

Article

Sustainable Risk Assessment through the Analysis of Financial Losses from Third-Party Damage in Bridge Construction

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Abstract: Due to the recent introduction of innovative construction methods and technologies, construction projects increasingly require sustainability in their high degrees of specialization and complex work processes. This is due to a wide variety of new risk factors associated with construction projects that can lead to extensive and severe damage. When an accident occurs during a construction project, it can cause material, property, or bodily damage not only within the actual construction site but also outside, affecting third parties. This study analyzed the record of such third-party damage and the subsequent financial losses in bridge construction management, to identify the objective and quantified relationship of risk indicators related to the damage and losses. In order to assess the actual losses in construction projects, we adopted the loss claim payout data as recorded and provided by a major Korean insurance company, and conducted a multiple regression analysis to identify the loss indicators and to develop a loss estimation model. In this study, the analysis of the data indicated that the superstructure type, the foundation type, floods, and company ranking by the amount of the contract were the four statistically significant risk indicators that affected financial losses from third-party damage, among the nine variables used as independent variables, which included the superstructure type, foundation type, superstructure construction method, maximum span length, floods, typhoons, total construction cost, total construction period, and company ranking. As this study focused on identifying the risk factors and producing a loss assessment model quantified in numerical values, the results provide important references for assessing and minimizing the risks to third parties and the consequential financial losses in bridge construction, while promoting sustainability objectives.

Keywords: bridge construction; risk analysis; loss assessment model; third-party damage; insurance

1. Introduction

1.1. Background and Purpose of the Study

Bridges are important infrastructure and industrial facilities for urban growth and economic development, as they allow a large volume of logistics and transportation by connecting rivers, canyons, islands, and lands. Due to the recent introduction of innovative construction methods and technologies, construction projects increasingly require sustainability in their high degrees of specialization and complex work processes. This is due to a wide variety of new risk factors associated with construction projects, which can lead to extensive and severe damage. The high level of expertise and technology also highlights the need for a sustainable and systematic management of finances, as well-organized fiscal management and fund execution, which can contribute to the sustainable practices of safety and risk management.

It is also important to reinforce the reliability of information regarding risks in construction projects and to use this information as a means for rational decision-making and effective strategy-making for sustainable risk management. However, there are limits to relying solely on government-led risk and safety management systems, which tend to be too broad and general, and thus the role of the private sector is becoming more emphasized [1]. More specifically, the current trend of risk management in construction projects should be more numerical, quantified, and thus more objective, as opposed to the empirical custom of the past, which relied on the individual experiences of experts and judgments from previous cases [2,3].

Risk management is defined in the *Principles for Risk Management* of the International Organization for Standardization (ISO) as: (1) a part of decision-making; (2) should clearly address uncertainty; (3) should be based on the best information available; (4) should be adapted to a specific purpose or method; and (5) should be comprehensive and obvious [4]. Risk management in construction is commonly focused on reducing risk factors, as well as transferring risk through purchasing construction insurances. For this reason, a risk management approach that recognizes internal and external risk factors in advance and analyzes the extent of possible losses, in order to share the risks according to the causes, is strongly required [5]. In other words, construction management and loss estimation models require a more sophisticated and scientific methodology. Furthermore, it is also crucial that such models consider the comprehensive aspects of losses, by including not only material damage within the site but also third-party damage, which is directly and indirectly due to the influence of construction activities or accidents.

In this study, a “third party” is defined as an outside entity not aligned with any of the stakeholders (including the workers, subcontractors, or general contractors) of a construction project. Therefore, “third-party damage” refers to the damage caused by construction activities or accidents to the third party’s bodies and/or properties, including damage to, physical injury to, loss of, or destruction of tangible property [6]. On the insurance record data, which this study collected and analyzed, the “loss claim payout” refers to the financial amount spent to indemnify the third-party damage.

Previous studies on safety accidents and risk management in construction have been mostly limited to the workers and structures within the construction site. Analyses and studies on third-party damage beyond the construction sites are much rarer [7–10]. Examples of third parties can include, among others, pedestrians and agricultural and commercial workers around the site. The occurrence of third-party damage can give rise to many problems, including cost compensation, suspension of construction work, and administrative punishment, resulting in reduced work productivity, economic losses, and harm to the reputation of the company in question. This, in turn, can lead to unexpected secondary losses despite many efforts to improve the productivity and profitability, such as cost-cutting, construction period reducing, and so on. Therefore, at a time when many construction companies seek to develop and strengthen more advanced risk assessment and management methods to minimize potential losses, a more comprehensive and sustainable management system needs to be established by taking into account the risk factors beyond the construction site, rather than relying on the existing risk management, focused on accidents taking place within the boundaries of construction sites [11].

