



IMPLEMENTATION OF RISK MANAGEMENT IN SUSTAINABLE BRIDGE CONSTRUCTION

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Abstract

The Indonesian government is currently intensifying infrastructure development, with bridge construction being one of its key initiatives. The Pandansimo Bridge is built over the Progo River in Ngentak, Poncosari, Srandakan, Bantul Regency, connecting to the Kulon Progo Regency in the Yogyakarta Special Region, Indonesia. The bridge plays a crucial role in transportation mobility, economic sector development, and logistics in the Bantul and Kulon Progo regions. However, the construction of the Pandansimo Bridge involves various risks, one of which is earthquakes, as the bridge is located only 10 km from the Opak Fault, which caused a major earthquake in 2006. Therefore, a risk management study is essential in constructing the Pandansimo Bridge. This study aims to identify potential risk factors that may arise during construction, determine the level of risk, and control potential risks that could impact the bridge's sustainability and functionality. The initial step involves identifying risk sources through literature studies and interviews. Subsequently, risk assessment is conducted through questionnaires, followed by risk analysis. The risk rating matrix is used to classify risk levels. The analysis identified seven main risk sources with thirty-seven specific risks, of which seven are classified as high-risk: flooding, river overflow, unpredictable weather conditions, frequent equipment failures, earthquakes, material damage or theft, and unstable soil conditions. Mitigation strategies are integrated into urban planning to ensure the sustainability and resilience of Pandansimo Bridges. The mitigation measures implemented are improved drainage systems, riverbank reinforcement and embankments, bridge elevation and structural adaptation, early warning and monitoring systems, and sustainable land use planning.

Keywords: Infrastructure, Bridge, Risk Management, Risk Factor, Risk Rating

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INTRODUCTION

One of the infrastructure developments currently being promoted by the Indonesian government is the construction of bridges. A bridge is a structure that connects two parts of a road that are cut off due to obstacles such as deep valleys, rivers, railroads, and so on.

On the south coast of Yogyakarta, the Pandansimo Bridge was built. The Pandansimo Bridge stands 1,900 meters above the Progo River, connecting the Srandakan District in Bantul Regency with the Galur District in Kulon Progo Regency. The construction of the Pandansimo Bridge is a priority program as it is part of the Trans-South Java route, which is expected to improve the community's economy, promote economic equality, and support the development of tourist destinations in Southern Java.

The Pandansimo bridge was designed with attention to environmental sustainability with local cultural aesthetics. Namely, in the middle of the bridge, it is designed using mountains with typical Yogyakarta batik motifs. Along the bridge, typical south coast plants such as shrimp pine are planted. On the right and left, pedestrian paths are made for those who want to enjoy the beauty.

In bridge construction, there are many risks. The risks that occur can cause losses. According to Rivida et al. (2019), risks can affect productivity, performance, and costs. According to several studies, the risks associated with bridge construction vary. There are also risks in the construction of the Pandansimo bridge. One of the risks that occurs is an earthquake. It occurs because D.I. Yogyakarta is an area with a complex geological structure and is located near the plate collision zone. The presence of fault activity on the surface, namely the Opak-Oyo fault, causes the Yogyakarta area to experience a fairly high earthquake frequency (Wibowo and Sembri, 2017).

Meanwhile, the Pandansimo bridge is located near the epicenter of the Opak fault earthquake with a radius of less than ten km. Therefore, the Pandansimo bridge is designed to be earthquake-resistant. Although it has been designed to be earthquake-resistant, it still has a liquefaction vulnerability, which causes the construction of this bridge to be included in the category of high-risk projects, in addition to the risk of earthquakes. Other risks arise, including social problems that have numerous impacts, both negative and positive, on the surrounding environment.

Not all risks that will occur can be prevented. These risks can be minimized. It is done to reduce the losses that will be incurred. To minimize the occurrence of risk, risk management is needed. Risk management is a science used to identify, analyze, and respond to risks. The purpose of this research is to identify risk factors that affect construction. In addition, it is also necessary to calculate the level of risk that occurs and how to handle the risk.

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LITERATURE REVIEW

Risk Management

Risk contains the possibility that it could cause a loss. Risk can be defined as an uncertain condition that, if it occurs, can hinder the objectives of a project (Mbachu and Taylor, 2014). Risks can occur in construction, such as bridges or some types of construction projects (Safayet et al., 2018). The owner, consultant, or contractor can experience the risks that occur. According to Sebayang et al. (2018), the risk is the potential for an incident to occur that can be avoided and minimized so that the impact that occurs is as small as possible according to the plan or can be accepted above the permitted tolerance. To minimize losses caused by risk, risk management is needed. The risks that will occur can be minimized by using risk management. Risk management, as defined in PMBOK (2013), is a systematic process that involves identifying, analyzing, responding to, and controlling risks on a project. In risk management, there are several stages, namely risk management planning, risk identification, risk analysis, risk response planning, risk monitoring, and control.

