weather

Tab.2 *Causes of delays identified in pipeline constructions in this study*

Author	Study area	Major causes of delays
Alshibani et al. (2022)	Saudi Arabia	client-related materials, delays in materials and equipment delivery, permit approval, delays in subcontractor work, and delays in preparing and approving engineering drawings
Fallahnejad (2013)	Iran	imported materials, unrealistic project duration, client-related materials, land expropriation, change orders, contractor selection methods, payment to contractor, obtaining permits, suppliers, and contractor's cash flow
Mohammed & Suliman (2019)	Bahrain	poor managerial skills; slow decision-making; lack of communication; inadequate design teams; scope variations; delays in drawing preparation
Orangi et al. (2011)	Australia	design changes, design errors, poor communication, customer/end-user related issues, subsurface investigation inadequacies, issues regarding permissions/approvals, weather conditions, procurement delays
Yang & Liao (2012)	Taiwan	moving existed conduits later than planned schedule, unforeseen site conditions and delayed construction planning report approval

2.2 Precast concrete sheet pile retaining wall constructions in Taiwan

Concrete sheet pile walls are one of the oldest earth retention systems applied in construction (Bilgin & Erten, 2012). They have been widely used as major materials for retaining wall constructions for riverbanks, ocean banks and highway sidewalks, due to such advantages as the wide range of lengths/sizes, quick/easy installation, and the need for little maintenance (Amit Kumar & Pendharka, 2023).

In Taiwan, concrete sheet piles are designed and fabricated in thicknesses of 50 or 60 centimeters and lengths ranging from 3 to 18 meters, according to the Chinese National Standard CNS 7935:2017 A2115 "Prestressed Concrete Sheet Piles" (Bureau of Standards, Metrology and Inspection, Taiwan, 2017), and are constructed under the guidelines outlined in Chapter 02459, "Technical Regulations for Precast Concrete Sheet Pile Constructions" (Water Resources Agency Taiwan, 2017). To form the walls, multiple precast concrete sheet piles are driven into the soil using hydraulic vibrators. The joints between the piles are grouted with cement mortar after the piles have been driven to the required depth. Additionally, the pile heads are connected by reinforcement beams to ensure the stability of the walls (see Figure 2).

Fig. 2-1 *Pile driving applying vibrators*

Fig. 2-2 *Pile heads rebar works*

Fig. 2-3 *Pile heads form works*

Fig. 2-4 *Coastline retaining wall*

Fig. 2-5 *Roadside retaining wall*

Fig. 2 *Precast concrete sheet pile constructions*

2.3 Major approaches applied in finding causes of delays of linear constructions

2.3.1 Survey Questionnaire

A questionnaire survey is the best and most reliable methodology for gathering data about the causes of delays and quantifying the delay factors (Ram & Paul, 2015). Some studies have utilized questionnaire surveys as the primary tool for identifying causes of delays in linear constructions as listed in Table 3.

Tab.3 *Questionnaire survey applied in finding causes of delays in linear constructions*

Author	Title of Studies
Azman et al. (2019)	Relative importance index (RII) in ranking of quality factors on industrialized building system (IBS) projects in Malaysia
Dixit et al. (2019)	Study of significant factors affecting construction productivity using Relative Importance Index in Indian construction industry
Fallahnejad (2013)	Delay causes in Iran gas pipeline projects
Kayelle et al. (2023)	Identifying the causes of delay using the Analytic Hierarchy Process (AHP) method in Brazilian public road infrastructure projects
Khatib et al. (2020)	Delay factors management and ranking for reconstruction and rehabilitation projects based on the Relative Importance Index (RII)
Mahamid et al. (2012)	Causes of delay in road construction projects
Nikjow et al. (2021)	Triggers of delays in international projects using engineering procurement and construction delivery methods in the Belt and Road Initiative: Case study of a high-speed railway projects
Ram & Paul (2015)	Study on construction sequence delay for road infrastructure projects
Seboru (2015)	An investigation into factors causing delays in road construction projects in Nigeria
Vishal & Kuma (2021)	Causes and impacts of delay in construction industry of India
Youniss et al., 2017	A conceptual model of delay factors affecting road construction projects in Libya

2.3.2 Analytic hierarchy process (AHP)

The Analytic Hierarchy Process (AHP) has been proposed as a simple and comprehensive approach for solving various multi-criteria decision-making problems (Saaty, 2008) and has been widely applied in the field of construction management. Some studies applying AHP for identifying causes of delays in linear constructions are listed in Table 4.

