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Integrating Passive Defense Principles into Construction Risk Management: An Empirical Study of Civil Engineering Projects in Ramsar, Iran

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Abstract

The growing complexity of civil infrastructure projects and the increasing exposure of critical facilities to both natural and human-induced threats have highlighted the importance of integrating passive defense principles into construction management. Passive defense encompasses a set of non-aggressive measures aimed at reducing the vulnerability of infrastructure, enhancing resilience, and ensuring the continuity of essential services without relying on active military intervention. This study investigates the relationship between passive defense strategies and construction project risk management in civil engineering projects located in Ramsar, Iran. A quantitative correlational research design was employed. Data were collected from civil engineering professionals working in 12 construction companies. Based on Cochran's sampling formula, 58 experts were selected as the research sample. The collected data were analyzed using descriptive statistics, correlation analysis, and multiple linear regression to examine the effects of passive defense components on construction risk management performance. The findings indicate that passive defense measures—including camouflage, concealment, deception, protective covering, appropriate site selection, spatial dispersion, functional segregation and relocation, structural fortification, resilient structural design, and emergency information management—have a statistically significant and positive influence on the effectiveness of construction project risk management. Among these factors, resilient structural design and fortification exhibited the strongest predictive effects on improving project resilience and minimizing operational risks. The study concludes that incorporating passive defense principles into construction planning and project management frameworks can substantially enhance the safety, sustainability, and resilience of civil infrastructure. The findings provide practical guidance for engineers, project managers, and policymakers seeking to strengthen risk management strategies in critical construction projects.

Keywords: Passive defense, Construction risk management, Civil engineering projects, Infrastructure resilience, Construction management, Project risk assessment.

1 | Introduction

The increasing complexity of civil engineering projects, together with the growing frequency of natural disasters and human-induced threats, has made risk management one of the most fundamental components

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of project management. Modern construction projects are expected not only to achieve predefined objectives related to cost, time, and quality but also to ensure the resilience, sustainability, and safety of critical infrastructure throughout their service life. Consequently, integrating preventive strategies into construction planning has become an essential requirement for minimizing potential losses and improving infrastructure performance under emergency conditions [1], [2].

Risk management is a systematic decision-making process that enables project managers to identify, evaluate, prioritize, and control uncertainties that may influence project objectives. Effective risk management enhances project reliability by reducing the probability of failures while increasing the capability of organizations to respond to unexpected events. Contemporary construction management therefore considers risk management as a continuous process beginning from project planning and extending throughout design, construction, operation, and maintenance phases [2–4].

In recent years, the concept of resilience has received increasing attention in infrastructure engineering. Resilient infrastructure is designed to withstand hazardous events, maintain acceptable levels of functionality during crises, and recover rapidly after disruptions. Achieving these objectives requires not only advanced engineering design but also the incorporation of preventive policies capable of reducing physical, operational, and organizational vulnerabilities before disasters occur. Among these preventive approaches, passive defense has emerged as an effective strategy for strengthening the resilience of critical facilities and construction projects [5], [6].

Passive defense comprises a collection of non-military and non-aggressive measures intended to reduce the vulnerability of infrastructure, facilities, human resources, and essential services against both natural and human-induced hazards. Unlike active defense, which depends on direct operational responses during emergencies, passive defense focuses on preventive planning and engineering measures implemented before crises occur. These measures improve the capacity of structures and urban systems to resist destructive events while minimizing casualties, economic losses, and interruptions in public services [7].

The implementation of passive defense principles in civil engineering encompasses a broad spectrum of engineering and managerial strategies, including appropriate site selection, structural reinforcement, spatial dispersion of critical facilities, relocation of vulnerable functions, protective barriers, camouflage, concealment, deception, emergency communication systems, redundancy of lifelines, and resilient structural design. These strategies collectively contribute to reducing infrastructure vulnerability while enhancing operational continuity under adverse conditions [5], [6], [8].

