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RISK MANAGEMENT OF TIE BACK REDESIGN ON THE CENGKARENG DRAIN

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Abstract

The coastal area of North Jakarta faces significant pressure due to land subsidence, sea level rise, and complex hydrodynamics. These conditions increase the risk of failure of coastal protection structures, especially in retaining walls with corrugated concrete sheet piles (CCSP). This study aims to analyze risk management in the redesign of the coastal protection tie-back system at the Cengkareng Drain site, DKI Jakarta. The research method combines qualitative and quantitative approaches through field observations, document studies, expert interviews, and risk analysis using Failure Mode and Effect Analysis (FMEA) and Analytic Hierarchy Process (AHP). The analysis results indicate that technical risks in the form of slope instability and lateral deformation of the CCSP are prioritized risks with a very high category. The application of the tie-back system in the redesign was able to reduce lateral deformation from 59.6 cm to 37.1 cm and increase the safety factor to 1.521. This study confirms that an integrated risk management approach is effective in supporting decision-making for more reliable and sustainable coastal protection structure redesign.

Keywords: Risk Management, Tie-Back, Redisign, FMEA, AHP.

INTRODUCTION

The vulnerable conditions of Jakarta's coast, characterized by land subsidence, sea level rise, and the dynamics of shoreline change, as described by BIG (2023), Kurniyaningrum et al. (2024), and Aniendra et al. (2020), serve as the primary basis for this research. Shoreline changes influenced by hydro-oceanographic processes, sediment transport, and land subsidence demonstrate that Jakarta's coastal protection system operates in a highly dynamic and constantly changing environment, as also emphasized by Nordstrom et al. (1986) and Melisa et al. (2020). These previous studies illustrate that abrasion, accretion, and coastal morphological instability are inseparable phenomena from urban coastal areas. In the context of Jakarta, these conditions are exacerbated by the presence of long-standing coastal protection infrastructure designed based on past geotechnical and hydrodynamic assumptions. A study of shoreline changes due to abrasion and landslides by Saily et al. (2025) further emphasizes that failure of coastal protection systems not only impacts the physical aspects of the coast but also has the potential to threaten the sustainability of coastal areas more broadly. On the other hand, various studies related to coastal protection structures and breakwaters, such as those conducted by Suh et al. (2011), Syamsuri et al. (2018), Thaha et al. (2015), and Sulaiman and Larasari (2017), show that structural performance is significantly influenced by the design, dimensions, materials, and environmental conditions in which the structure is constructed. These findings indicate that a mismatch between structural design and actual field conditions can reduce the effectiveness of coastal protection and increase the risk of failure. Based on this background, this study specifically focuses on redesigning coastal protection tie-back systems using a risk management approach. Unlike previous studies that focused more on analyzing shoreline changes or partial structural performance, this study integrates aspects of coastal dynamics, current geotechnical conditions, and technical, environmental, and operational risks within a single, comprehensive analytical framework. This approach is relevant considering that shoreline changes, abrasion, and structural degradation, identified by previous studies, directly impact the stability and reliability of tie-back systems. Therefore, this study serves as a bridge between shoreline change studies and coastal protection structural engineering studies. The results of previous studies serve as a basis for identifying key risk sources, while the analysis in this study is directed at formulating tie-back redesign solutions that are more adaptive and reliable to Jakarta's dynamic coastal conditions. This approach is expected to make a significant contribution to the development of a coastal protection system that is not only structurally sound but also sustainable and suited to the challenges of climate change in Jakarta's coastal areas.