Tab.4 *AHP method applied in finding causes of delays in linear constructions*

Author	Title of Studies
Abdelmaguid & Elrashidy (2019)	Halting decisions for gas pipeline construction projects using AHP: A case study
Aminbakhsh et al. (2013)	Safety risk assessment using analytic hierarchy process (AHP) during planning and budgeting of construction projects
Choi, Junho & Choi, Jaepil (2022)	Technical feasibility study model of aged apartment renovation applying analytic hierarchy process
Ghaleh et al. (2021)	Delays in the road construction projects from risk management perspective
Hyun et al. (2015)	Risk analysis using fault-tree analysis (FTA) and analytic hierarchy process (AHP) applicable to shield TBM tunnels

Kayelle et al. (2023)	Identifying the causes of delay using the Analytic hierarchy process (AHP) Method in Brazilian public road infrastructure projects
Kuo & Chao (2017)	AHP model for evaluation of pile installation methods
Tian et al. (2013)	Application of the analytic hierarchy process to a sustainability assessment of coastal beach exploitation: A case study of the wind power projects on the coastal beaches of Yancheng, China
Tarek et al. (2022)	Relative Importance Index for the key performance indicators for the construction industry in Egypt
Vishal & Kuma (2021)	Causes and impacts of delay in construction industry of India

2.3.3 Relative importance index of factors (RII)

The Relative Importance Index (RII) is a valuable tool commonly utilized to calculate the relative index for the frequency of the occurrence, severity of impact, and importance of causes of delay. Many studies have applied this method to determine the relative impact of each delay cause. Numerous early studies have focused on identifying linear construction causes of delays, some of which are listed in Table 5.

Tab.5 *RII applied in finding causes of delays in linear constructions*

Author	Title of Studies
Alfakhri et al. (2018)	The effects of delays in road construction projects in Tripoli, Libya
Arif & Pathirana (2022)	Evaluation of risk in water supply projects by Relative Importance Index method
Azman et al. (2019)	Relative Importance Index (RII) in ranking of quality factors on industrialized building system (IBS) projects in Malaysia
Amarkhil et al. (2020)	A meta-analysis of critical causes of project delay using Spearman's rank and Relative Importance Index integrated approach
Boakye et al. (2023)	A Relative Importance Index approach to on-site building construction workers' perception of occupational hazards assessment
Dixit et al. (2019)	Study of significant factors affecting construction productivity using Relative Importance Index in Indian construction industry
Khatib et al. (2020)	Delay factors management and ranking for reconstruction and rehabilitation projects based on the Relative Importance Index (RII)
Rooshdia et al. (2018)	Relative Importance Index of sustainable design and construction activities criteria for green highway
Tchantchane et al. (2020)	Relative Importance Index of delay factors in construction industry: Case of Dubai

2.3.4 Spearman rank correlation

The Spearman rank correlation coefficient (Spearman ρ) has been applied in many studies to investigate various issues in construction management. This nonparametric measure is utilized to determine the strength and direction of a linear relationship between two variables (Al-Hameed, 2022). The Spearman correlation coefficient (ρ) ranges from +1 to -1. A ρ value of +1 indicates perfect agreement of ranks; a ρ value of 0 indicates no agreement of ranks; and a ρ value of -1 indicates a perfect negative agreement between ranks.

3 RESEARCH METHODOLOGY

Three major methods were used to analyze the collected data, and one statistical technique was employed to measure the correlation between the study results obtained.

3.1 Analytic hierarchy process (AHP)

In this study, the Analytic Hierarchy Process (AHP) was adopted to assess the perceived relative importance of causes of delays from the perspectives of piling subcontractors, contractors, consultants, and owners through a questionnaire survey.

The principles of AHP for solving problems are as follows (Satty, 2008):

1. Build a hierarchical structure with an overall goal at the top level, followed by groups at the levels below, and factors at the bottom level (see Figure 3).