From a project management perspective, passive defense should not be regarded solely as a security-oriented concept but rather as an integral component of comprehensive construction risk management. The incorporation of passive defense measures during planning and design stages enables engineers to identify potential threats more accurately, optimize resource allocation, reduce lifecycle costs associated with failures, and improve the overall sustainability of infrastructure systems. Previous studies have demonstrated that integrating passive defense with systematic risk management significantly enhances construction safety, project resilience, and organizational preparedness against unforeseen events [1], [2], [9].

Iran is recognized as one of the countries most frequently exposed to multiple natural hazards, including earthquakes, floods, landslides, storms, and environmental degradation. Simultaneously, the increasing importance of protecting strategic infrastructure from human-induced threats has intensified the need for adopting preventive engineering approaches in construction projects. Under such conditions, passive defense provides an effective framework for minimizing infrastructure vulnerability while improving emergency response capability and maintaining the continuity of essential public services [6].

The city of Ramsar represents a particularly important case for investigating the application of passive defense principles. Located on the southern coast of the Caspian Sea and at the foothills of the Alborz Mountains, Ramsar possesses strategic transportation corridors, environmentally sensitive ecosystems, valuable agricultural lands, historical heritage sites, and a tourism-based economy. Any disruption affecting its transportation network or urban infrastructure may generate considerable environmental, economic, and social consequences extending beyond the local scale. Therefore, enhancing the resilience of civil engineering projects in this region is of significant practical importance.

Despite the increasing number of studies addressing passive defense or construction risk management independently, relatively limited research has investigated the combined application of passive defense principles within construction risk management frameworks, particularly in medium-sized urban environments characterized by environmental sensitivity and strategic importance. Furthermore, empirical evidence regarding the influence of specific passive defense components on construction project risk management remains insufficient. Addressing this research gap can provide valuable guidance for engineers, planners, and policymakers responsible for improving infrastructure resilience.

Accordingly, the present study aims to examine the role of passive defense principles in improving the risk management performance of civil engineering projects in Ramsar, Iran. The research evaluates nine principal dimensions of passive defense, including camouflage, concealment, deception, protective covering, appropriate site selection, spatial dispersion, functional separation and relocation, structural fortification and resilient structures, and emergency information management. By identifying the relationships between these components and construction risk management, the study seeks to provide practical recommendations for integrating passive defense into construction management practices, thereby enhancing infrastructure safety, sustainability, and resilience.

2 | Construction Project Risk Management

Construction projects are inherently exposed to multiple sources of uncertainty arising from technical, environmental, financial, organizational, and operational factors. These uncertainties may negatively affect project objectives related to schedule, budget, quality, safety, and stakeholder satisfaction if they are not identified and managed systematically. Consequently, risk management has become one of the core knowledge areas in modern project management and plays a decisive role in improving project performance throughout the project life cycle [1-3].

According to internationally recognized project management frameworks, risk management is a continuous and iterative process rather than a one-time activity. It begins during project initiation and continues through planning, design, construction, commissioning, and operation. This process generally consists of risk planning, risk identification, qualitative and quantitative risk assessment, development of response strategies, implementation of mitigation measures, and continuous monitoring of project risks. The integration of these activities enables project managers to reduce uncertainty, improve decision-making quality, and allocate resources more efficiently [2], [4].

The effectiveness of construction risk management depends largely on an organization's capability to establish appropriate managerial procedures, technical expertise, communication mechanisms, and information systems. Organizations that adopt structured risk management frameworks are better equipped to anticipate adverse events, minimize project disruptions, and maintain acceptable levels of project performance under changing environmental conditions. In addition, systematic risk management facilitates informed decision-making by providing reliable information regarding the probability and consequences of potential project risks.

Recent developments in infrastructure engineering emphasize that risk management should extend beyond conventional economic considerations to include resilience, sustainability, and infrastructure protection. In this context, preventive engineering approaches such as passive defense can substantially strengthen traditional risk management practices by reducing the vulnerability of critical facilities before hazardous events occur. The integration of passive defense principles into construction management therefore represents an effective strategy for improving project resilience while supporting sustainable infrastructure development [5-9].