Risk Identification

Risk identification is carried out to identify potential problems. Therefore, in identifying risks, it starts with identifying the source of the problem. Mohamed Azmi and Ramli (2023) explain risk management in construction property projects based on strata-titled, including employee competencies, litigation, financial liquidity, non-compliance laws, security management, and customer service. Abdullah Habib et al. (2020) identified risks based on risk sources, namely social, legal, political, contractual, financial, process, and technical risks. Meanwhile, Septiani et al. (2015) identified risks at the construction stage, namely licensing (pre-construction), design and study, land acquisition, financing, construction (construction), risk equipment, force majeure, and social politics. Another risk that occurs in construction is work accidents. According to Nik Him et al. (2023), the construction sector is known for its high risk of work accidents. Work accidents can occur due to several factors, including workers' negligence in performing tasks or being in unhealthy conditions without using personal protective equipment. According to Damayanti and Wahyuningsih (2023), the number of work accidents in construction increased by 5.7% in 2021 and by 12.36% in 2022.

Risk Assessment

After risk identification based on the risk source, a risk assessment is carried out. Risk assessment will prioritize the risks that need to be managed based on the predefined risk categories, such as project, design, material, labor, financial, and human risks (Mohd Nawawi et al., 2020). Risk assessment is carried out to determine the level of possibility and level of impact, where the possibility and impact are given a score of 1 to 5. After the risk assessment is carried out, the risk level can be determined using a risk level matrix.

Risk Response Planning

Risk response planning is grouped into several categories. The first approach is to avoid risk by not carrying out activities that can cause it. Another strategy is reducing risk through mitigation, where the risk that occurs can be reduced by implementing measures that minimize the potential impact. In some cases, accepting risk may be appropriate, which means accepting the losses that arise; this approach can be adopted when the risk is relatively small and manageable. Finally, risk can be transferred to another party, allowing organizations to shift the potential consequences to entities better equipped to handle them or through mechanisms such as insurance or outsourcing arrangements.

RESEARCH METHODOLOGY

This study began by conducting risk identification to find the source of risk. It was obtained from literature studies and field observations. Field observations were conducted through interviews with related parties. The related parties are the service providers for the construction of the Pandansimo bridge. From the results of the interviews, seven sources of risk were obtained. The seven sources of risk are project risk, technical risk, natural risk, human resource risk, financial risk, and environmental risk. From the seven sources of risk, thirty-seven risks were obtained.

Based on the interview results, a questionnaire was created. Six individuals from competent service providers completed the questionnaire. The questionnaire aims to assess the likelihood and magnitude of potential risks. In the questionnaire, a scale of likelihood and impact is created so that a risk assessment can be carried out. The scale of likelihood and impact can be seen in Tables 1 and 2.

Table 1: Likelihood

Likelihood	Scale
Usual	5
Likely	4
Possible	3
Unlikely	2
Rare	1

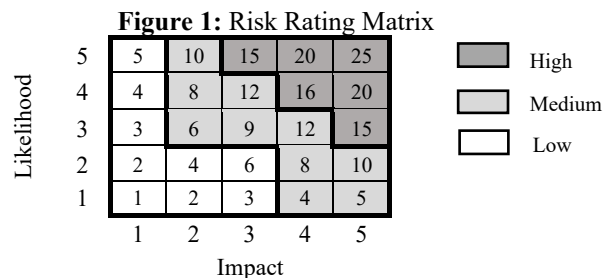
Source: Standards Australia/Standards New Zealand (AS/NZS: 4360) in Rifani et al. (2018)

Table 2: Impact

Impact	Scale
Severe	5
Major	4
Moderate	3
Minor	2
Incidental	1

Source: Revantoro, et al. (2017)

From the results of the questionnaire distribution, the probability level and impact level were obtained. Next, a risk analysis was carried out. In analyzing the likelihood of occurrence and its impact, the average value was found. Then, we multiply the likelihood of occurrence by the impact to determine the risk rating. The risk rating is grouped into low risk, medium risk, and high risk. Then the risk level is entered into the risk rating matrix. The risk rating matrix can be seen in Figure 1.