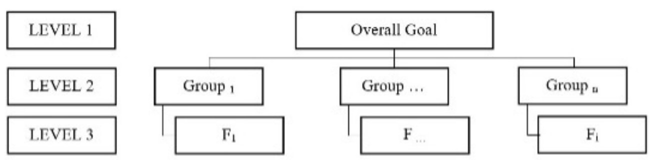

Fig. 3 *Hierarchical structure of AHP*

2. Determine the relative importance of the factors using a scale of 1 to 9.
3. Ensure the consistency of the decision-maker by utilizing the consistency index (CI) and the consistency ratio (CR) to assure the consistency of the evaluation. The CR must not exceed 0.1 and can be calculated using equation (1):

$$CR = \frac{CI}{RI} \tag{1}$$

where CI is the consistency index; RI is the random index (see Table 6).
RI was 1.45 for this study as a result of n=9 (Satty, 2008).

Tab.6 *Random index (Satty, 2008)*

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The implementations of AHP for this study are as follows:

The factors/groups in the hierarchical structure (see Fig. 4) are assumed to be independent. Level 1 represents the overall perception of the respondents. The influence of each factor/group on the construction delay was compared in pairs by the respondents to derive its weight. For Level 2, the influence of Group 1 should be compared to that of Groups 2 through 9 to determine its weight in the group, which is denoted as WGi (level 2, i=1~9). This comparison process should also be applied to the other nine factors. For Level 3, the influence of Factor 1 should be compared to that of Factors 2 through 7 to determine its weight, which is denoted as WFi (level 3, i=1~25) within its corresponding group. The same comparison process should also be applied to the remaining factors in the other groups. A combined weight for each factor, Wi (combi, i=1~25), was further calculated by multiplying WGi (level 2) and WFi (level 3). Wi (combi, i=1~25) indicates the perceived effect of each factor on the construction delay as observed by all the respondents.

3.2 Relative importance index of factors (RII)

The cause with the highest Relative Importance Index (RII) indicates the maximum impact on construction delays, while the cause with the lowest RII indicates the least impact. The RII can be calculated using equation (2):

$$\mathrm{RII} = \frac{\sum \mathrm{w}}{\mathrm{A} \times \mathrm{N}} \tag{2}$$

where w is the weight given to each cause by the respondent;
A is the highest weight;
N is the total number of respondents.

3.3 Spearman rank correlation

The Spearman rank correlation can be calculated using equation (3):

$$\rho = 1 - \frac{6 \sum \mathrm{d}^2}{\mathrm{n}(\mathrm{n}^2 - 1)} \tag{3}$$

where ρ= Spearman rank correlation;
d= the difference between the ranks of corresponding values Xi and Yi;
n= number of values in each data set.

4 DETERMINATION OF CAUSES OF POSSIBLE DELAYS

4.1 Pilot study using pre-established questionnaires

Due to the lack of related studies available, adapting a pre-established questionnaire that has been extensively tested for its reliability and validity is one of the most logical solutions (Hyman et al., 2006). It is also an effective method for conducting a study in terms of saving time and money (Boynton & Greenhalgh, 2004). Therefore, this study adapted the results provided by Fallahnejad (2013) because of their similar characteristics, including the execution of linear tasks, the need for repetitive jobs along the routes, and the linear features of precast concrete sheet pile retaining walls. However, the reliability of the questions in a questionnaire can be influenced by various complex factors, such as the conditions, economy, politics, culture, weather, and unique atmosphere of the region or country where the projects were located (Hyman et al., 2006; Aithal & Aithal, 2020; Ricci et al., 2019). Given these factors, the results provided by Fallahnejad (2013) were used as a pilot questionnaire to verify the feasibility, reliability, and validity of these causes, as shown in Table 7.

Tab.7 *Factors used for pilot questionnaires (Fallahnejad, 2013)*

Group 1: Owner	
F1	Unrealistic contract durations imposed by client
F2	Delays in contractor's payment by client
F3	Frequent change of client managers
F4	Insufficiency of incentives ahead of schedule projects or delay penalties
F5	Slow land expropriation due to resistance from occupants
F6	Owner's change orders - large quantities of extra work
F7	Inadequate path design
Group 2: Consultant	
F8	Waiting time for approval of shop drawings and tests
F9	Lack of effective project control
Group 3: Contractor	
F10	Limited experience of contractor in planning and controlling the project
F11	Accidents during construction - labour injuries - infectious disease
F12	Unavailability of utilities on site (such as water, electricity, or telephone)
F13	Contractor's poor cash flow management
F14	Mistakes during construction stage - wrong jobs
Group 4: Material	
F15	Slow delivery of material by client
F16	Low quality and defective material provided by client
F17	Non-adherence of material specifications-provided by client-to drawings
F18	Contractor's poor procurement management
F19	Financial instability in markets

