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Manajemen Proyek Dan Ketahanan Struktur Pesisir: Studi Eksploratif Di Kabupaten Karawang

Project Management And Coastal Structure Resilience: An Exploratory Study In Karawang Regency

Wuwuh Asrining Puri[a], M. Adik Rudianto[b], Rakhmad Wahyudi[c], Hafizh Fianto Putra[d]
Universitas Islam Majapahit, Mojokerto, Indonesia[a,b,c,d]
[a]asriningpuriw7@gmail.com, [b]adikrudianto4@unim.ac.id,
[c]rakhmad_wahyudi4@gmail.com, [d]hafizhfp@unim.ac.id

Abstract

Coastal protection structures such as breakwaters and groins are essential for mitigating shoreline erosion along Indonesia's vulnerable coastlines, including the Karawang coast on the north coast of Java. This study explores the relationship between project management practices and the resilience of coastal protection structures through an exploratory case study of eight breakwater and groin projects in Karawang. Data were collected using structured surveys administered to project managers and technical personnel, complemented by field assessments of structural condition and functional performance. These indicators were combined into a Coastal Structure Resilience Index (CSRI), a composite measure of each structure's physical integrity and functional effectiveness. Descriptive and regression analyses indicate a positive association between project management performance and structural resilience, with quality management appearing as the most prominent directional factor. Due to the limited sample size, the results should be considered exploratory rather than statistically conclusive. Nevertheless, the findings suggest that projects characterized by stronger quality control and schedule management tend to achieve better long-term structural conditions. The study highlights the potential importance of effective project management in coastal infrastructure resilience and recommends broader studies across multiple Indonesian coastal regions to support more robust conclusions.

Keywords: *Coastal Erosion, Coastal Structure Resilience, Construction Performance, Karawang, Project Management Quality*

Abstrak

Struktur pelindung pantai seperti pemecah gelombang (*breakwater*) dan groin berperan penting dalam mengurangi erosi garis pantai di wilayah pesisir Indonesia yang rentan, termasuk pesisir Karawang di pantai utara Jawa. Penelitian ini mengeksplorasi hubungan antara praktik manajemen proyek dan ketahanan struktur pelindung pantai melalui studi kasus eksploratif terhadap delapan proyek pemecah gelombang dan groin di Karawang. Data dikumpulkan menggunakan survei terstruktur yang diberikan kepada manajer proyek dan personel teknis, serta dilengkapi dengan penilaian lapangan terhadap kondisi fisik dan kinerja fungsional struktur. Indikator-indikator tersebut kemudian digabungkan ke dalam *Coastal Structure Resilience Index* (CSRI), yaitu ukuran komposit yang merepresentasikan integritas fisik dan efektivitas fungsional masing-masing struktur. Analisis deskriptif dan regresi menunjukkan adanya hubungan positif antara kinerja manajemen proyek dan ketahanan struktur, dengan manajemen mutu tampak sebagai faktor yang memiliki arah pengaruh paling menonjol. Mengingat ukuran sampel yang terbatas, hasil penelitian ini perlu dipandang sebagai temuan eksploratif dan belum dapat dianggap sebagai bukti yang konklusif secara statistik. Meskipun demikian, temuan ini mengindikasikan bahwa proyek yang menerapkan pengendalian mutu dan pengelolaan jadwal yang lebih baik cenderung menghasilkan kondisi struktur yang lebih baik dalam jangka panjang. Penelitian ini menyoroti potensi pentingnya manajemen proyek yang efektif dalam meningkatkan ketahanan infrastruktur pesisir serta merekomendasikan dilakukannya penelitian yang lebih luas di berbagai wilayah pesisir Indonesia guna menghasilkan kesimpulan yang lebih kuat.