Source: Sebayang, et al. (2018)

RESULTS

From the literature study and the results of interviews with service providers in the construction of the Pandansimo bridge, risk identification was obtained. Risk identification was carried out to determine the source of risk. From the results of risk identification, seven risk variables were obtained, namely project risk, engineering risk, natural risk, human resource risk, occupational health and safety risk, financial risk, and environmental risk. From the seven risk variables, thirty-

seven risk indicators were obtained. The seven risk variables and thirty-seven risk indicators obtained from the results of risk identification can be seen in Table 3.

Table 3: Risk Identification

Source of Risk	Code	Indicator
Project Risk	RK1	Lack of availability of large-scale material unloading sites
	RK2	Damage or loss (theft) of materials
	RK3	Delay in the delivery of materials from suppliers
	RK4	Materials that do not meet requirements
	RK5	Slow delivery of construction equipment
	RK6	Lack of available labor in the field
	RK7	Difficult site conditions
	RK8	Differences in basic soil conditions
	RK9	Difficulty in installing foundations
	RK10	Concrete quality does not meet specifications.
	RK11	Wrong implementation methods
	RK12	Structural collapse
Technical Risk	RK13	The equipment used is often damaged
	RK14	Damage or interference with lifting equipment
	RK15	Design changes
	RK16	Incomplete design data
Natural Risk	RK17	River overflows
	RK18	Earthquakes
	RK19	Floods
	RK20	Unpredictable weather
Human Resource Risk	RK21	Lack of personnel who can operate certain equipment
	RK22	Security disturbances at the project site
	RK23	Less disciplined equipment operators (arrive late) so that productivity is less than optimal
	RK24	Unskilled labor
	RK25	Low labor productivity
	RK26	Ineffective working hours
	RK27	Lack of control and coordination within the team
	RK28	Inexperienced staff
Occupational Health and Safety Risks	RK29	Lack of worker discipline in using PPE
	RK30	Lack of implementation of K3 in the field
Financial Risk	RK31	Cost estimation error
	RK32	Time estimation error
Environmental Risk	RK33	Unstable soil conditions
	RK34	Water pollution
	RK35	Soil pollution
	RK36	Air pollution
	RK37	Endemic flora and fauna population

Source: Data processing (2024)

After risk identification is done, the next step is to conduct a risk assessment. This risk assessment is obtained from the results of filling out the

questionnaire from the service provider. The likelihood level is obtained with the impact level. Then conduct a risk analysis. In analyzing the risk, the impact that occurs with likelihood is multiplied. The results of the risk analysis for the risk assessment can be seen in Table 4.

Table 4: Risk Assessment Results

Source of Risk	Code	Impact	Probability	Risk	Risk Level
Project Risk	RK1	4.0	2.0	8.00	Moderate
	RK2	4.3	3.8	16.61	High
	RK3	3.8	3.0	11.50	Moderate
	RK4	4.5	2.0	9.00	Moderate
	RK5	3.5	3.0	10.50	Moderate
	RK6	4.0	2.2	8.66	Moderate
	RK7	3.2	3.0	9.50	Moderate
	RK8	3.7	3.0	11.00	Moderate
	RK9	3.5	3.0	10.50	Moderate
	RK10	5.0	2.0	10.00	Moderate
	RK11	5.0	2.0	10.00	Moderate
	RK12	5.0	2.0	10.00	Moderate
Technical Risk	RK13	4.2	4.0	16.66	High
	RK14	3.3	3.5	11.66	Moderate
	RK15	3.8	3.0	11.50	Moderate
	RK16	4.3	2.5	10.83	Moderate
Natural Risk	RK17	4.0	4.3	17.33	High
	RK18	4.3	3.8	16.61	High
	RK19	4.0	4.3	17.33	High
	RK20	4.2	4.0	16.66	High
Human Resource Risk	RK21	3.7	2.3	8.55	Moderate
	RK22	3.0	2.8	8.50	Moderate
	RK23	4.7	2.0	9.33	Moderate
	RK24	3.5	2.6	9.33	Moderate
	RK25	3.8	2.0	7.66	Moderate
	RK26	3.8	3.0	11.5	Moderate
	RK27	4.7	2.0	9.33	Moderate
	RK28	3.5	2.0	7.00	Moderate
Occupational Health and Safety Risks	RK29	3.7	3.0	11.00	Moderate
	RK30	4.3	2.0	8.66	Moderate
Financial Risk	RK31	4.5	2.0	9.00	Moderate
	RK32	4.0	2.5	10.00	Moderate
Environmental Risk	RK33	5.0	3.0	15.00	High
	RK34	3.0	2.0	6.00	Low
	RK35	3.0	2.0	6.00	Low
	RK36	4.0	2.8	11.33	Moderate
	RK37	3.0	2.0	6.00	Low

Source: Data processing (2024)

The results of the risk assessment are entered into the risk rating matrix. The risk levels that occur can be seen in Figure 2.