F20	Delays in suppliers and subcontractors' work
F21	Shortage of materials in markets
F22	Lack of water for hydrostatic test
F23	Poor ability of contractor to provide imported material
Group 5: External issues	
F24	Act of God - bad weather
F25	Vandalism- robbery
F26	Unavoidable changes in construction/execution methods
Group 6: Communication	
F27	Excessive bureaucracy in project owner's operation
F28	Difficulty of coordination between various parties working on the project
F29	Major disputes and negotiations- adversarial atmosphere
F30	Poor documentation
Group 7: Interface	
F31	Interferring with other projects
F32	Traffic control regulation- transportation delays
F33	Environmental concerns and restrictions
F34	Obtaining permits from governmental organization
F35	Changes in laws and regulations
Group 8: Contract	
F36	Improper construction methods - non-updated procedures
F37	Unsuitable type of contract
F38	Inadequate and inconsistent contract terms
F39	Type of project bidding and award
F40	Inconsistency of technical specifications
Group 9: Labour & equipment	
F41	Labour problems - personal conflicts - strikes
F42	Insufficient or low productivity equipment
F43	High turnover of skilled staff

4.2 Final questionnaire for the study

A total of 10 professionals were interviewed for the pilot study, including two piling subcontractors, two contractors, two consultants, two owners, and two professors from university civil engineering departments. The professionals interviewed could be considered representative, as they were chosen from industry, government administrations, and academic circles.

Based on the opinions of these professionals, the factor "slow delivery of material by client (F15)" was modified to "slow delivery of material by pile supplier", and "low quality and defective material provided by client (F16)" was changed to "low quality and defective material provided by pile supplier". This adjustment was made because the clients (owners) were not responsible for the supply of material in sheet pile installation projects in Taiwan. The factors "lack of water for hydrostatic test (F22)" and "poor ability of contractor to provide imported material (F23)" were deleted due to their inappropriate application to sheet pile installation.

Sixteen factors, including F2, F4, F13, F17, F18, F19, F21, F25, F30, F32, F34, F35, F37, F38, F39, and F40, were eliminated as a result of very low occurrences. The factor "insufficient or low productivity equipment (F42)" in Group 9 was excluded because the equipment used is uncomplicated and not prone to malfunctioning. Furthermore, there are always alternatives available for piling and repair parts for maintenance. Therefore, Group 9 "Labour & Equipment" was modified to "Labour." The factor "labour problems - personal conflicts - strikes (F41)" was changed to "shortage of skilled personnel" for the following reasons: (1) there were no such incidents reported in the professionals' experience; (2) the surveyed projects were executed during the years 2019 to 2021, which covered part of the period of the novel coronavirus disease (COVID-19) pandemic. Thus, the "shortage of skilled personnel" induced by the pandemic should be a significant concern based on the research conclusions (Chen et al., 2023).

As a result of the pilot study, the final questionnaire for the study consisted of nine groups and a total of twenty-five factors, as presented in Table 8. The hierarchical structure is illustrated in Figure 4.

Tab.8 *Factors used for the study*

Group 1: Owner	
f1	Unrealistic contract durations imposed by client
f2	Frequent change of client managers
f3	Slow land expropriation due to resistance from occupants
f4	Owner's change orders - large quantities of extra work
f5	Inadequate path design
Group 2: Consultant	
f6	Waiting time for approval of shop drawings and tests
f7	Lack of effective project control
Group 3: Contractor	
f8	Limited experience of contractor in planning and controlling the project
f9	Accidents during construction - labour injuries - infectious disease
f10	Unavailability of utilities on site (such as water, electricity, or telephone)
f11	Mistakes during construction stage - wrong jobs
Group 4: Material	
f12	Slow delivery of material by pile supplier
f13	Low quality and defective material provided by pile supplier
f14	Delays in suppliers and subcontractors' work
Group 5: External issues	
f15	Act of God - bad weather
f16	Unavoidable changes in construction/execution methods
Group 6: Communication	
f17	Excessive bureaucracy in project owner's operation
f18	Difficulty of coordination between various parties working on the project
f19	Major disputes and negotiations - adversarial atmosphere
f20	Poor documentation
Group 7: Interface	
f21	Interferring with other projects
f22	Environmental concerns and restrictions

Group 8: Contract	
f23	Improper construction methods- non-updated procedures
Group 9: Labour	
f24	Shortage of skilled personnel
f25	High turnover of skilled staff