Kata Kunci: Erosi Pantai, Ketahanan Struktur Pantai, Kinerja Konstruksi, Karawang, Kualitas Manajemen Proyek

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1. Introduction

Indonesia possesses approximately 55,000 km of coastline, exposing millions of people to coastal hazards, particularly shoreline erosion. Along the north coast of Java (*pantai utara Jawa* or Pantura), erosion is a persistent problem driven by wave action, sediment transport, tidal dynamics, and anthropogenic pressures such as mangrove degradation, sand mining, and land subsidence (Arjasakusuma et al., 2021; Fajar & Helmi, 2026; Intergovernmental Panel on Climate Change (IPCC), 2022).

Karawang Regency, located in the Pantura corridor of West Java, is among the areas most affected. Shoreline change analyses indicate that abrasion exceeded accretion during 1988–2015, resulting in annual land losses exceeding 15 ha, with projections suggesting approximately 118 ha of coastal land could be lost between 2018 and 2028 if current trends continue (Fauzie, 2017; Nandaniko et al., 2019). Impacts extend beyond land loss to agricultural disruption, settlement vulnerability, and environmental degradation (Nugraha et al., 2021), leading to Karawang's classification as a highly vulnerable coastal region requiring sustained protection efforts (Handiani et al., 2022).

To mitigate erosion, coastal protection measures including offshore breakwaters, groins, and rehabilitation programs have been constructed along the Karawang coastline (Nopiana et al., 2020). Breakwaters and groins are considered suitable structural solutions for local conditions, reducing wave energy and regulating longshore sediment transport (Pasaribu et al., 2021). Nevertheless, continued erosion indicates that the long-term effectiveness of these structures remains a significant challenge.

While engineering design is fundamental to coastal protection performance, structural resilience is also shaped by project management during construction. Coastal infrastructure projects in Indonesia frequently encounter delays, budget limitations, and quality-control challenges, and inadequate construction practices, insufficient supervision, and poor material quality have similarly been linked to premature deterioration and reduced service life of infrastructure assets (Nolan et al., 2021; Nurhidayah et al., 2022; Okoh et al., 2024).

Effective time, cost, and quality management are consistently linked to improved construction project outcomes (Hasibuan et al., 2025; Maw et al., 2025). However, studies of coastal protection structures in Indonesia have largely focused on hydraulic and structural performance, including wave attenuation, armor stability, sediment dynamics, and overtopping, while the influence of project management on long-term structural resilience remains underexplored (Santoso et al., 2026). Consequently, limited evidence exists regarding which managerial factors are most closely associated with sustained asset performance.

This study addresses that gap through an exploratory quantitative investigation of eight breakwater and groin projects along the Karawang coastline. It examines the relationships between time, cost, and quality management and structural resilience, evaluates the implementation of project management practices across the sampled projects, and identifies the managerial dimension most strongly associated with observed structural performance. Given the limited sample size, the findings are exploratory and hypothesis-generating and are offered as a foundation for future studies with larger datasets and broader geographic coverage.

2. Literature Review

Coastal erosion is a globally pervasive hazard, particularly along densely populated, low-lying coastlines of developing nations where natural recovery capacity is limited and the socioeconomic costs of land loss are high (Portz et al., 2024). Hard engineering structures, including breakwaters, groins, seawalls, and revetments, have historically been the dominant response in locations where the rate of shoreline retreat demands immediate physical intervention. Breakwaters intercept incoming wave energy offshore, creating sheltered zones where sediment accumulates and shoreline retreat is reduced. Groins function perpendicular to the shoreline by interrupting longshore sediment transport, thereby promoting updrift accretion, although poor design can accelerate downdrift erosion (Angnuureng et al., 2023). For the Karawang coastline specifically, technical analysis of wave climate, bathymetry, and topography has identified a combination of breakwaters and groins as the most appropriate structural response (Pasaribu et al., 2020).