The purpose of this study is to provide a loss assessment model for third-party damage that can contribute to minimizing risks in a more systematic and evidence-based way. In other words, this study aims to identify the statistically significant risk factors in bridge construction projects from onset to completion and to present a risk prediction model, while reflecting the actual record of damage that occurred in bridge construction projects. Both aims are ultimately directed at the achievement of sustainable risk management.

1.2. Method and Scope of Research

This study analyzed the record of damage incurred to the third parties and subsequent financial losses to indemnify the damage in actual bridge construction projects, in order to identify the correlation between the risk factors of the damage and financial losses. To ascertain the actual losses in construction

projects, we adopted the loss claim payout data recorded and provided by a major Korean insurance company as the data in this study, for the purpose of achieving the quantification of third-party damage in numerical values. More specifically, the loss claim payout record was used due to its clarity and objectivity [12], which can represent the cost of financial losses in construction work well. This quantified representation of insurance records can be especially useful, because of the specific and detailed information about each case of damage, which allows engineers, insurance underwriters, etc., to accurately and logically review, examine, and determine the loss in construction management.

We conducted risk analysis in order to find valid factors based on the accumulated past data and statistics. In the insurance industry, generalized linear models (GLMs) are commonly used to support critical decisions [13]; more specifically, the choice of variables in the model first considers all variables used in the calculation of insurance premium and filters out statistically meaningless variables through a statistical analysis process. Adopting this method, in this study, variables were selected based on the insurance claim payout record and the correlations with quantified losses were analyzed.

Based on the data, the financial loss incurred to compensate the third-party damage was then referred to as the “loss from third-party damage” in this study, and the term and concept of the “loss ratio” was established as the dependent variable. To identify the risk factors and the relationships between the loss and the factors, first, the dependent variable was defined using the term, “loss ratio.” The loss ratio is defined as the amount of financial loss incurred to indemnify third-party damage, divided by the total cost of the construction project. We used the term and concept of loss ratio as it seemed reasonable to consider the fact that, even when the loss amount was relatively little in a project, if the size of the project was rather small, the extent of the loss could be more detrimental and severe, and the contrary fact that even when the loss amount was relatively large, if the size of the project was rather big, the extent of the loss could be considered somewhat benign and insignificant.

Second, the key risk factors in bridge constructions were selected based on previous studies and past insurance compensation records. The risk factors regarding the characteristics of bridge constructions were based on the project base information, and the occurrence of natural disasters were entered as the independent variables. Therefore, a total of eight variables (superstructure types, maximum span length, superstructure construction method, flood, typhoon, total construction duration, and company rank) were selected for the analysis. Third, a multiple regression analysis using the stepwise variable selection method was conducted to identify and verify the statistically significant risk factors as well as the correlation between the variables and to develop a loss assessment model. Figure 1.

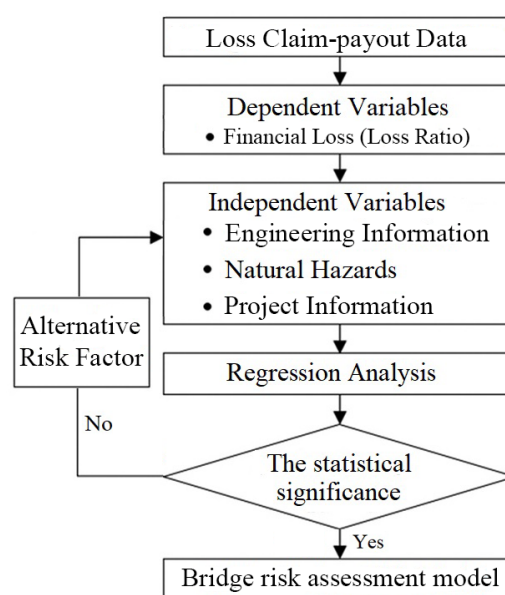


Figure 1. Our study procedure.

2. Review of Literature

2.1. Construction Insurance

Construction insurance covers the damage caused by unexpected accidents and consequential losses occurred during construction and civil engineering works, such as temporary construction work, main construction, and damage to the construction materials. The compensation for such damage can be divided into two types: first, the compensation for construction materials within the construction sites, and second, the compensation for third-party physical and property losses incurred beyond the construction site due to accidents involving the construction work [14].