LITERATURE REVIEW

Coastal Protection

Coastal protection is a protection system consisting of physical structures and non-structural approaches designed to maintain coastline stability and protect land areas from the dynamic effects of the ocean, such as waves, currents, tides, abrasion, and sea level rise. In the discipline of coastal engineering, coastal protection plays a strategic role in controlling the balance between erosion and sedimentation processes to maintain the natural functions of the coast while simultaneously protecting infrastructure and human activities in coastal areas. The existence of coastal protection structures is becoming increasingly important as environmental pressures increase due to climate change and anthropogenic activities in coastal areas. Technically, coastal protection structures are designed as an integrated system, with each component having a specific yet mutually supportive function. Retaining walls such as seawalls and revetments serve as the primary elements in resisting wave energy and ocean currents. Vertical seawalls are generally used in areas with limited space and function to directly resist wave energy, while inclined revetments utilize the slope and porosity of the material to dampen wave energy, making them more adaptable to dynamic hydrodynamic conditions. Both types of structures serve as the first line of defense against abrasion and tidal flooding. To increase the stability of a structure against lateral soil and water pressure, a tie-back system is used as an additional reinforcement element. Tie-backs work by distributing tensile forces to deeper, more stable soil layers, thereby reducing the potential for shifting or collapsing the retaining wall. In modern designs, this system is often combined with monitoring technology to continuously monitor structural stresses and deformations. Furthermore, structural stability is also significantly affected by the condition of the foundation, so toe protection is necessary to prevent seabed erosion caused by currents and waves. Another equally important component is the core and filter layers, which control water seepage and pore water pressure behind the structure. These layers prevent internal erosion (piping), which can lead to progressive structural failure. The outer protective layer (armor layer), typically consisting of large stones or interlocking concrete blocks, absorbs and reduces wave energy before it reaches the main structure. Drainage systems, supplementary structures such as aprons and parapets, and well-drained backfill also play a role in maintaining the overall stability and service life of coastal protection structures.

Redesign

Redesign is derived from the term "redesign," which means re-designing an existing product or structure with the aim of improving its performance, function, or reliability. Nugroho (2012) defines redesign as a redesign process that can involve changes to physical aspects, function, or both to achieve more optimal results. In the context of civil engineering, redesign is generally undertaken in response to the initial design's inconsistency with actual field conditions, changes in functional requirements, or the emergence of unanticipated technical risks. The implementation of a redesign must consider the relationship between the existing structure and the new elements added to ensure the system continues to function as an integrated system. Dibner (1985) states that there are several important aspects in the redesign process: the size and shape of the building, which must be designed in harmony with the initial structure; the availability and limitations of land; re-evaluation of the structural system to ensure its capacity to withstand additional loads; and adjustments to the mechanical and electrical systems to optimally support the function of the redesigned structure. In coastal protection planning, the concept of redesign cannot be separated from the classification of the type of coastal protection applied. In general, coastal protection can be categorized into four main groups: shoreline stabilization, backshore protection, inlet stabilization, and harbor protection. Each category has different problem characteristics and treatment approaches, depending on hydrodynamic and geotechnical conditions, as well as coastal land use patterns. Coastal problems can be structural, such as slope instability and structural failure, or non-structural, related to land use and human activities. Therefore, redesigning coastal protection requires a comprehensive approach that integrates technical, environmental, and managerial aspects to ensure effective and sustainable solutions.