However, design alone does not guarantee long-term effectiveness. Common failure pathways include armor layer instability under wave loading beyond design parameters, progressive toe scour, and deterioration resulting from deficiencies in concrete quality (Stagnitti et al., 2022). Placement errors that deviate from design specifications similarly reduce hydraulic stability and accelerate deterioration (Utami et al., 2023). These pathways illustrate the technical mechanisms through which poor construction execution, which is the focus of this study, leads to reduced structural resilience.

Project management in construction is broadly defined as the coordination of resources and activities to deliver a defined scope within time, cost, and quality constraints, commonly referred to as the “Iron Triangle” that underpins project performance assessment in both practice and research (Atkinson, 1999; Ofori, 2013). Time management covers schedule planning and delay control. In coastal contexts, this aspect is further complicated by limited weather windows for offshore or intertidal work (Nassar & Elbisy, 2024). Cost management encompasses budgeting and expenditure control and is commonly undermined by poor scope definition and inaccurate cost estimates (Albtoush et al., 2020). Quality management involves the supervision and verification processes that ensure the completed structure conforms to design specifications, with failures typically attributed to inadequate supervision, insufficient training, or improper material use (Ford et al., 2023). Because these three dimensions are interdependent, schedule or budget pressures can compromise quality control in practice. This dynamic has particularly significant consequences for assets such as coastal protection structures, which are designed to remain in service for 25 to 50 years and incur substantial costs when failures occur (Simm et al., 2021; Sørensen & Burcharth, 2004).

While the link between project management quality and general construction success is well established, its connection to the long-term physical performance of the completed asset, particularly in coastal engineering, remains underexplored (Mashwama & Phesa, 2025). Most performance frameworks in construction management emphasize delivery outcomes, such as schedule adherence, cost performance, and client satisfaction, rather than post-completion structural behavior. As a result, a project can be delivered on time and within budget while still producing a structure that underperforms because of quality compromises made during execution. This gap is particularly consequential in Indonesia, where systemic weaknesses, including fragmented contracting, inadequate site supervision, procurement irregularities, and short-duration contracts, have been documented across infrastructure sectors (Abiad & Teipelke, 2017; Mohamed et al., 2019). Coastal protection structures in Indonesia also face continuous exposure to waves, tides, and corrosive marine conditions, making their long-term performance highly dependent on construction quality.

Prior research on coastal protection in Karawang and the broader Pantura region has focused on shoreline erosion trends, hydraulic performance of structures, and engineering countermeasure design (Fauzie, 2017; Haryani et al., 2021; Miyagawa et al., 2025; Setyandito et al., 2020; Solihuddin et al., 2021). None of this work has examined project management performance during construction as a factor in the long-term resilience of the resulting structures, a gap this study addresses directly.

Accordingly, this study investigates whether project management quality, operationalized through the Iron Triangle dimensions of time, cost, and quality, is associated with the structural resilience of coastal protection structures in Karawang, providing preliminary empirical evidence from an understudied coastal context.

Given the exploratory nature of this study and the constraints of a small purposive sample, formal statistical hypotheses are not considered appropriate. Instead, the following propositions guide the analysis:

$\mathbf{P_1}$: Projects demonstrating stronger time management practices are expected to be associated with higher coastal structure resilience scores.

$\mathbf{P_2}$: Projects demonstrating more disciplined cost management practices are expected to be associated with higher coastal structure resilience scores.

$\mathbf{P_3}$: Projects demonstrating more rigorous quality management practices are expected to be associated with higher coastal structure resilience scores.

These propositions are examined through descriptive and regression-based analyses. Given the exploratory scope and limited sample size, findings are interpreted as preliminary evidence of potential relationships rather than definitive causal conclusions.

3. Methodology

Research Design

This study employs a quantitative, explanatory research design to examine the relationship between project management practices, namely time, cost, and quality management, and the resilience of coastal protection structures along the Karawang coastline. Study sites were purposively selected from coastal segments where breakwaters and groins have been constructed as part of erosion mitigation efforts along the north coast of Karawang Regency, West Java. An explanatory design is adopted because the study examines directional relationships between project management variables and a composite Coastal Structure Resilience Index (CSRI), rather than merely describing existing conditions.