The regulations on the compensation not only for construction materials but also for third-party damage have recently become more stringent. For example, it has become obligatory for construction projects ordered by the Korean central or local governments to purchase construction insurance, carried out mainly through a turn-key base contract or alternative bidding, mostly by large construction companies. The projects requiring pre-qualification are bridges over 50 meters in span. These regulations also require that the insurance purchased in such cases must guarantee the collateral damage for materials and third-party liability (Article 55 of the government's bidding and contract enforcement standards). The Korean Public Procurement Service is also seeking to reduce the loss burden on construction companies by applying construction insurance, which includes third-party liability, to the public building corporation in downtown areas starting from August 2019.

This study used the loss claim payout data from Contractor's All Risk (CAR) insurance. As mentioned earlier, construction insurance is designed to cover the entire range of unexpected losses at all stages of construction projects. If an accident occurs during a construction project, this could cause damage to the existing property of the contractors and to those involved in the construction around the construction site, and also to a third-party that is not necessarily directly related to the construction activities. In addition to property and material damage, damage such as death, physical injuries and/or any bodily harm can occur to third parties. For example, the *Korea National Environment Dispute Resolution Commission* recently ordered hundreds of millions of KRW (South Korean Won) in compensation for damage, such as damage to crops due to sunlight interruption from highway bridges and damage from mass death in fish farms due to the noise and water pollution from bridge construction. Such construction events relating to third-party damage, in turn, can cause losses to the owners, including the suspension of work or delay of completion.

2.2. Loss from Third-Party Damage

Many leading companies involved in construction projects make a great deal of effort to estimate the possible losses during construction work. In particular, insurance and re-insurance companies have developed their own loss assessment models to predict and prepare for the potential losses [15]. These loss estimation models in fact help the insurers and their customers to understand and estimate the potential risks in construction projects. However, there is a disadvantage that these models can only be accessed and used by certain insurers or limited customers, which makes it difficult for the others who are also involved in construction work to utilize the models. Therefore, it is quite difficult for general operators or public institutions to gain access to such models and to estimate the losses incurred during construction work.

Many vendors, including EQECAT, Risk Management Solution, and Applied Insurance Research, have designed and provided risk estimation models to evaluate the construction risks [16,17] to be generally used, but applying these models over a wide range of regions and countries has some limitations. This is because differences in the size and frequency of local vulnerabilities in construction projects and natural disasters can increase the uncertainty in forecasting losses, and models that do not adequately reflect the characteristics of a region or country may result in errors. This, in turn, can increase the differences or errors, especially in identifying third-party losses, as third-party losses tend to be heavily affected by the surrounding environmental conditions. More specifically, because

third-party losses incur to people and places beyond the actual sites of construction, particular regional differences easily arise due to a variety of surrounding environmental factors and the construction related regulations and laws.

Therefore, for users, not only are the loss assessment models developed by insurance and re-insurance companies difficult to understand due to their black box type algorithms but also these models cannot easily be adjusted to reflect the important characteristics particular to specific regions and countries. For this reason, there is a need for studies to analyze the risk factors for third-party damage and also the losses from third-party damage, and to develop a loss assessment model that evaluates the losses from third-party damage, which can be applied to a wide range of regions with their particular details regarding the environment and laws.

2.3. Risks in Bridge Construction Projects

Existing studies on the risks in bridge construction have also been conducted with a wide range of approaches, including technical, social, environmental, and economic points of views, as risk is a combination of factors, such as disaster, vulnerability, and exposure, and is not solely or independently determined by a single factor [18]. Hastak and Baim proposed risk factors that influenced the cost-effectiveness of management and the operation and maintenance of urban infrastructures, such as bridges, highways and subway stations. They determined that the risk factors specific to bridges include the training of inspection personnel and deicing salts [19]. Wang and Elhag performed a comparative study that analyzed bridge risk modeling, focusing on safety, functionality, substantiality, and the environment by comparing multiple regression analysis and neural network analysis methods [20].