METHOD

Case Study

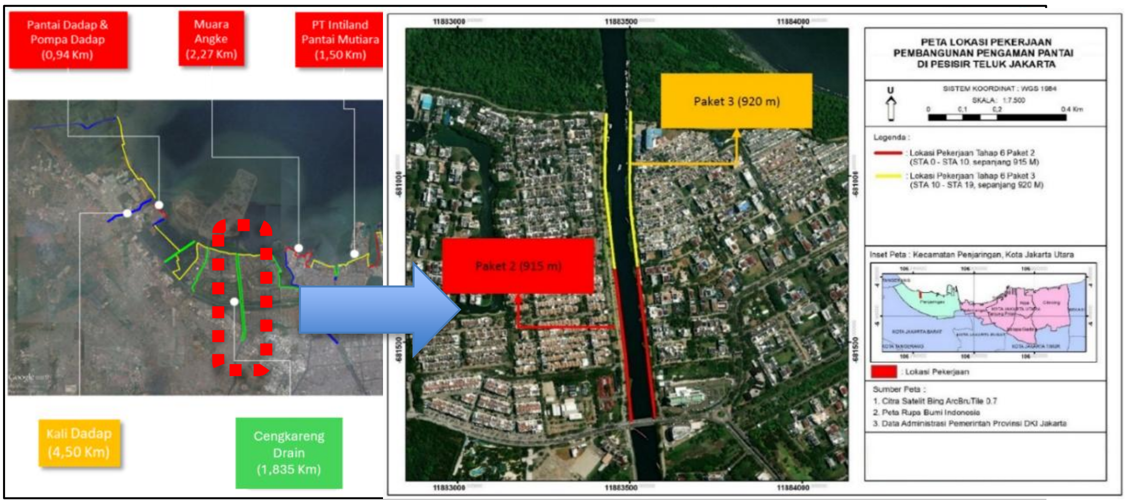

Figure 1. Study Case

The research locations for coastal protection projects in Jakarta are located in two provinces, namely Banten Province and DKI Jakarta Province, as further detailed in Figure 1. The locations in Banten Province are: Dadap River, Dadap Beach, and Dadap Pump. The locations in DKI Jakarta Province are Cengkareng Drain, Muara Angke, Mutiara Beach, East Muara Baru, Sunda Kelapa Port, Tanjung Priok, West Kali Baru, East Kali Baru, Cakung Drain, Blencong River, and Marunda. This research on coastal protection projects in Jakarta only discusses the Cengkareng Drain location located in Kamal Muara and Kapuk Muara Villages, Penjaringan District, North Jakarta Administrative City.

Research Variables

Table 1. Indicator Risk

No.	Variable	Indicators	Sources
1	Technical	Slope stability; Soil bearing capacity; Material specifications; Elevation; Slope inclination; Availability and quality of materials; Readiness and maintenance	Putera et al. (2019); Gunawan et al. (2006)
2	Environmental	Changes in storage capacity; Erosion and sedimentation; Impacts on local biodiversity; River flow pattern; Aquatic ecosystem disturbance; Soil erosion; Pollution; Ecosystem changes; Social disturbance	Gunawan et al. (2006); Meylani (2018)
3	Construction	Delays due to design changes; Increase in construction costs; Mobilization of heavy equipment and additional materials; Project site accessibility	Meylani (2018); Gunawan et al. (2006)
4	Occupational Health and Safety (OHS)	Increased work accidents due to changes in construction methods; Safety risks in steep slope works; Worker fatigue due to increased workload	Nata et al. (2016); Yuliana (2017)
5	Operational	Decreased efficiency of irrigation function; Disturbance to flood control systems; Adjustments to raw water management systems	Nata et al. (2016)
6	Administrative and Regulatory	Permitting and environmental impact assessment (EIA) documents; Land use compliance; Technical approvals	Meylani (2018)

The research methodology in this study was designed in a structured and systematic manner to ensure that the risk analysis for the coastal protection tie-back redesign was measurable and scientifically reliable. The research began with problem identification and a preliminary study to understand existing coastal protection conditions through literature review, technical documents, and initial evaluation of structural issues. This was followed by data collection, comprising primary data from field observations, expert interviews, and questionnaires, as well as secondary data from design documents, soil investigation reports, numerical analyses, and relevant literature. Subsequently, potential risks related to technical, environmental, construction, occupational health and safety, operational, and regulatory aspects were identified. Risk analysis and assessment were then conducted using the Failure Mode and Effect Analysis (FMEA) method to determine risk levels and the Analytic Hierarchy Process (AHP) to establish risk priorities based on expert judgment. High-priority risks were further evaluated through technical analysis, particularly by comparing structural performance before and after the tie-back redesign. The final stage involved formulating risk control and mitigation strategies aimed at reducing the likelihood and impact of critical risks while enhancing structural safety and sustainability.

RESULTS AND DISCUSSION

This chapter presents comprehensive research results and discussions based on field data, technical documents, numerical analysis, and risk assessments conducted on the coastal protection project at the Cengkareng Drain site in DKI Jakarta. The discussion focuses on the existing condition of the structure and soil, identification of key issues, the results of the technical and risk analysis, and the implications of implementing tie-back redesign on the structure's performance and safety.