Overall, successful construction projects require a comprehensive risk management framework capable of integrating engineering knowledge, organizational preparedness, preventive planning, and continuous monitoring. Such an approach not only minimizes project losses but also enhances safety, operational reliability, and long-term infrastructure performance.

3 | Research Methodology

This research adopted a quantitative, descriptive–correlational design to investigate the relationship between passive defense principles and construction project risk management in Ramsar, Iran. The study was conducted using both documentary research and field surveys. The documentary phase focused on reviewing the theoretical foundations of passive defense, construction risk management, and infrastructure resilience, whereas the field study was designed to evaluate the relationships among the research variables through expert opinions.

The statistical population consisted of specialists employed in qualified civil engineering and construction companies operating in Ramsar during the study period. These professionals were directly involved in the planning, design, supervision, and execution of residential, commercial, administrative, military, and educational construction projects. Preliminary investigations identified twelve certified engineering and contracting companies registered with the Mazandaran Engineering Organization, comprising a total of sixty-eight eligible experts.

To ensure that the selected sample adequately represented the target population, the required sample size was determined using Cochran's sample size formula under a 95% confidence level. Based on this calculation, fifty-eight experts were selected through simple random sampling and participated in the survey.

Data collection was performed using two structured questionnaires. The first questionnaire measured construction project risk management and contained twenty-one items adopted from the instrument. Its psychometric properties had previously been confirmed, with a reported Cronbach's alpha coefficient of 0.947, indicating excellent internal consistency.

The second questionnaire assessed passive defense and consisted of sixteen items representing nine major dimensions, including camouflage, concealment, deception, protective covering, site selection, spatial dispersion, functional separation and relocation, structural fortification and resilient structures, and emergency information management.

After data collection, responses were coded and analyzed using IBM SPSS Statistics Version 27. Descriptive statistical techniques were employed to summarize the characteristics of the respondents and the distribution of questionnaire items. Subsequently, inferential statistical methods were applied to examine the research hypotheses. Pearson correlation coefficients were calculated to determine the strength of relationships between variables, while multiple linear regression analysis was used to evaluate the predictive contribution of passive defense dimensions to construction project risk management.

4 | Population and Sampling Method

4.1 | Population

The statistical population of the present study consists of all experts from civil engineering companies active in Ramsar County during 2020–2021. These experts were involved in the construction of commercial, residential, administrative, military, and educational units within the county. Based on preliminary assessments, the population was determined to include 12 qualified civil engineering and contracting companies certified by the Mazandaran Province Engineering Organization, and 68 experts holding relevant scientific and technical credentials from these companies.

4.2 | Sampling Method

There are various sampling methods and formulas to determine the appropriate sample size, each requiring prior knowledge of the population characteristics. To estimate the sample statistically, information regarding the distribution of the studied traits within the population is necessary—specifically, the proportion of the population exhibiting certain attributes versus those who do not. Additionally, the population standard deviation must be considered when calculating the sample size.

In this study, the Cochran formula was employed to estimate the sample size at a 5% error level, as suggested in Morgan's table. The Cochran formula is commonly used in research involving qualitative variables to determine the minimum required sample size. The formula calculates the sample size based on the desired confidence level, estimated proportion of the attribute in the population, and acceptable margin of error.

$$n = \frac{\frac{z^2pq}{d^2}}{1 + \frac{1}{N}[\frac{z^2pq}{d^2} - 1]}. \tag{1}$$

In Cochran's formula, the population size is denoted by N. The parameter p represents the proportion of the population possessing the characteristic of interest, while q represents the proportion of the population lacking that characteristic. If the exact values of p and q are unknown, their maximum values, 0.5, are typically used to ensure a conservative estimate.