Cho and Kim proposed a probabilistic risk assessment in a virtual construction to evaluate the risks of erection control and the main cable wires' fracture during the construction phases [21]. Hashemi et al. identified the key bridge construction risk factors, i.e., delayed payment on the contract and extras, a shortage of labor, materials, and equipment, construction permitting issues, and poor relationship among parties [22]. Li et al. pointed out the risk factors for bridge construction using factor analysis. They categorized seven risk factors: economic, contract and law, building technology, design, environment, staff, and materials and equipment [23]. Choudhry et al. identified the critical risk factors related to bridge construction projects, including the financial risks, external risks, design risks, management risks, construction risks, contractual risks, and health and safety risks. They determined that financial risks were the key factor that affected the costs and schedule of bridge construction projects [24].

Various studies have been conducted on risk assessment methods and losses in bridge construction, and these studies contributed to recognizing certain critical risk factors. In existing studies, however, two major gaps can be pointed out. First, studies that identify significant risk factors through objective and statistical analysis using quantified data are still insufficient. Second, most of the previous studies on bridge construction risks did not distinguish the material damage that occurred within the construction sites from third-party damage, as it is difficult to exclusively distinguish and evaluate the losses from third-party damage. Thus, for a scientific and objective analysis of losses caused by third-party damage, and for the development of the loss assessment models, the use of data with quantified risk, as well as statistical analysis and verification, is crucial and necessary.

3. Data Collection and Analysis

3.1. Data Collection

For quantitative risk analysis and evaluation, in this study, we collected the data of 296 loss cases of third-party damage claim payouts from construction insurance coverages of actual bridge construction projects between 1999 and 2016. The collected data included various information, such as the date and place of accidents, structure component types, construction period, loss details, the amount of insurance coverage, and the loss amount in the bridge construction project. The detailed information in the data

was then classified into three groups, for the sake of convenience: (1) accident information (accident date, site address, and accident details); (2) characteristic information of the bridge construction projects (superstructure types, maximum span length, and superstructure construction method); and (3) the project scale, represented by the total construction duration and company rank. Not all information was used to select the independent variables. However, the above information was used to form sets of independent variables, which will be introduced in the next section. For example, the accident information itself was not selected as an independent variable, but based on such information, such as the accident date, site address, and accident details, the indicators of natural hazards (floods and typhoons) were determined and used as independent variables.

3.2. Comparison of Material Loss and the 3rd Party Loss

Table 1 shows a descriptive statistical comparison between the losses from material damage and the losses from third-party damage from the collected data. The frequency of third-party damage was not very high, as it was estimated to be about half of the material damage. However, the average amount of the financial loss incurred to indemnify the third-party damage was approximately 20% higher than the loss incurred to indemnify the material damage.

Furthermore, a statistical comparison for a clearer verification was performed and is represented in Table 2. The table illustrates the results of analyzing the differences between the two groups. As can be seen, there is no significant difference in the average between the losses from the materials and from the third-party, which evidently indicates that the loss from third-party damage can and should be an important part of the consideration for construction loss analysis, and requires an equivalent and immediate level of management with the loss from the material damage.

Table 1. Comparison with materials and third-party losses.

Category	Frequency (%)	Avg. Loss (Mil. KRW)	Max. (Mil. KRW)	Min (Mil. KRW)	Std. Deviation
Material	66.8	84.98	1915	1.15	328.22
Third-party	33.2	95.34	841	1.03	176.41

Table 2. ANOVA test for materials and third-party losses.

Category	Sum of Squares	Mean Square	F-Value	Sig.
Between Groups	5.079e+15	5.079e+15	0.147	0.833
Within Groups	5.054e+18	4.458e+16		
Total	5.059e+18			

3.3. Multiple Regression

3.3.1. Dependent Variable

In this study, multiple regression analysis was used to define the relationship between the loss ratio and loss indicators to develop a loss estimation model. More specifically, through multiple regression analysis, we identified the loss indicators in quantitative, numerical values through analyzing the third-party losses, and determined the significant loss indicators among them. Based on the data, the term and concept of the “loss ratio” were established. This is the amount of the loss incurred to indemnify the third-party damage, divided by the size of the construction project. The size of the construction project in this study was represented by the total sum insured (TSI), which reflects the total bridge construction cost. This can be expressed in an equation as follows in Equation (1):

$$LR = \frac{CP}{TSI}. \quad (1)$$

where:

LR: Loss Ratio

CP: Claim-Payout

TSI: Total Sum Insured

In each case, the loss from third-party damage was relatively small, compared to the TSI, and most loss ratios (LR) were inclined toward zero when expressed by Equation (1). For this reason, the dependent variables used in the regression analysis were converted by natural logarithms in order to meet the normal distribution. The value of the dependent variable used in the regression analysis is shown in Equation (2):

$$\text{Transformed Loss Ratio} = \ln(LR). \quad (2)$$

As mentioned, the normality test for the dependent variable was performed for the regression analysis. The LR tended to be excessively left-leaning, which required conversion to a normal distribution. As shown in Equation (2), the dependent variable was log transformed, and then the normality was tested by histogram, Q-Q plot, and Shapiro–Wilk tests (see Table 3 and Figure 2). As the p-value of the Shapiro–Wilk test was greater than 0.05, the dependent variable data can be interpreted as being normally distributed.