Existing Structure and Soil Conditions

Field observations and a review of technical recommendation documents indicate that the coastal protection structure at the study site utilizes 17 m long W-400 Corrugated Concrete Sheet Piles (CCSP) combined with red soil fill to an elevation of +3.00 m. The subgrade at the Cengkareng Drain site is dominated by a silty clay layer to a depth of approximately 14 m, with an average N-SPT value of approximately 10, indicating moderate to low soil bearing capacity. These soil characteristics are not ideal for withstanding the significant lateral pressures caused by the fill and additional loads from construction activities.

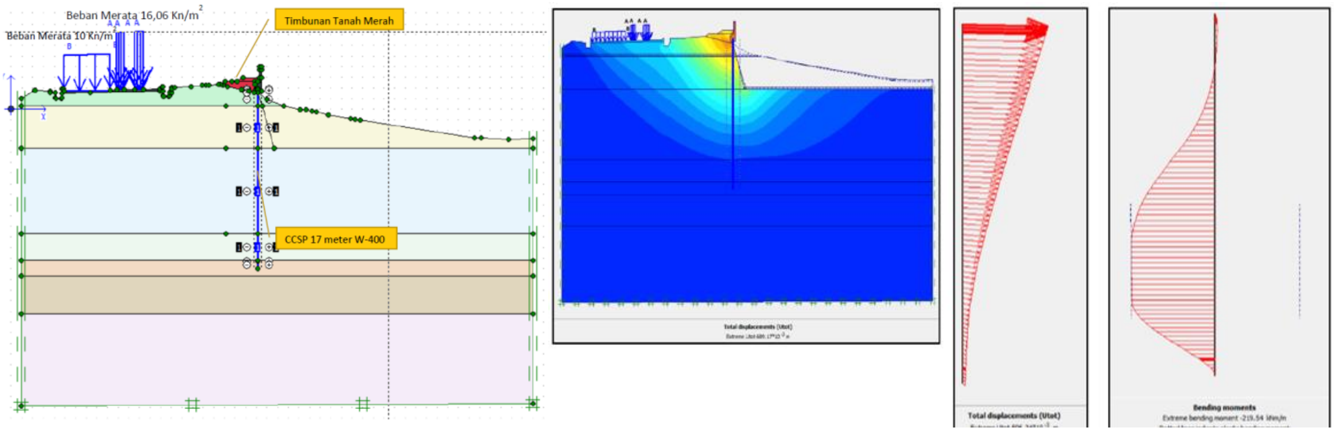

Figure 2. Results of lateral deformation modeling without tie back

Initial geotechnical analysis indicated that the existing design lacked additional reinforcement systems such as tie-backs or toe protection in several segments. Furthermore, variations in seabed elevation and uneven soil conditions led to an uneven distribution of lateral pressure on the CCSP. This condition triggered significant lateral deformation and potentially reduced the overall stability of the coastal protection structure.

Identification of Key Issues

Based on field observations and technical evaluations, the main issues underlying the need for tie-back redesign can be identified as follows. First, lateral deformation of the CCSP exceeded technical tolerances. PLAXIS numerical modeling results indicated a maximum lateral deformation of 59.6 cm in certain segments, a value far exceeding the performance criteria for coastal protection structures. Second, the low bearing capacity of the subgrade was unable to withstand the combined load of the embankment and the lateral pressure of seawater. Third, the initial implementation method did not fully consider actual geotechnical conditions and the limited work space in the field. Fourth, coastal environmental pressures in the form of currents, tides, and potential erosion accelerated the degradation of the structure's stability.