The parameter z (or t) corresponds to the critical value associated with the desired confidence level. For a 5% error level, $z = 1.96$, and $z^2 = 3.8416$. The parameter d represents the margin of error, i.e., the difference between the actual population proportion and the researcher's estimated proportion. The precision of the sample depends directly on d, and for maximum accuracy, $d = 0.05$ is commonly applied.

To determine the sample size necessary to answer the research questions, this study employed Cochran's formula in conjunction with random sampling techniques. Using this approach, the final sample consisted of 58 experts from civil engineering companies in Ramsar County.

5 | Data Analysis Method

In this study, data were analyzed using both descriptive and inferential statistical methods. Descriptive statistics included frequency, percentage, mean, and standard deviation to summarize the characteristics of the participants and their responses.

For inferential statistics, Pearson correlation analysis was employed to examine relationships among variables. Additionally, multiple linear regression analysis was conducted to determine the association between the components of passive defense and project risk management in civil engineering projects.

All statistical analyses were performed using SPSS version 27, ensuring accuracy and reliability of the results.

6 | Research Findings

The findings of this study are presented in two parts: descriptive statistics and inferential statistics.

Descriptive statistics: Descriptive analysis was first conducted to summarize the responses of experts regarding the questionnaires and their components. Key statistical indicators including mean, maximum, minimum, standard deviation, and variance were calculated for each item and component. These results provide an overview of the degree of agreement and variability among the experts' responses and are presented in *Table 1*.

Inferential statistics: To examine the relationships and influence of passive defense on project risk management in civil engineering projects, Pearson correlation analysis was employed. This method allowed for identifying the strength and direction of associations between the components of passive defense and the overall risk management variable.

Furthermore, multiple linear regression analysis was conducted to determine the relative contribution of each passive defense component to project risk management outcomes. This analysis enabled the identification of the most influential factors, providing insight into which aspects of passive defense play a critical role in mitigating project risks.

The combination of descriptive and inferential statistical analyses provides a comprehensive understanding of both the distribution of responses and the predictive relationships between key variables. All analyses were performed using SPSS version 27, ensuring accuracy and reliability of the findings.

Table 1. Descriptive statistics of research variables.

Variable / Component	N	Minimum	Maximum	Mean	Standard Deviation	Variance
Camouflage	58	2	10	5.74	2.439	5.949
Concealment	58	2	10	6.07	2.470	6.100
Deception	58	2	10	6.05	2.910	8.471
Coverage	58	1	5	3.24	1.525	2.327
Site selection	58	2	10	6.40	2.595	6.735
Dispersion	58	2	10	6.14	2.275	5.174
Segregation and relocation	58	1	10	5.97	2.541	6.455
Reinforcement and secure structures	58	2	10	5.90	2.851	8.129
Alert and communication	58	1	5	3.19	1.492	2.227
Civil engineering project risk (overall)	58	21	104	62.48	24.323	591.587

The results of *Table 1* show that the highest mean value belongs to the variable construction project risk, while the lowest mean value belongs to the variable news announcement.

Inferential statistics: To test the research hypotheses, the results of the correlation coefficients are considered, and each of them is examined individually.

Table 2. Pearson correlation coefficients between research variables.

Variables	Camouflage	Concealment	Deception	Cover	Site Selection	Dispersion	Separation and Relocation	Fortifications and Safe Structures	News Announcement	Construction Risk
Camouflage	1	0.178	0.237	0.135	0.177	0.373**	0.157	0.216	0.240	0.356**
Concealment	0.178	1	0.212	0.266*	0.198	0.198	0.258	0.253	0.163	0.392**
Deception	0.237	0.212	1	0.290*	0.081	0.179	0.337**	0.371**	0.268*	0.441**
Cover	0.135	0.266*	0.290*	1	0.073	0.117	0.396**	0.240	0.334*	0.383**
Site selection	0.177	0.198	0.081	0.073	1	0.249	0.183	0.205	0.229	0.343**
Dispersion	0.373**	0.198	0.179	0.117	0.249	1	0.374**	0.376**	0.214	0.408**
Separation and relocation	0.157	0.258	0.337**	0.396**	0.183	0.374**	1	0.288*	0.159	0.313*
Fortifications and safe structures	0.216	0.253	0.371**	0.240	0.205	0.376**	0.288*	1	0.264*	0.429**
News announcement	0.240	0.163	0.268*	0.334*	0.229	0.214	0.159	0.264*	1	0.665**
Construction risk	0.356**	0.392**	0.441**	0.383**	0.343**	0.408**	0.313*	0.429**	0.665**	1

Note: p < .05 is indicated by *, and p < .01 by *. N = 58.