Table 3. Normality test of the dependent value.

Shapiro–Wilk Test								
Statistic		df	sig.		Statistic		df	sig.
LR	0.386	296	0.000	Ln (LR)	0.965	296	0.084	

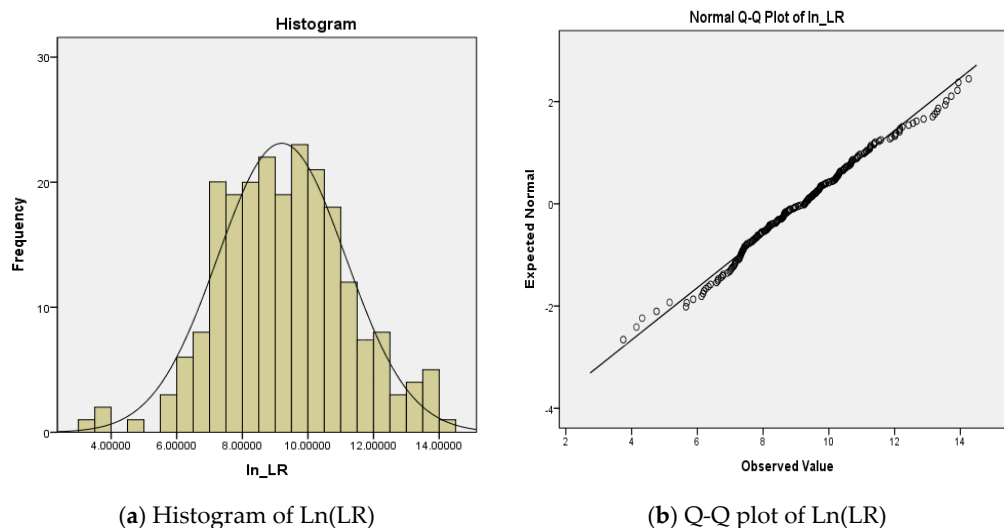


Figure 2. Normality test by histogram and Q-Q plot.

3.3.2. Independent Variables

This section introduces the independent variables in detail, focusing on how they were selected. This study included eight independent variables, which were categorized into three groups. The first is technical components, including the types of superstructures, types of foundations, construction methods, and lengths of bridges. The second group concerns natural disasters, such as floods and typhoons. The last group includes information regarding construction projects, e.g., the total duration

of construction work and the sizes of the construction companies (company ranking by amount of contract). Numerical construction information indicates the complexity, scale, and task level of the construction projects and can reflect the risk of the work [25].

Technical Components

The types of superstructures of bridges refer to the structure above the bridge's abutment and bridge deck, and are determined by the composite assessment of constructability, economic feasibility, and safety along with topographical and environmental conditions. The Korean Public Procurement Service assesses the previous performance record by classifying them into A to D grades according to the difficulty of the construction in the contractor pre-qualification criteria for bridge construction. Researchers have suggested that optimizing the selection of the superstructure types can be done on the basis of such factors as the number and length of bridge spans and the approximate construction cost [26,27]. Differentiation according to the characteristics of the superstructure types can be considered as a risk factor in bridge construction. This study classified the types of superstructures into the order of the ordinal scale of arch bridges, pre-cast concrete (PSC) beam bridges and cable-stayed bridges, by the distribution of the average loss claim payout.

In addition, for long spanned bridges, the difficulty of construction can increase, and the risks can also increase due to the influence of the increased period and the cost, as well as severe wind speed risks [28–30]. In this study, ordinal scales were classified on the basis of 50, 100, and 500 m.