Research Location and Objects

The study was conducted at eight locations along the Karawang coastline designated as priority areas for erosion mitigation, each containing an operational breakwater or groin constructed under separate project contracts. Offshore breakwaters dissipate incoming wave energy before it reaches shore, reducing wave height and creating sheltered zones conducive to sediment accumulation; groins, constructed perpendicular to the shoreline, interrupt longshore sediment transport to stabilize shoreline position. Each structure is evaluated from two perspectives: a technical perspective (physical condition and functional performance via field observation) and a managerial perspective (project management quality via structured questionnaires administered to project personnel).

Population and Sample

The target population consists of breakwater and groin projects constructed along the Karawang coastline within the study's scope. Eight projects were selected via purposive sampling based on: (1) sufficiently complete planning and construction documentation to assess managerial practices, (2) at least one to two years of operational history to allow initial performance evaluation, and (3) accessibility of project personnel for questionnaire administration.

A three-predictor regression model applied to eight observations yields only four degrees of freedom for error, meaningfully limiting the precision of coefficient estimates and the reliability of significance tests. Results are therefore interpreted as directional and indicative rather than confirmatory, providing a preliminary basis for future research with larger samples across multiple Indonesian coastal regions.

For each project, questionnaire respondents were drawn from personnel directly involved in project execution, including project managers, site engineers, field supervisors, and owner representatives. A minimum of two respondents was targeted for each project to enable partial cross-validation. Where fewer than two respondents were available, supplementary information was obtained through document review and brief structured interviews.

Types and Sources of Data

Primary data comprised (1) questionnaire responses on time, cost, and quality management implementation, providing scores for X_1, X_2, and X_3, and (2) respondents' structured assessments of physical and functional condition, forming the basis of the CSRI (Y). Secondary data comprised technical planning documents (hydro-oceanographic analyses, design drawings, technical justifications) and post-construction monitoring reports, used to triangulate primary assessments. Where monitoring reports were incomplete or unavailable, primary respondent assessments carried proportionally greater weight, a noted source of potential assessment bias.

Research Variables and Operational Definitions

Three independent variables represent distinct dimensions of project management quality.

Time Management (X_1) measures schedule management effectiveness, including baseline schedule preparation, progress monitoring, delay management (including weather- and wave-related delays), and coordination meeting regularity.

Cost Management (X_2) measures budget control effectiveness, including cost estimation quality, expenditure monitoring, cost-overrun management, and documentation of budget adjustments from scope changes.

Quality Management (X_3) measures quality assurance/control implementation, including specification compliance, material testing and verification, supervision of armor unit placement, and inspection documentation completeness.

All variables are measured on a five-point Likert scale (1 = Very Poor to 5 = Very Good), with each variable's score calculated as the mean of its questionnaire items.

Coastal Structure Resilience (Y) is operationalized as the Coastal Structure Resilience Index (CSRI), a composite of Physical Condition and Functional Performance, converted to a 0–100 Relative Resilience Index for regression analysis (detailed below).

Research Instrument: Project Management Questionnaire

Items were developed from the *PMBOK® Guide* (7th ed.) (Project Management Institute [PMI], 2021), adapted to the Indonesian coastal construction context using Soeharto's framework (Soeharto, 1999), consistent with prior Likert-scale survey research in Indonesian construction (Marleno et al., 2018; Willar et al., 2015).

Time Management Items (X_1)

- X1.1: The project implementation schedule was prepared in a detailed and realistic manner at the outset, accounting for seasonal wave conditions and work window constraints.
- X1.2: Construction activities were carried out according to the planned schedule without significant delays affecting the critical path.
- X1.3: Delays from adverse weather, wave conditions, or material supply disruptions were identified promptly and managed through documented corrective actions.
- X1.4: Schedule coordination meetings were conducted regularly and properly documented.