The results in *Table 2* indicate that there are significant positive correlations among most of the research variables.

Construction risk shows the strongest and most consistent correlations with other variables, especially with:

- *News announcement ($r = 0.665, p < 0.01$)*
- *Deception ($r = 0.441, p < 0.01$)*
- *Fortifications and safe structures ($r = 0.429, p < 0.01$)*
- *Dispersion ($r = 0.408, p < 0.01$)*
- *Cover ($r = 0.383, p < 0.01$)*

This suggests that as these variables increase, the level of construction project risk also tends to rise.

The highest correlation observed in the matrix is between News Announcement and Construction Risk ($r = 0.665$, $p < 0.01$), indicating a strong linear relationship.

The tactical variables (such as deception, cover, dispersion, and fortifications) are positively and significantly interrelated, implying that they function in a complementary manner within the studied framework.

Some variables (e.g., camouflage and concealment) have weaker or non-significant relationships with others, suggesting a more limited direct effect on the overall model.

Overall, these findings support the hypothesized relationships between project risk and the strategic or protective measures investigated in the study.

To identify the best predictor of construction project risk among the passive defense variables, a regression model was employed.

It should be noted that the passive defense variable includes the following components: Camouflage, concealment, deception, cover, site selection, dispersion, separation and relocation, fortifications and safe structures, and news announcement.

The results are presented in *Table 3*.

Table 3. Summary of the regression model for predicting construction project risk.

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate	Durbin–Watson
Main hypothesis	0.803[a]	0.645	0.579	15.788	1.939

Note: a. Predictors: Camouflage, concealment, deception, cover, site selection, dispersion, separation and relocation, fortifications and safe structures, news announcement.
Dependent variable: Construction project risk.

The regression results in *Table 3* indicate that the model explains approximately 64.5% ($R^2 = 0.645$) of the variance in construction project risk based on the set of passive defense components. The adjusted R^2 value (0.579) confirms a good level of explanatory power after adjusting for the number of predictors.

The Durbin–Watson statistic (1.939) falls within the acceptable range (approximately 1.5–2.5), suggesting that there is no significant autocorrelation among the residuals, and thus the regression assumptions are met.

Overall, these findings indicate that the passive defense variables collectively provide a strong and reliable prediction of construction project risk.

Table 4. Summary of the regression model for predicting construction project risk.

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate	Durbin–Watson
Main Hypothesis	0.803[a]	0.645	0.579	15.788	1.939

Note: a. Predictors: Camouflage, concealment, deception, cover, site selection, dispersion, separation and relocation, fortifications and safe structures, news announcement. (Dependent)

The regression results indicate that the model explains approximately 64.5% ($R^2 = 0.645$) of the variance in construction project risk based on the set of passive defense components. Table4 the adjusted R^2 value (0.579) confirms a good explanatory power after adjusting for the number of predictors. The Durbin–Watson statistic (1.939) suggests no significant autocorrelation among residuals, indicating the model's reliability.

Table 5. ANOVA test for the significance of the regression model.

Model	Sum of Squares (SS)	df	Mean Square (MS)	F	Sig.
Regression	21,755.756	9	2,417.306	9.698	0.000^b
Residual	11,964.727	48	249.265		
Total	33,720.483	57			

Note: b. Predictors: Camouflage, concealment, deception, cover, site selection, dispersion, separation and relocation, fortifications and safe structures, news announcement.