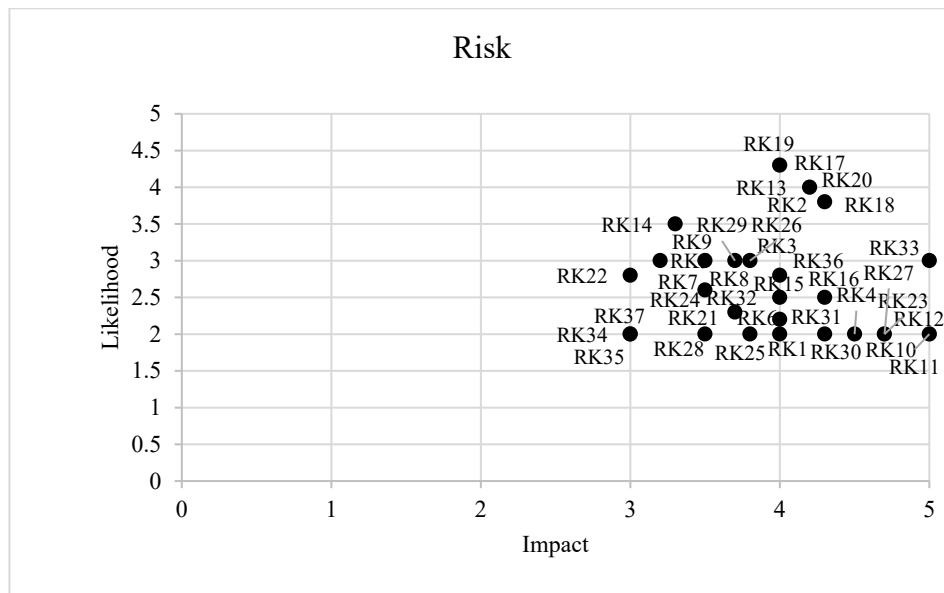


Figure 2: Risk Level Matrix
Source: Data processing (2024)

DISCUSSION

Risk According to Contractor Perception

Based on the contractors' perception, seven sources of risk have been identified. These seven sources encompass a total of thirty-seven risks. The analysis results indicate that three risks fall into the low-risk category, twenty-seven risks are classified as moderate, and seven risks are categorized as high. The high-risk category includes project risk variables (RK2), engineering risk variables (RK13), natural risk variables (RK17, RK18, RK19, RK20), and environmental risk variables (RK33). The high-risk levels can be observed in Table 5.

Table 5: High Risk Level

Source of Risk	Code	Probability	Impact	Risk	Risk Level
Project Risk	RK2	3.83	4.33	16.61	High
Technical Risk	RK13	4	4.16	16.66	High
	RK17	4.33	4	17.33	High
	RK18	3.83	4.33	16.61	High
Natural Risk	RK19	4.33	4	17.33	High
	RK20	4	4.16	16.66	High
Environmental Risk	RK33	3	5	15.00	High

Source: Data processing (2024)

The Pandansimo Bridge is located approximately 10 kilometers from the Opak Fault, which was responsible for the earthquake in 2006. Due to this seismic risk, the construction of the Pandansimo Bridge incorporated *Lead Rubber Bearing* (LRB) technology to enhance its structural resilience.

LRB is a type of seismic isolator composed of laminated rubber, a lead core, and steel plates, designed to increase deformation capacity and dissipate energy during earthquakes.

The implementation of LRB serves several important purposes in bridge engineering. First, it provides damping of seismic vibrations, thereby reducing the transmission of earthquake forces to the main structure. Additionally, LRB enhances bridge flexibility, allowing it to adapt to ground movements caused by tectonic activity. Finally, this technology contributes to extending the service life of the bridge by minimizing damage from dynamic loads, ultimately improving the structure's long-term performance and safety under seismic conditions. In addition to LRB technology, the Pandansimo Bridge is also equipped with earthquake detection instruments. It enables the mitigation of potential losses during seismic events. Thus, the application of LRB in the Pandansimo Bridge is an integral part of an urban planning strategy focused on disaster resilience and sustainable development. With this technology, the bridge can function optimally in supporting regional mobility and economic activities while providing maximum protection against earthquake risks.