The foundation of the bridge is an important structural factor in the construction of a bridge and bears important risk factors and uncertainties, which necessitate specific management of the hazards [31]. In addition to this, increased flow rates and water speeds resulting from floods and typhoons can bring about scour, which can cause unforeseen damage and the collapse of bridges [32]. This, in turn, can trigger material and third-party damage. As such, the occurrence of scour can be a fatal hazard to the life and stability of a bridge. The data collected regarding the foundation of the bridge can be used as a major risk factor, and based on the distribution of the average loss claim payouts, the classification criteria of an ordinal scale, including pre-cast concrete pile, cast in place, and open-caisson type, were established.

The superstructure construction method is determined based on economic feasibility, construction speed, and overhead clearance (valid height from the bottom of the bridge body to the surface of the water or road). Previous studies analyzed the structural safety and optimal design methods, according to bridge construction methods [33–36]. These studies found that differences existed between the influence of loads according to the construction methods and the economic design methods. For this, risk analyses based on the characteristics of the different construction methods and their classifications are required. Kim and Cho developed a rough estimation model for the construction costs according to the classification of the typical construction methods of bridge superstructures and found that the classification of the superstructure construction methods was necessary [37]. In this study, the criteria for classification of ILM (Incremental Launching Method), FCM (Free Cantilever Method), and MSS (Movable Scaffolding System) were established on the basis of the average loss claim payout through classification of the construction method.

Natural Disasters

Losses from natural disasters were calculated through indicators, e.g., typhoons and floods, using the reinsurer's Natural Disaster Assessment Network (NATHAN). The map of world natural disasters uses the existing natural disaster occurrence data to index the risks of disasters in specific areas, e.g., floods, typhoons, and earthquakes. We used the risks, such as typhoon and flood, to represent the indicators of natural disasters. Natural disaster hazards were collected using the location information (address) from each construction project site. Meteorological accidents have been considered as a key factor that affects construction risks [38,39]. Construction sites located in major hurricane-prone areas

face frequent construction delays due to hurricane-induced gusts and heavy rains, and there is a direct link to construction risks according to the risk levels of natural disasters [40–42].

Information Regarding Construction Project

In previous studies, the total duration of the project was used as a measure of the construction project risk and could be a key indicator in estimating the loss [43–45]. We found that, in these previous studies, in general building construction, the loss ratio became lower as the total period of the project became longer.

In addition, studies have suggested that the differences in the sizes of construction companies can entail notable differences in the awareness and support for safety accident prevention and risk management, which indicates that company sizes could be used as a major measure of risk analysis [46,47]. In this study, we used the company ranking by the number of contracts to indicate the size of the construction companies.

Table 4 shows the categories of the bridge project risk indicators.

Table 4. The categories of bridge project risk indicators.

Factor	Engineering			Natural Hazard		Project	
	Super-structure	Span Length	Construction Method	Foundation	Flood	Typhoon	Total Duration
Unit	Ordinal scale	meters	Ordinal scale	Ordinal scale	Ordinal scale (Zone)	Ordinal scale (Zone)	Month
Description	1: Arch 2: PSC beam 3: Cable-stayed	Max. span length	1: ILM 2: FCM 3: MSS	1: Precast conc' pile 2: Cast in place 3: Open caisson	Occurrence per year (times) Zone 1: 1 Zone 2: 2 Zone 3: 3 Zone 4: 4 Zone 5: 5	Max. speed (Km/h) 1: 76–141 2: 142–184 3: 185–212 4: 213–251 5: 252–290 6: 300–	Total duration of the project
							Company rank by contract amount

4. Results

Tables 5 and 6 show the descriptive statistics of the variables and the results of the regression analysis, respectively. Eight variables were used as independent variables, including the superstructure type, foundation type, superstructure construction method, maximum span length, floods, typhoons, total construction duration, and company rank by amount of contract. The analysis found that four independent variables were significant indicators that affected the loss ratio from third-party damage in the bridge construction. These are the superstructure type, foundation type, flood, and company rank. The p-value of the F test was less than the significance level (0.05).

Table 5. Descriptive statistics of the variables.

Variables	Min.	Max	Mean	Std. Deviation
Dependent variable				
Ln (Loss Ratio)	1.14	18.41	9.27	7.14
Independent variables				
Superstructure	1.00	2.00	1.24	0.65
Foundation	1.00	3.00	2.64	0.71
Flood	1.00	5.00	3.52	1.83
Company Rank	1.00	84.00	42.59	14.42

Table 6. Regression analyses results.