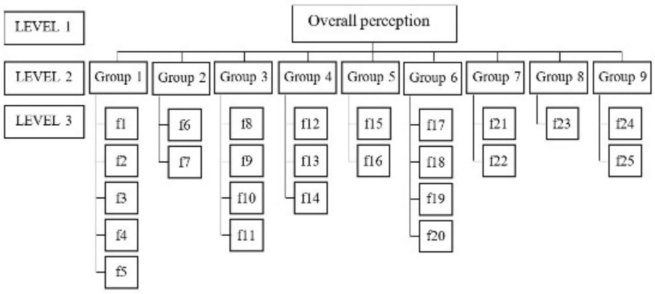

Fig. 4 AHP hierarchy structure of the study

5 SURVEYS

5.1 Surveys of "causes of actual delays" from completed projects

The information in a site diary is always considered vital, especially in the case of a material supply diary documented by a pile supplier. This study examined the material supply request records of a major sheet pile supplier in southern Taiwan, which covered a total of 113 completed precast concrete sheet pile retaining wall constructions, including various projects executed between 2019 and 2021. The factors causing each individual delay were identified from the records. The project profiles are presented in Table 9.

***Tab.9** Completed project profile for RII*

Project type	Planned duration (month)			Total	%
	<3	4-6	>6		
Riverbank retaining wall	23	33	6	62	55 %
Roadside retaining wall	13	6	1	20	18 %
Coastline retaining wall	2	15	4	21	19 %
Hillside retaining wall	3	5	2	10	9 %
Total	41	59	13	113	--
%	36 %	52 %	12 %	--	--

The factors that caused construction delays were identified based on the descriptions in Table 2 related to material supply request records. The frequencies of occurrence for each factor, as well as their corresponding groups, were collected. The relative importance index (RII) for each factor and group was then computed to assess their significance, and the ranking of each factor and group was established. A total of 98 events causing construction delays were identified across 113 completed projects. Some projects never experienced any delays, while others encountered delays more than once. The survey results of the completed projects are presented in Table 10.

***Tab.10** Survey results of completed projects*

Factors	Occurrence Frequency	RII (×100)	Rank	Groups	Occurrence Frequency	RII (×100)	Rank
f1	7	0.2212	3	G1: Owner	15	0.4282	3
f2	2	0.0632	13				
f3	3	0.0948	6				
f4	2	0.0632	13				
f5	1	0.0316	24				
f6	3	0.0948	6	G2: Consultant	9	0.2569	5
f7	6	0.1896	4				
f8	3	0.0948	6	G3: Contractor	16	0.4568	2
f9	3	0.0948	6				
f10	2	0.0632	13				
f11	8	0.2528	2				
f12	2	0.0632	13	G4: Material	6	0.1713	6
f13	2	0.0632	13				
f14	2	0.0632	13				
f15	28	0.885	1	G5: External issues	31	0.885	1
f16	3	0.0948	6				
f17	2	0.0632	13	G6: Communication	10	0.2855	4
f18	4	0.1264	5				
f19	1	0.0316	24				
f20	3	0.0948	6				
f21	2	0.0632	13	G7: Interface	5	0.1427	7
f22	3	0.0948	6				
f23	2	0.0632	13	G8: Contract	2	0.0571	9
f24	2	0.0632	13	G9: Labour	4	0.1142	8
f25	2	0.0632	13				

With the highest RII score of 0.885, G5 (External issues) was identified as the most significant group, followed by G3 (Contractor, RII = 0.4568), G1 (Owner, RII = 0.4282), G6 (Communication, RII = 0.2855), G2 (Consultant, RII = 0.2569), G4 (Material, RII = 0.1713), G7 (Interface, RII = 0.1427), G9 (Labour, RII = 0.1142), and G8 (Contract, RII = 0.0571). The factors categorized under G5 (External issues) were likely to be the critical ones contributing to project delays.

The five most significant factors, ranked by their RII scores, were f15 (Act of God - bad weather), f11 (Mistakes during construction stage-wrong jobs), f1 (Unrealistic contract durations imposed by the client), f7 (Lack of effective project control), and f18 (Difficulty of coordination among various parties working on the project), with RIIs of 0.885, 0.2528, 0.2212, 0.1896, and 0.1264, respectively. With an occurrence frequency of 28, f15 (Act of God - bad weather) ranked the highest. Bad weather may be considered crucial to the successful completion of construction projects.