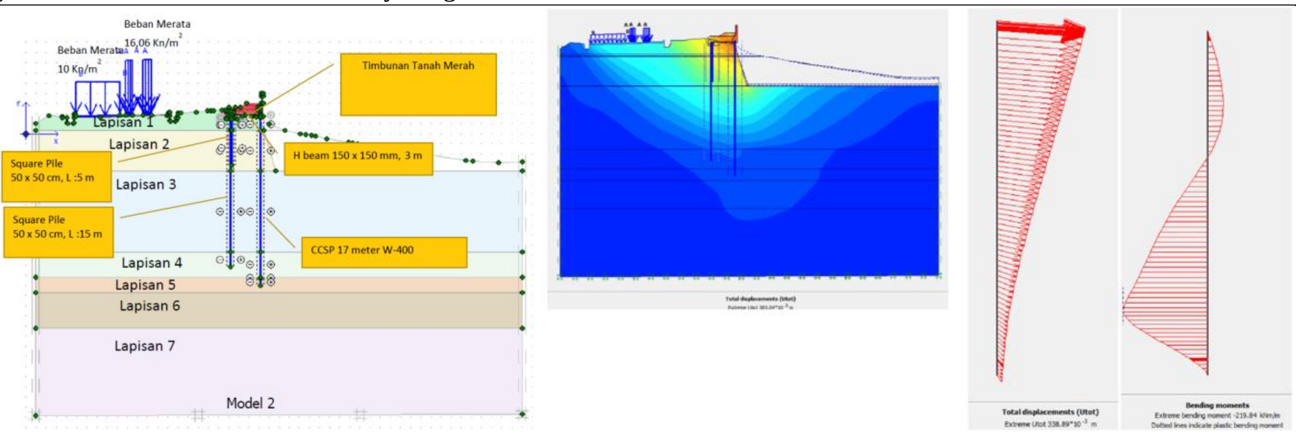

Figure 3. Results of lateral deformation modeling with tie back

These problems are interrelated and create a high-risk situation that could lead to structural failure if appropriate redesign interventions are not implemented immediately.

Technical Analysis Results

A technical analysis was conducted using numerical modeling to evaluate the structural performance before and after the implementation of the tie-back system. In the untied condition, the CCSP experienced significant lateral displacement seaward due to the pressure of the red soil fill and water pressure. The maximum deformation of 59.6 cm indicated that the structure was unstable and at high risk of progressive failure. After the redesign with the addition of the tie-back system, the analysis results showed a significant improvement in structural performance. The lateral deformation decreased to 37.1 cm, and the safety factor increased to 1.521, which is above the minimum required value (SF > 1.5). This reduction in deformation indicates that the tie-back system was effective in distributing lateral forces to more stable soil layers, thereby reducing the direct load on the CCSP. These results confirm that tie-back redesign is an appropriate technical solution to address structural instability issues in soft soil conditions and dynamic coastal environments.

Risk Analysis Results

The risk analysis was conducted with experts through focus groups (FGDs) and questionnaires to assess the likelihood and impact of various risk indicators. The assessment results indicate that technical variables are the most dominant source of risk, categorized as very high, particularly the risk of slope instability and low soil bearing capacity. These risks carry the highest risk rating because they have the potential to directly cause structural failure. Regarding environmental variables, the risk of erosion and toe erosion is categorized as very high. Erosion has the potential to reduce soil support on the CCSP foundation and accelerate deformation. Other environmental risks, such as sedimentation, changes in flow patterns, and ecosystem disruption, are categorized as moderate, but still require control to ensure the sustainability of the structure and the environment. Significant construction risks include implementation delays due to design changes and difficulties mobilizing heavy equipment on soil with low bearing capacity. Limited site access and the location in a densely populated area increase the potential for delays and increased construction costs. In terms of occupational health and safety (OHS), the risk of heavy equipment instability and potential work accidents are categorized as very high, necessitating the implementation of stricter OHS procedures during the redesign. The AHP weighting results indicate that technical risks have the highest priority, followed by OHS and construction risks. This finding confirms that technical risk control should be a primary focus in coastal protection redesign.