Variables	Coef.	Beta Coef.	p > z	VIF
Engineering factor				
Superstructure	4.243	0.708	0.008	1.032
Foundation	2.275	0.454	0.024	1.051
Natural Hazard factor				
Flood	1.075	0.353	0.021	1.072
Project factor				
Company rank	−0.092	−0.582	0.018	1.043
Number of Observations = 296				
F value = 16.341				
Adj-R ² = 0.361				

In addition, the independent variables, such as the superstructure construction method, maximum span length, typhoons, total construction cost, and total construction period were found to be non-significant to the dependent variable and the loss ratio, as their levels of significance were greater than 0.05. In the regression analysis of the loss ratio of the bridge construction, as illustrated in Table 5, the revised R² value was 0.361, which indicated that 36.1% of the loss ratio could be explained by the regression model. In addition, the variance inflation factor (VIF) value range shown is from 1.032 to 1.072, reflecting no multicollinearity among the variables.

The standardized coefficient (beta value) is the value of the relationship between the independent and the dependent variables that compares the influence of the independent variable on the dependent variable. In other words, the standardized regression coefficient indicates the importance of the regression coefficient, and the higher the value of the beta coefficient of the variable, the greater the effect on the dependent variable. When prioritized by the absolute value of the beta coefficient, in order to understand each indicator's impact on the loss ratio, the variables were organized as follows: (1) the superstructure type (beta coefficient = 0.708); (2) the company ranking (beta coefficient = −0.582); (3) the foundation type (beta coefficient = 0.454); and (4) floods (beta coefficient = 0.353).

According to the analysis values, when the value of the superstructure type, one of the independent variables, was changed to the ordinal scale of 1 unit, the amount of change in the loss ratio increased by 0.708. In other words, it is possible to predict that the loss from third-party damage will increase when the superstructure type of the bridge is constructed in a cable-stayed bridge rather than a PSC bridge. In terms of the impact of the construction company ranking, the results show that companies with a greater number of contracts tended to have less losses from third-party damage. Regarding the foundation types, the selection of precast concrete pile, cast in place, and open-caisson type had an influence of 0.454 on the loss ratio. When the risk level of flood increased by one level, the influence of 0.353 arose on the loss ratio. This indicates that the higher the risk rating of flood, the higher the loss ratio due to loss from third-party damage. Figure 3 shows the scatter plot comparing the results of the log transformed loss ratio and predicted log transformed loss ratio. The plot proves that both values are well matched and verified that the values were consistent.

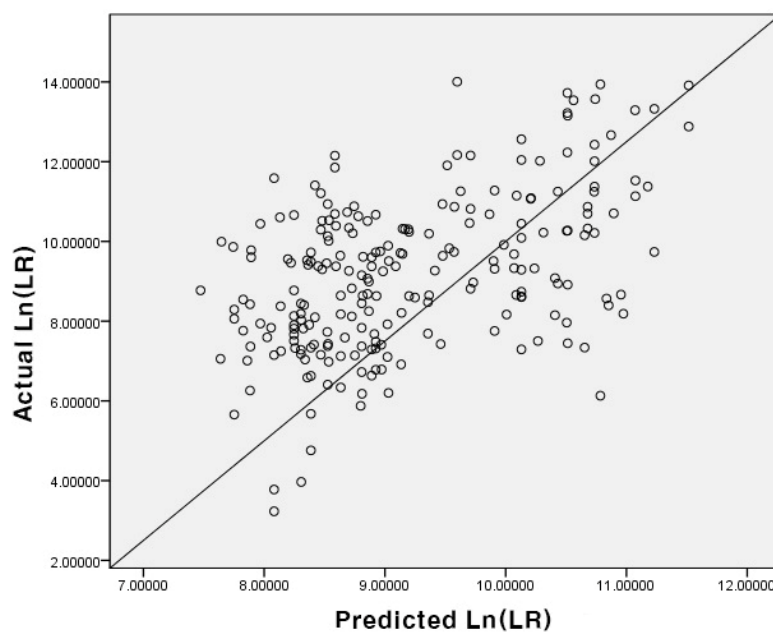


Figure 3. The scatter plot of actual Ln(LR) and predicted Ln(LR).

5. Conclusions and Discussion

Bridge construction projects increasingly require more thorough and sustainable risk management due to the scattering risks in the projects, such as heavy-duty construction equipment and high-altitude work under unstable environmental conditions. Consequently, in the fields of construction management, the processes and practices of risk assessment that align with sustainability objectives are all the more necessary. For this reason, studies that identify more objective and quantified risk factors at construction sites and develop a loss assessment models are called for.