5.2 Surveys of "causes of perceived delays" using the AHP questionnaire survey

The respondents were selected from parties involved piling subcontracting, contracting, consulting, and ownership, all of whom had working experience on precast concrete sheet pile installation projects. The collected data was used to analyze the perceptions of the project participants. As shown in Table 11, a total of 66 questionnaires were distributed via email. With a response rate of 74.2%, 49 valid responses were obtained. More than 90% of the respondents had over five years of experience in related work. The survey results should reflect the perceived ideas fairly accurately.

Both the response rates for piling subcontractors and owners were 100%, while the rates were 74% for contractors and 69% for consultants. These high response rates indicate a strong interest among all the parties in identifying the causes of delays in precast concrete sheet pile retaining wall constructions. Furthermore, the high response rates also suggest a strong willingness to adopt precast concrete sheet piles as the primary material for retaining walls. Questionnaire statistics are presented in Table 12.

Tab.11 *AHP respondent's profile*

Project party	Work experience (years)				Total
	<5	6-10	11-20	<20	
Piling subcontractor	0	0	2	2	4
Contractor	1	17	5	6	29
Consultant	2	3	4	2	11
Owner	1	1	3	0	5
Total	4	21	14	10	49
Work experience rate (%)	8.2	42.8	28.6	20.4	100

Tab.12 *AHP questionnaire response rate (%)*

Project party	Sent		Received		Response rate (%)
	No.	%	No.	%	
Piling subcontractor	4	6.1	4	8.2	100
Contractor	41	62.1	29	59.2	71
Consultant	16	24.2	11	22.4	69
Owner	5	7.6	5	10.2	100
Total	66	100	49	100	74.2

The collected data was analyzed from the perspective of each individual party to determine their respective weights. Groups with higher weights have a greater influence on construction projects than others. Table 13 displays the ranked orders of "causes of perceived delays" for each party. The greatest concern for piling subcontractors and contractors was G5 (External Issues), while G4 (Materials) was the primary concern for consultants and owners. The least concern for piling subcontractors was G8 (Contract), whereas G9 (Labour) was the least concern for the other parties.

Tab.13 *AHP survey results from project parties*

Group \ Party	Piling subcontractors		Contractors		Consultants		Owners	
	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank
G1(Owner)	0.1748	3	0.14	3	0.1444	4	0.1015	5
G2(Consultant)	0.1461	4	0.13	4	0.1415	5	0.1519	4
G3(Contractor)	0.1045	5	0.199	2	0.1554	2	0.1522	3
G4 (Material)	0.1922	2	0.113	5	0.1833	1	0.2305	1
G5 (External issues)	0.1942	1	0.233	1	0.1508	3	0.1554	2
G6(Communication)	0.0706	6	0.062	6	0.0736	6	0.0672	6
G7 (Interface)	0.0396	8	0.05	7	0.0602	7	0.0579	7
G8(Contract)	0.0373	9	0.04	8	0.0479	8	0.0418	8
G9 (Labour)	0.0407	7	0.032	9	0.0428	9	0.0416	9
RI	0.087		0.092		0.09		0.082	

5.3 Rank correlation in all the surveys

As summarized in Tables 9 and 13, the rank orders of all the groups are presented in Table 14. To measure the degree of agreement between the rank orders of each pair of parties, the Spearman rank correlation (ρ) was utilized. A threshold of ρ = 0.683 was established for this study, with a significance level of 0.95 and n=9. The Spearman rank correlations for all the groups are displayed in Table 15.

Tab.14 *Rank orders from all the surveys*

Rank	Results of completed projects (Actual causes of delays orders)	AHP survey results from project parties (Perceived causes of delays orders)			
		Piling subcontractors	Contractors	Consultants	Owners
1	External issues	External issues	External issues	Material	Material
2	Contractor	Material	Contractor	Contractor	External issues
3	Owner	Owner	Owner	External issues	Contractor
4	Communication	Consultant	Consultant	Owner	Consultant
5	Consultant	Contractor	Material	Consultant	Owner
6	Material	Communication	Communication	Communication	Communication
7	Interface	Labour	Interface	Interface	Interface
8	Labour	Interface	Contract	Contract	Contract
9	Contract	Contract	Labour	Labour	Labour

Tab.15 *Spearman rank correlation for all the parties (significance level= 0.95, n=9, rs=0.683)*