Pandansimo Bridge, situated in a dynamic coastal and riverine environment, is susceptible to river overflow, especially during heavy rainfall and extreme weather events. Flooding can disrupt transportation, damage infrastructure, and threaten surrounding communities. Therefore, mitigation strategies must be integrated into urban planning to ensure the bridge's sustainability and resilience.

Mitigation strategies for river overflow encompass a comprehensive approach involving multiple engineering and planning solutions. Improved drainage systems play a crucial role, where efficient drainage channels and retention ponds are constructed around the bridge to control water flow and reduce surface runoff, with proper stormwater management preventing excessive water accumulation on the bridge and nearby roads. Riverbank reinforcement and embankments provide additional protection by strengthening riverbanks with retaining walls, gabions, and vegetation to prevent erosion and reduce flooding risk, while elevated embankments along the river serve as protective barriers during high water levels. From a structural perspective, bridge elevation and adaptation are essential, with the bridge deck designed at sufficient height to minimize the impact of rising water levels and the use of flood-resistant materials ensuring durability even in extreme conditions. Early warning and monitoring systems enhance preparedness through sensors that detect changes in water levels and flow rates, enabling authorities to issue flood warnings and take preventive

actions such as temporary road closures or traffic diversions. Finally, sustainable land use planning integrates the bridge's flood mitigation plan with broader urban planning policies, ensuring that surrounding land use does not exacerbate flooding through proper zoning regulations, watershed management, and green infrastructure that help control water absorption and flow.

Thus, the Pandansimo Bridge can continue to function optimally even in the event of an increase in river discharge. Moreover, the implementation of these mitigation strategies contributes to the sustainability of infrastructure and the resilience of the surrounding environment, ensuring that the bridge can continuously support community mobility and regional economic development safely and sustainably.

It was known that seven high risks occurred in the construction of the Pandansimo bridge, namely flood, river overflow, unpredictable weather, equipment used is often damaged, earthquake, damage or loss (theft) of materials, and unstable soil conditions. Then it is necessary to carry out seven risk controls. This risk control was obtained from the results of interviews with the service provider. This risk control is carried out to minimize the occurrence of risk. Risk control can be seen in Table 6.

Table 6: Risk Control

No	Code	Risk Variables	Description
1	RK19	Flood	Work is temporarily stopped, and equipment is moved to higher ground.
2	RK17	River overflow	Monitoring local rainfall and river water discharge to predict flooding.
3	RK20	Unpredictable weather	Maximizing work productivity is best when the weather is sunny.
4	RK13	Equipment used is often damaged	Conduct equipment maintenance before and after routine use, and consider bringing in more productive equipment.
5	RK18	Earthquake	The bridge is designed to be earthquake-resistant with LRB (Lead Rubber Bearing) technology, which increases resistance to earthquakes by reducing lateral forces, thereby preventing deformation or damage to the building. Conducting an emergency evacuation to a safer location away from the buildings.
6	RK2	Damage or loss (theft) of materials	Enhanced supervision is being implemented for individuals entering and leaving the project.
7	RK33	Unstable soil conditions	Conducting land repairs, such as rehabilitation.

Source: Data processing (2024)

CONCLUSION

The conclusion of the research on risk management in the Pandansimo Bridge case study is that, based on interviews with contractors, seven sources of risk were identified, namely project risk, technical risk, natural risk, human resource risk, financial risk, and environmental risk. From the seven sources of risk, thirty-seven risk variables were obtained. Risk analysis was obtained from the contractor's assessment to determine the level of impact and frequency, thereby assessing the level of risk. From the results of the risk analysis, high-level risks were obtained, namely flooding, river overflows, equipment used is often damaged, earthquakes, damage, loss (theft) of materials, and unstable soil conditions. These seven high risks require risk control. This risk control is to minimize the occurrence of risk. The seven controls are work is temporarily stopped, equipment is moved to highlands, monitoring local rainfall and river water discharge to anticipate flooding, carrying out maximum and optimal work productivity during good or sunny weather, carrying out equipment maintenance before and after routine use or bringing in more productive equipment, bridges are designed to be earthquake resistant with LRB (Lead Rubber Bearing) technology to increase earthquake resistance by reducing lateral forces so that there is no deformation or damage to the building, carrying out emergency evacuation to a safer place and away from the building. Increasing supervision of people entering and leaving the project, and carrying out land improvements such as rehabilitation.

ACKNOWLEDGEMENT

This research is supported by internal funding from the Universitas Semarang (USM).

CONFLICT OF INTEREST

The authors have no conflict of interest with any parties in writing this article.

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Received: 2nd May 2025. Accepted: 10th September 2025