In response to these needs, this study analyzed the financial losses that incurred to indemnify third-party damage in actual bridge construction projects and developed a loss assessment model through a multi-linear regression analysis. This was based on the data of loss claim payouts for third-party damage in bridge construction, as recorded by a Korean insurance company. The analysis found that the four independent variables, i.e., superstructure types, foundation types, floods, and construction company rank, were the significant risk factors that demonstrated actual relationships with the financial losses incurred to indemnify the third-party damage.

Some of the findings of this study demonstrated consistency with those of the previous studies. As regards to structure type, Gurcanli et al. [45] and Kim et al. [48] found that the type of structure is a key factor to be considered in construction risk analysis. In this study, we specified the types as the superstructure type, foundation type, span length, and construction method in our analysis. We found that superstructure type was a significant factor in bridge construction risk analysis.

Previous studies have shown that natural hazards played a main role in defining the risks in construction projects [38,39]. Among the natural hazards, this study found that the occurrence of flooding was proportional to the increase in third-party losses in bridge construction, which is consistent with the findings of previous studies that revealed that the elements of flooding are also key risk factors in construction projects [44]. In addition, as Kim et al. [49] contended, the results of this study also indicate that the size of a construction project affects the potential loss. This study classified the size of a construction project into two different elements, the construction duration and rank of the construction company and verified that the rank of the company is the more significant factor of the two.

This study sought to statistically analyze and evaluate the practical effectiveness of secured information in risk assessment in a situation where it is necessary to predict the future risks of bridge construction with minimum information. Therefore, the units of ordinal scale applied to the risk analysis of superstructures and foundation types, as well as construction method, do not indicate or evaluate the difficulty of the construction or the level of safety. Rather, this study identifies the statistically significant kinds and extent of the risk factors in bridge construction as reflected in the collected data. In this study, the derived risk factors had a correlation with the incurred financial losses but did not objectively explain a causal relation between them.

For example, a correlation was identified where the higher the construction company rank, the less loss from third-party damage, while the causal relationship between the two, such as whether the reason for the decrease in the loss ratio was due to decent risk management or disaster prevention measures within the company, is still unexplainable. Therefore, further studies are required in order to obtain more effective risk assessment measures through additional investigation and analysis to identify the causal relationship in the future. In addition, this study used loss claim payout data from only one Korean insurance company. Further research is needed to support this study and its reliability based on data from many other insurers and their loss data to reflect a wide range of characteristics in construction projects.

As this study verified the quantified risk factors that reflected the actual loss claim payout record and presented the framework used for deriving the factors and developing the loss assessment model, the results can be used as important references for the government, construction companies, insurance and re-insurance companies, and others related to bridge construction projects, all of whom aim to manage and minimize the risks and consequential financial losses in bridge construction management. In particular, insurance and reinsurance companies can refer to this study to reconstruct their own loss assessment model of measuring the potential risks for particular bridge construction projects and to adapt the results from the model in estimating the rates of premiums.

Construction companies can benefit from this study, as we provided a substantial risk assessment for third-party loss in bridge construction based on the predicted total value of property, structure type, and the foundation type of the bridge. By doing so, such information can be reflected in predicting the life cycles and consequential management costs for third parties as well as for the bridge. This is because having risk factors for third party damage in bridge construction projects are quantified and proportioned helps in managing, responding to, and ultimately reducing potential loss.

Thus, the framework and the findings of this study will be able to contribute to improving the bridge construction companies' judgment in risk management. In addition, for the central and local governments and government-invested institutions, the utilization of the findings of this study is also expected to contribute to the establishment of effective measures and regulations of risk management and prevention that reflect the characteristics of actual damage and losses in bridge construction projects. This study is also expected to be applicable to other regions and countries where the construction environment and the natural disasters are similar to Korea. Taking particular consideration of the issues surrounding bridge superstructure types, foundations, floods, and company ranks, which were the four significant risk factors found in this study, will allow various resources to be efficiently distributed and allocated, ultimately contributing to robust and sustainable risk management in bridge construction.

Overall, this study is novel as it provided quantified and therefore measurable risk factors in bridge construction. In this study, we derived the risk factors based on the data of the actual accidents that occurred in bridge construction projects that had been carried out and developed a loss prediction model. These two outcomes of this study are believed to be useful for risk management in the construction industry, especially in the sense that this study was based on the numerical and tangible records of construction accidents, which were then perceptibly represented in financial values.

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