ρ	Completed projects	Piling subcontractors	Contractors	Consultants	Owners
Completed projects	-	0.733	0.933	0.7	0.683
Piling subcontractor	-	-	0.8	0.817	0.867
Contractor	-	-	-	0.817	0.817
Consultant	-	-	-	-	0.967
Owner	-	-	-	-	-

The rank order determined from the completed projects is a critical guideline because it reflects what actually occurred. The correlations of the rank orders between the completed projects and piling subcontractors (ρ=0.733), owners (ρ=0.683), and consultants (ρ=0.7) showed fairly good agreement. The results revealed that the perceived causes of delays orders determined from the piling subcontractors, consultants, and owners slightly aligned with the actual causes of delays orders. Additionally, there was a strong agreement between the actual causes of delays orders and those perceived by the contractors (ρ=0.933), indicating that the perceived causes of delays orders determined from the contractors were highly similar to the actual ones determined from the completed projects.

The perceived causes of delays orders determined from the contractors (ρ=0.8) and consultants (ρ=0.817) were slightly aligned with those determined from the piling subcontractors, while there was good agreement between those determined from the piling subcontractors and owners (ρ=0.817). The perceived causes of delay orders determined from the consultants (ρ=0.817) and owners (ρ=0.817) were slightly aligned with those determined from the contractors, and there was strong agreement between those determined from the consultants and owners (ρ=0.967). These results could be expected, given that their roles in implementing projects are often similar in most circumstances in precast concrete sheet pile retaining wall constructions.

6 FINDINGS AND DISCUSSIONS

The rank orders derived from "causes of actual delays" were closely aligned with those from "causes of perceived delays" and the rank orders in "causes of perceived delays" across all the project parties showed a strong positive correlation. This suggests that the rank orders based on "causes of actual delays" closely reflected real-world situations. Factors with high frequency occurrences were considered critical, and those with Relative Importance Indexes (RIIs) greater than 0.1 were identified as the top factors causing project delays. In order of ranking, these were: (1) act of God - bad weather, (2) mistakes during construction stage - wrong jobs, (3) unrealistic contract durations imposed by client, (4) lack of effective project control, and (5) difficulty of coordination between various parties working on the project. The discussions are as follows:

6.1 Act of God - bad weather (External issues-related)

With a RII of 0.885, "Act of God - bad weather" was ranked first.

Bad weather refers to natural phenomena that can affect construction activities, such as rain, snow, extreme temperatures, and strong winds. Numerous studies focusing on identifying causes of delays in linear construction have highlighted that adverse weather conditions are indeed a key factor. In road construction projects, bad weather is often unavoidable and typically leads to unfavorable site conditions (El-Rayes & Moselhi, 2001), reduces productivity, and extends durations of projects (Toriola-Coker et al., 2022; Ram & Paul, 2015). A study examining factors affecting productivity in Taiwan's highway construction activities even revealed that rainfall had the most significant adverse impact on durations of construction (Pan, 2005). However, weather conditions were not consistently identified as major factors in all the studies. As shown in Tables 1 and 2, the causes of delays vary by geographic region. Projects in areas with stable continental climates are less affected by weather conditions compared to those in tropical regions. Rainfall during the plum rain season from May to June (Central Weather Bureau Taiwan, 2022) and flooding caused by typhoons from July to October (Water Resources Agency Taiwan, 2017) make construction sites highly unsuitable for executing projects. Therefore, it is crucial for owners and consultants to account for weather conditions in planning the duration of projects.

6.2 Mistakes during construction stage - wrong jobs (Contractor-related)

With a RII of 0. 2528, “Mistakes during construction stage - wrong jobs” was ranked second.

The occurrence of “wrong jobs” during construction indicates that the work was either done improperly or did not comply with the specifications, which usually resulted in reworking and extensions to the construction period (Akomah & Jackson, 2016). The roots leading to reworking include project changes/errors, poor skills, poor quality management, poor use of information technology, and poor work capability. As shown in Figure 2, pile driving is relatively simple. However, some issues may still lead to major defects and result in reworking. Failing to ensure that piles are properly aligned with the intended location and reach the desired depths is a common cause of reworking. Other issues, such as encountering obstacles in the soil, neighborhood disturbances caused by the vibrations from pile driving, the loss of pile wall stability due to insufficient interlocking between piles (Eskandari & Kalantari, 2011), pile wall deformations caused by earth pressures during the piling process (Zhang et al., 2021), inconsistent soil mechanics on site (Bilgin et al., 2011; Tornborg et al., 2023), and instability of soil conditions due to sudden heavy rainfall (Fahmy & Schifano, 2023), can also lead to major defects and result in reworking.