Cost Management Items (X_2)

- X2.1: The project budget was prepared using detailed and realistic cost estimates reflecting coastal construction requirements.
- X2.2: Expenditures were monitored regularly against the approved budget at defined intervals.
- X2.3: Significant cost overruns occurred that were not adequately controlled or documented. (Reverse-scored.)
- X2.4: Design or volume changes were accompanied by formal, documented budget adjustments reviewed by the project owner.

Quality Management Items (X_3)

- X3.1: Clear quality assurance procedures and inspection protocols were established and consistently implemented.
- X3.2: Armor materials were tested and verified for weight, gradation, and durability compliance prior to placement.
- X3.3: Armor unit installation followed approved construction methods, layer thicknesses, and placement patterns.
- X3.4: Complete documentation was maintained for material testing, field inspections, and non-conformance resolutions.

Item X2.3 is reverse-scored prior to averaging so that higher scores uniformly indicate better management practice.

Development of the Coastal Structure Resilience Index (CSRI)

The CSRI operationalizes structural resilience by integrating two dimensions: Physical Condition and Functional Performance.

Physical Condition Index (PCI) assesses physical deterioration via field observation of armor layer damage, core deformation/settlement, and damage to secondary elements (geotextile layers, toe aprons, capping). Scoring is inverse (lower = better): 1 = Excellent (no visible damage) through 5 = Very Poor (severe damage, rehabilitation required).

Functional Performance Index (FPI) assesses continued fulfillment of protective function via observed shoreline change (accretion vs. erosion), wave overtopping/transmission relative to design intent, and available sediment/shoreline monitoring data, using the same inverse 1–5 scale.

Following condition-index frameworks used in civil infrastructure assessment (Amani et al., 2012), CSRI is calculated as in Equation (1):

$$CSRI = w_1 \times PCI + w_2 \times FPI, \tag{1}$$

where $w_1 + w_2 = 1$. This study assigns equal weights ($w_1 = w_2 = 0.5$) in the absence of empirical or expert basis for differential weighting, a conservative default that future research with larger samples could refine through expert elicitation or sensitivity analysis. To the authors' knowledge, no comparable composite index has previously been developed for coastal protection structures in Indonesia; the CSRI is proposed here as a novel instrument for this exploratory study.

CSRI values are classified as: $1 \leq CSRI \leq 1.5$ (Good, routine monitoring); $1.5 < CSRI \leq 2.5$ (Fair, routine maintenance/minor repairs); $CSRI > 2.5$ (Poor, comprehensive review and rehabilitation required).

For regression analysis, CSRI is converted to a sample-relative Relative Resilience Index (Y) on a 0–100 scale as in Equation (2):

$$Y = \frac{CSRI_{max} - CSRI}{CSRI_{max} - CSRI_{min}} \times 100, \tag{2}$$

where Y = 100 represents the most resilient structure in the sample and Y = 0 the least. It should be noted that Y values cannot be compared directly between studies with different samples.

Data Collection Procedures

Data were collected in four stages. (1) Document review: technical planning documents and post-construction reports were reviewed for design parameters, construction specifications, and available performance evaluations. (2) Field survey: site visits documented armor layer condition, deformation, shoreline condition, and indicative overtopping/transmission behavior. (3) Questionnaire administration: structured questionnaires were distributed to project personnel and reviewed for completeness upon collection, with follow-up for ambiguous responses. (4) Supplementary interviews: brief structured interviews with key respondents (typically project managers or senior engineers) clarified questionnaire responses or supplemented insufficient documentation, informing qualitative interpretation of the quantitative findings.

Data Analysis Techniques

Analysis proceeded in three stages. Descriptive analysis calculated means, standard deviations, and ranges for X_1, X_2, X_3, and Y. These descriptive statistics carry particular analytical weight in the present study because, unlike inferential analysis, they are not subject to the same statistical power limitations associated with the small sample size.