Table 2. Technical Risk Assessment

No.	Technical Risk	Likelihood (L)	Impact (I)	Risk Level (L×I)	Category
1	Structural and slope instability (lateral deformation of 59.6 cm)	5	5	25	Very High
2	Moderate soil bearing capacity (N-SPT = 31)	5	4	20	Very High
3	Inadequate material specifications (absence of base reinforcement)	4	4	16	High
4	Incompatibility of elevation and embankment slope	4	3	12	Medium–High

Table 3. Environmental Risk Assessment

No.	Environmental Risk	Likelihood (L)	Impact (I)	Risk Level (L×I)	Category
1	Erosion and scouring at the structure toe	4	5	20	Very High
2	Sedimentation and changes in flow pattern	3	3	9	Medium
3	Ecosystem disturbance due to construction activities	3	2	6	Medium

Table 4. Construction Risk Assessment

No.	Construction Risk	Likelihood (L)	Impact (I)	Risk Level (L×I)	Category
1	Project delays due to unfeasible initial design	4	4	16	High
2	Difficult mobilization of heavy equipment (soft soil and limited access)	5	4	20	Very High
3	Cost adjustments due to additional reinforcement works	3	3	9	Medium

Table 5. Occupational Health and Safety Risk Assessment

No.	Occupational Health and Safety Risk	Likelihood (L)	Impact (I)	Risk Level (L×I)	Category
1	Heavy equipment instability on soils with moderate bearing capacity	5	5	25	Very High
2	Work on unstable slopes (local sliding)	4	4	16	High
3	Worker fatigue due to prolonged working duration	3	2	6	Medium

Discussion of the Implications of Tie-Back Redesign

The results of the Analytic Hierarchy Process (AHP) analysis provide a clear hierarchy of risk priorities that influence the redesign of the tie-back system for the coastal protection structure at Cengkareng Drain. The weighting process, derived from expert judgments with acceptable consistency, demonstrates how different risk aspects contribute to decision-making and highlights the dominant factors requiring primary attention. For each criterion (Technical, Construction Implementation, K3, and Environmental), five alternative mitigation measures were assessed, including:

Alternatives:

1. A1 = Tie-Back Installation
2. A2 = H-Beam + Concrete Beam Installation
3. A3 = Geotextile Installation on Red Soil Embankment
4. A4 = Square Pile Installation
5. A5 = Reinforcement Combination

Table 6. Pairwise matrix against technical criteria

A(K1)	A1	A2	A3	A4	A5	weights
A1	1	1/3	3	5	1/5	0.118
A2	3	1	5	7	1/3	0.298
A3	1/3	1/5	1	3	1/7	0.034
A4	1/5	1/7	1/3	1	1/9	0.010
A5	5	3	7	9	1	0.540

Based on the results above, the following conclusions are drawn:

1. The combination of reinforcement (H-Beam + Concrete Beam) is superior because it produces the greatest reduction in deformation.
2. The combination of reinforcement (H-Beam + Concrete Beam) tied to a Square Pile is the single most effective method for resisting lateral forces.
3. Tie-backs are effective only when field conditions permit anchorage.

4. Geotextiles are effective as a support, not the primary solution.

The analysis indicates that the technical aspect holds the highest priority weight, accounting for 42% of the overall importance. This dominant weighting reflects the critical role of structural performance in coastal protection systems, particularly under soft soil conditions and significant lateral loading. Experts consistently emphasized that excessive lateral deformation and slope instability represent the most immediate threat to structural safety. This perception is strongly supported by numerical modeling results, which showed a lateral deformation of 59.6 cm in the existing condition without tie-back reinforcement. Consequently, technical risks form the foundation of the redesign decision, as failure to address these risks would render mitigation efforts in other aspects ineffective. The occupational health and safety (K3) aspect ranks second with a weight of 26%, underscoring the strong interrelation between structural instability and worker safety. The high weighting assigned to K3 reflects the hazardous nature of construction activities on soft soils and unstable slopes, particularly during heavy equipment operation. Experts recognized that technical deficiencies directly amplify safety risks, such as equipment overturning and slope failure, which may lead to severe accidents. Therefore, the prioritization of K3 highlights that safety considerations are not secondary outcomes, but integral components of the redesign strategy.