6.3 Unrealistic contract durations imposed by client (Owner-related)

With a RII of 0.2212, “Unrealistic contract durations imposed by client” was ranked third.

“Unrealistic contract durations imposed by client” refers to inadequate construction scheduling, improper planning, ineffective project management, and poor time estimation. This issue has been identified as a risk to the success of projects in Taiwan’s construction industry (Lin & Chen, 2021). Numerous studies have also recognized it as one of the primary causes of delays in linear construction projects (Rivera et al., 2020; Ram & Paul, 2015; Nikjow et al., 2011; Seboru, 2015; Fallahnejad, 2013; Kayelle et al., 2023; Bajjou & Chafi, 2020). More importantly, it has been found to be the most significant root cause of change orders in linear construction projects (Halwatura & Ranasinghe, 2013), as well as a major source of conflict (Tariq & Gardezi, 2023) and interface problems (Chen et al., 2008; Al-Hammad, 2000) among project parties. Project owners are obligated to resolve interface issues that could affect project execution before determining the project duration (Lin & Jeng, 2017).

6.4 Lack of effective project control (Consultant-related)

With a RII of 0.1896, “Lack of effective project control” was ranked fourth.

Consultants play a vital role in the successful delivery of construction projects. Factors related to consultants that contribute to project delays include changes in quantity, delayed responses to environmental impact factors (Rivera et al., 2020), insufficient supervisory experience, mistakes or discrepancies in documentation, poor communication and coordination with other project stakeholders (Abdulghafour & Salman, 2023), design errors, and slow decision-making processes (Amarkhil et al., 2020). In Taiwan, according to the government document titled "Guidelines for Performing Quality Management of Public Construction Works" (Public Construction Commission Taiwan, 2023), consultants are responsible for ensuring proper procedures for construction inspections and maintaining quality-related documents and records. Adhering to these guidelines helps ensure project completion on schedule.

6.5 Difficulty of coordination between various parties working on the project (Communication-related)

With a RII of 0.1264, “Difficulty of coordination between various parties working on the project” was ranked fifth.

As mentioned in the previous section, although the success of pile driving primarily depends on driving technique and skill, other critical factors also contribute to construction failures. In Taiwan, the installation of prestressed concrete sheet piles is carried out entirely by the piling subcontractors, while the contractors are responsible for managing quality, schedules, and costs. Given this common practice, the collaboration between a skilled piling subcontractor and a contractor with strong abilities in fostering effective coordination, communication, and collaboration with other subcontractors is crucial for the success of a project (Hassan, et al., 2023).

7 CONCLUSIONS

The primary contribution of this study is identifying the major causes of delay in prestressed concrete sheet pile retaining wall projects in Taiwan. The top five factors were:

“act of God - bad weather (RII = 0.885)”, “mistakes during construction stage- wrong jobs (RII = 0.2528)”, “unrealistic contract durations imposed by client (RII = 0.2212)”, “lack of effective project control (RII = 0.1896)”, and “difficulty of coordination between various parties working on the project (RII = 0.1264)”. The study also revealed that the outbreak of the novel coronavirus disease (COVID-19) pandemic had no significant impact in terms of a shortage of skilled personnel (RII = 0.0632).

Based on these findings, the study suggests that all project parties should: (1) incorporate the effect of weather into construction scheduling, (2) in addition to experience, fully consider all factors that may affect the progress of a project to create more realistic construction schedules, (3) eliminate factors that may lead to reworking, (4) implement construction projects in accordance with government regulations, (5) select professional and skilled piling subcontractors, and (6) involve consultants with a high level of integration and coordination capabilities.

To the author’s knowledge, no previous study has addressed the causes of delay in precast concrete sheet pile retaining wall construction. As a limitation, the projects and questionnaire respondents involved in this study were limited to Taiwan, meaning the results may not be fully applicable to other regions. However, these findings may pave the way for further research.

List Of Symbols

A = the highest weight
N = the total number of respondents
d = the difference between the ranks of corresponding values Xi and Yi
n = number of values in each data set
ρ = Spearman rank correlation

List Of Abbreviations

AHP = Analytical Hierarchy Process
RII = Relative Importance Index
CI = consistency index
CR = consistency ratio
RI = the random index

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