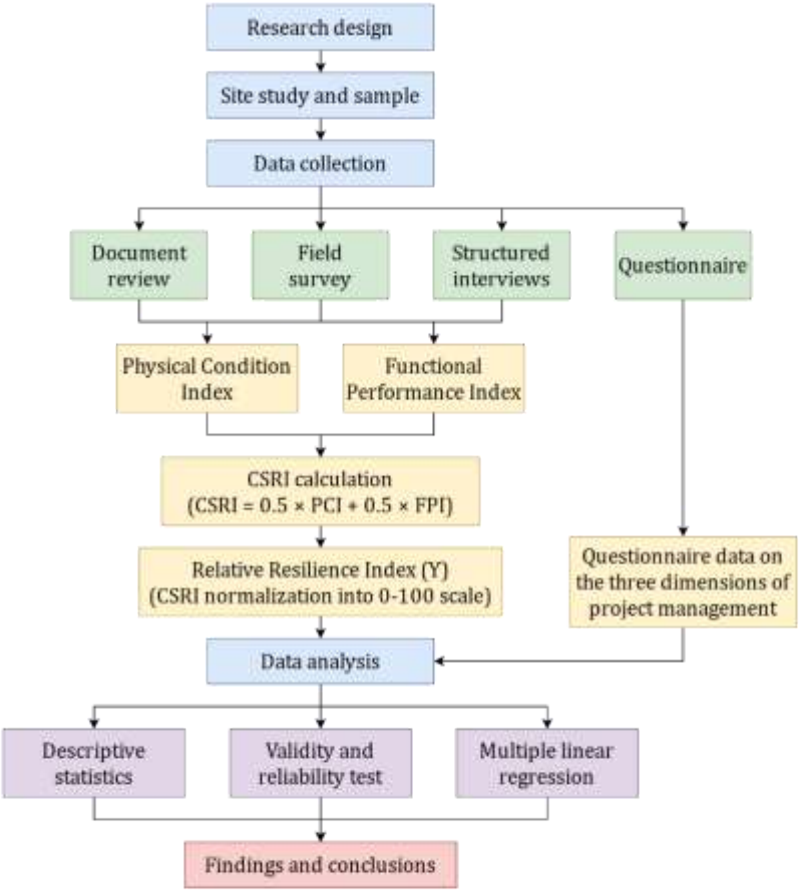
Validity and reliability assessment used item-total correlation (threshold $r \geq 0.30$) and Cronbach's Alpha (threshold $\alpha \geq 0.70$), interpreted diagnostically given that reliability estimates are themselves unstable at $n = 8$.

Multiple linear regression examined the relationship between X_1, X_2, X_3, and the Relative Resilience Index (Y) with the formula written in Equation (3):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon. \tag{3}$$

Given the four degrees of freedom for error noted above, F- and t-tests are reported for completeness but are not the primary basis for conclusions; the direction and relative magnitude of standardized coefficients are treated as the more informative output. Adjusted R^2 is reported as the primary fit measure, as it penalizes for predictor count relative to sample size.

Summary of Research Procedure



Picture 1. Research Procedure Visualization.

Picture 1 summarizes the complete methodological workflow, from site and sample selection through parallel data collection (document review, field survey, questionnaire administration, supplementary interviews), CSRI calculation, and the descriptive, reliability, and regression stages of analysis.

4. Results and Discussion

Overview of the Study Area

Document review and field observations confirm that coastal protection along the Karawang coastline consists primarily of breakwaters and groins. Structure types identified in prior technical studies as appropriate for the local wave climate, bathymetry, and topography. Eight structures (four breakwaters, four groins) were included in the study sample, across segments designated as coastal erosion priority areas by the Karawang Regency government.

Validity and Reliability of the Research Instrument

All items across the three variable scales exceeded the minimum item-total correlation threshold of r = 0.30 (Table 1), and all three scales met the Cronbach's Alpha threshold of $\alpha \geq 0.70$ (Table 2), with quality management (X_3, $\alpha = 0.794$) showing the highest internal consistency. These results confirm adequate instrument validity and reliability for the subsequent analysis.