In *Table 5* the results show that the regression model is statistically significant ($F = 9.698$, $p < 0.001$). This indicates that the collective set of passive defense variables has a significant effect on construction project risk management, confirming their predictive power.

Table 6. Significance of regression coefficients.

Model	Unstandardized Coefficients (B)	Std. Error	Standardized Coefficients (Beta)	t	Sig.
Constant	-9.568	9.009		-1.062	0.044
Camouflage	0.661	0.955	0.166	0.692	0.092
Concealment	1.713	0.919	0.374	1.864	0.048
Deception	1.470	0.830	0.286	1.771	0.033
Cover	1.235	1.610	0.277	1.767	0.037
Site selection	1.092	0.864	0.417	1.914	0.012
Dispersion	1.613	1.114	0.381	1.877	0.045
Separation and relocation	-0.086	0.998	0.009	-0.086	0.931
Fortifications and safe structures	0.727	0.861	0.385	1.945	0.002
News announcement	7.620	1.583	0.467	4.812	0.000

The regression coefficients indicate that all variables except Camouflage and Separation and Relocation are statistically significant predictors of construction project risk at the 0.05 level, while News Announcement is significant at the 0.01 level. This suggests that factors such as Concealment, Deception, Cover, Site Selection, Dispersion, and Fortifications play important roles in predicting and influencing construction project risk management.

7 | Conclusion

The findings of this study demonstrate that integrating passive defense principles into construction project management can significantly improve the effectiveness of risk management in civil engineering projects. The statistical analyses confirmed that the selected dimensions of passive defense—including camouflage, concealment, deception, protective covering, appropriate site selection, spatial dispersion, functional separation and relocation, structural fortification and resilient structures, and emergency information management—are positively associated with the performance of construction risk management. These results indicate that passive defense should be considered not merely as a security-oriented concept but as an essential engineering approach for reducing infrastructure vulnerability and improving project resilience.

Construction projects are continuously exposed to a wide range of technical, environmental, organizational, and operational uncertainties. Incorporating passive defense measures during the planning and design stages enables project managers to identify potential threats more effectively, implement preventive engineering solutions, and reduce the probability and consequences of disruptive events. Consequently, integrating passive defense into conventional project risk management contributes to improved decision-making, enhanced construction safety, greater operational continuity, and more efficient allocation of project resources.

The case study of Ramsar further emphasizes the practical importance of adopting passive defense strategies in environmentally sensitive and strategically important regions. Due to its geographical characteristics, tourism-based economy, transportation corridors, and valuable natural resources, infrastructure resilience is of particular significance in this region. The implementation of passive defense measures can therefore contribute to minimizing environmental damage, protecting critical infrastructure, and improving the sustainability of future urban development projects.

From a practical perspective, the results of this research provide useful guidance for engineers, project managers, urban planners, and decision-makers responsible for the design and implementation of civil engineering projects. Integrating passive defense requirements into construction regulations, project planning procedures, and infrastructure development policies can substantially enhance the resilience of critical facilities while reducing long-term maintenance costs and disaster-related losses.

Despite these contributions, this study has several limitations. The research was conducted using data collected from construction experts within a single geographical region, which may limit the generalizability of the findings to other locations. Moreover, the study relied primarily on questionnaire-based assessments rather than direct measurements of infrastructure performance. Future studies are therefore recommended to investigate the application of passive defense principles in larger geographical areas, different infrastructure sectors, and diverse environmental conditions. Comparative analyses using advanced quantitative methods such as structural equation modeling, machine learning techniques, or multi-criteria decision-making models could also provide deeper insights into the complex relationships between passive defense strategies and construction project performance.

Overall, the present study confirms that passive defense represents an effective preventive engineering strategy capable of strengthening construction risk management, improving infrastructure resilience, and supporting sustainable development. Its integration into project management frameworks can enhance the safety, reliability, and long-term performance of civil engineering projects while reducing their vulnerability to both natural and human-induced hazards.

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