The construction aspect, with a weight of 19%, occupies the third level of priority. Risks within this aspect are primarily associated with constructability issues, including difficulties in mobilizing heavy equipment, design changes during implementation, and cost adjustments due to additional reinforcement requirements. Although these risks significantly affect project schedule and budget performance, experts considered them less critical than risks that could directly lead to structural failure or serious safety incidents. Nevertheless, the relatively substantial weight assigned to construction risks indicates that practical feasibility remains an important consideration in the redesign process. The environmental aspect has the lowest priority weight at 13%, reflecting its more indirect influence on immediate project outcomes. While environmental risks such as erosion, scouring, and ecosystem disturbance are recognized as important, their impacts are generally long-term and progressive. Experts assessed that these risks, although significant, could be effectively managed once the primary technical and safety issues were adequately addressed. However, the weighting does not imply that environmental aspects are negligible; rather, it suggests that they function as supporting factors that may exacerbate technical risks if left unmanaged.

Further analysis of sub-criteria reinforces the dominance of structural and slope instability within the technical aspect, followed by soil bearing capacity, confirming that ground conditions and structural response are the principal drivers of risk. Similarly, within the K3 aspect, heavy equipment instability emerged as the most critical safety concern. These findings demonstrate strong consistency between the AHP results, the risk assessment matrix, and the numerical analysis outcomes. Overall, the AHP analysis provides a coherent and defensible basis for prioritizing risks in the redesign of the coastal protection structure. The results clearly justify the selection of the tie-back system as the primary mitigation measure, as it directly addresses the highest-weighted risks related to structural stability and safety. By focusing on the most influential risk aspects, the redesign approach enhances the reliability, safety, and long-term performance of the coastal protection system under complex geotechnical and environmental conditions.

Tabel 7. Ranking of criteria weights

Alternatif	weights	Ranking
A5- Kombinasi perkuatan	0.521	1
A2- H-Beam + Balok Beton	0.327	2
A1- Tie Back	0.122	3
A3- Geotekstile	0.021	4
A4- Square Pile	0.009	5

CONCLUSION

1. Based on the risk identification results, there are four main risk groups affecting the tie-back redesign process: technical risks, environmental risks, construction risks, and occupational safety (OHS) risks. Technical risk indicators include slope instability, lateral deformation of the structure, low soil bearing capacity, non-conforming material specifications, slope elevation and slope conditions, and the availability of reinforcement materials. Environmental risk indicators include erosion and sedimentation, changes in flow capacity, and disruption to the local ecosystem. Construction risks include limited space, obstacles to heavy equipment mobilization, and potential delays due to design changes. Meanwhile, OHS risks relate to the potential for accidents in narrow work areas and unstable, soft ground conditions.
2. The results of the FMEA (risk analysis) analysis method indicate that the highest priority risk is the technical risk of slope instability and lateral deformation of the structure, triggered by the very low bearing capacity of the

subgrade and high lateral soil pressure. The next priority risk is limited space for tie-back installation, which makes the initial design unsuitable for certain segments. OHS risks are also a priority due to the high potential for work accidents in confined areas and the soil's susceptibility to subsidence. These three risks are the primary determinants of the need to review the design and implement mitigation strategies that are more adaptive to field conditions.

3. Based on the AHP analysis, the most effective control measure is the application of a combination of reinforcement, including the installation of H-Beams and concrete beams, the use of geotextiles to spread the load, and the installation of square piles to increase the shear strength of the soil. This combination of reinforcement is the primary solution because it addresses lateral deformation issues, increases subgrade stability, and can be implemented even when working space is very limited. The next control alternative is the use of H-Beams and concrete beams as the sole reinforcement in segments requiring reinforcement of the structural toe. Meanwhile, the tie-back method can only be used in areas that meet space requirements and have sufficiently stable soil conditions. Additional controls are implemented through increased work safety, access arrangements, and deformation monitoring during and after structure installation.

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