Table 1. Item-Total Correlation Results.

Variable	Item	ITC Value	Status
Time management (X_1)	X1.1	0.771	Valid
	X1.2	0.761	Valid
	X1.3	0.843	Valid
	X1.4	0.787	Valid
Cost management (X_2)	X2.1	0.760	Valid
	X2.2	0.779	Valid
	X2.3	0.870	Valid
	X2.4	0.697	Valid
Quality management (X_3)	X3.1	0.679	Valid
	X3.2	0.788	Valid
	X3.3	0.838	Valid
	X3.4	0.859	Valid

Table 2. Cronbach's Alpha Results.

Variable	Cronbach's Alpha	Status
Time management (X_1)	0.760	Reliable
Cost management (X_2)	0.766	Reliable
Quality management (X_3)	0.794	Reliable

Descriptive Statistics

All three management variables recorded means above 3.9 on the 5-point scale (Table 3), indicating generally "Good" practice across the sampled projects. Quality management (X_3) recorded both the highest mean (4.031) and the narrowest range (3.750–4.333), suggesting relatively consistent implementation across projects, while time management (X_1) showed the widest range (3.583–4.333), indicating greater project-to-project variation in schedule adherence. The large standard deviation of Y reflects meaningful variation in structural resilience across the eight structures. This variation is analytically important because a highly compressed distribution of Y would provide little variability for regression analysis.

Table 3. Descriptive Statistics of Research Variables.

Variable	Mean	Std. Dev.	Min.	Max.
Time management — X_1 (per-item avg.)	3.932	0.259	3.583	4.333
Cost management — X_2 (per-item avg.)	3.961	0.213	3.583	4.188
Quality management — X_3 (per-item avg.)	4.031	0.257	3.750	4.375
Relative Resilience Index — Y (0–100)	54.44	37.22	0.00	100.00

Structural Performance Assessment

Physical condition and functional performance for each structure were combined into the CSRI and normalized Relative Resilience Index (Y), as presented in Table 4. Five of the eight structures fall into the "Good" category, while the remaining three are classified as "Fairly Good." Segment H (groin) recorded the highest overall condition (CSRI = 1.18; Y = 100), whereas Segment G (breakwater) recorded the lowest (CSRI = 1.80; Y = 0). Functional performance indices are consistently slightly higher than physical condition indices across all structures, suggesting that functional degradation tends to lag behind observable physical deterioration. This pattern is consistent with the expectation that early-stage physical damage does not immediately impair wave attenuation or sediment-trapping capacity.

Structure type alone does not explain this variation. Segment G (breakwater, Y = 0) and Segment B (breakwater, Y = 27.42) both underperformed relative to Segments C and A, which are also breakwaters but scored higher on management variables. Similarly, Segment E (groin, Y = 11.29) underperformed relative to Segments H and F. This within-type variation reinforces the study's central argument that structure type explains part of coastal protection effectiveness, whereas management quality accounts for much of the remaining variation in the performance of structures within the same category.

Table 4. Coastal Structure Resilience Index and Relative Resilience Index.

No.	Segment	Type	PCI	FPI	CSRI	Y (0–100)	Category
1	A	Breakwater	1.30	1.40	1.35	72.58	Good
2	B	Breakwater	1.55	1.70	1.63	27.42	Fairly good
3	C	Breakwater	1.20	1.35	1.28	83.87	Good
4	D	Groin	1.40	1.50	1.45	56.45	Good
5	E	Groin	1.65	1.80	1.73	11.29	Fairly good
6	F	Groin	1.25	1.30	1.28	83.87	Good
7	G	Breakwater	1.70	1.90	1.80	0.00	Fairly good
8	H	Groin	1.10	1.25	1.18	100.00	Good

Multiple Linear Regression Results

Multiple linear regression was conducted with the Relative Resilience Index (Y) as the dependent variable and time (X_1), cost (X_2), and quality management (X_3) as predictors. The model explains 94.2% of the variance in Y (R = 0.971, R^2 = 0.942; adjusted R^2 = 0.899, SE = 11.82), and the overall F-test is significant ($F(3,4)$ = 21.82, p = 0.006), confirming that the three management variables jointly predict structural resilience better than chance. Coefficient estimates, standard errors, and confidence intervals are presented in Table 5.

Table 5. Coefficient Results.

Variable	Coefficient (β)	Std. Error	t	p-value	95% CI
Intercept	−546.18	87.78	−6.22	0.003	[−789.90, −302.45]
X_1 (time)	11.955	12.990	0.920	0.409	[−24.11, 48.02]
X_2 (cost)	8.402	16.314	0.515	0.634	[−36.89, 53.70]
X_3 (quality)	17.330	10.321	1.679	0.168	[−11.33, 45.99]

The regression equation is written in Equation (4).

$$\hat{Y} = -546.18 + 11.955X_1 + 8.402X_2 + 17.330X_3. \quad (4)$$

Among the individual predictors, quality management (X_3) has the largest coefficient (17.330), followed by time management (X_1, 11.955) and cost management (X_2, 8.402), but none reach conventional significance (all p greater than 0.05). This is most plausibly explained by the very low statistical power available with only four degrees of freedom for error, and by correlation among the three predictors, since projects that manage schedules well also tend to manage costs and quality well, which inflates standard errors and makes it difficult to isolate each variable's unique contribution. These limitations point to the need for replication with larger samples rather than undermining the value of this exploratory study.

The coefficient ordering (X_3 greater than X_1 greater than X_2) is consistent with the general expectation that construction quality, including armor unit mass, placement density, and material compliance, has a more direct relationship to structural resilience than time or cost management, which may influence resilience indirectly through their effects on quality. This remains a plausible interpretation rather than a confirmed one, given the lack of statistical significance.

Field observations offer some tentative alignment with this pattern. Segments G and E, which recorded the lowest Y values, showed visible armor layer deterioration, while Segments H, C, and F, which recorded the highest Y values, were associated with higher X_3 scores. This is suggestive rather than conclusive.

5. Conclusions

This study examined the relationship between project management practices, specifically time, cost, and quality management, and the resilience of coastal protection structures along the Karawang coastline, using eight breakwater and groin structures as an exploratory case study. The three management dimensions jointly showed a strong positive association with structural resilience, while quality management exhibited the strongest directional relationship, followed by time management and cost management. Field observations were broadly consistent with this pattern. Structures associated with stronger quality control and better schedule discipline generally retained superior physical condition and functional performance. However, none of the individual management dimensions reached conventional statistical significance, and the small sample size indicates that these findings should be regarded as preliminary and directional rather than confirmatory.

Within this limitation, the findings suggest that quality management during construction may be worth particular attention in coastal protection projects, given its comparatively stronger association with resilience and its consistency with field-level observations of armor layer condition. Time and cost management showed weaker associations in this sample, and no strong claims are made here regarding specific management techniques for either dimension; further research is needed before more specific practical guidance can be offered with confidence.

This study is limited by its small sample of eight structures, which restricts the statistical power of the regression analysis and the confidence that can be placed in individual coefficient estimates. The CSRI developed for this study relies primarily on respondent judgment and field observation rather than instrumented data. In addition, its equal weighting of physical condition and functional performance was adopted because no empirical basis was available for an alternative weighting scheme. Both aspects would benefit from further refinement in future research. The study is also geographically confined to the Karawang coastline, and the extent to which its findings can be generalized to other Indonesian coastal contexts remains untested. Future studies involving larger samples across multiple coastal regions, more objective condition assessment methods, and empirically derived index weightings would help determine whether the patterns observed in this study are applicable more broadly.

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