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Risk Analysis of Steel Railway Bridges Based on Rating Factor, Earthquake, and Importance Factor

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ABSTRACT

Railway bridges are critical infrastructure components that are essential to support and maintain the integrity of major rail transportation networks. Indonesia is located in a tectonic zone known as the Ring of Fire. Risk assessment of these bridges is critical. This research not only considers the physical condition or vulnerability of the bridge itself but also the risk posed by earthquakes and the level of importance of the bridge. The research was conducted on 4 bridges located in East Java Province, namely the BH-129, BH-262, BH-275, and BH-314 Bridges. The rating factor, hazard level, and importance factor influence the risk level. The assessment process starts by using the Bridge Management System (BMS) method and Structure Analysis Program (SAP2000) to assist in calculating the Rating factor. Determining the level of danger by referring to the Earthquake Hazards Map and the Indonesian Earthquake Code (SNI 2833: 2016), The importance is taken based on the level of operational importance of the bridge referring to the same standard. The results show that the four bridges have the same risk value of 0.7809 for each bridge. The results underscore the urgent need for proactive measures to reduce the potential adverse impacts of bridge structure failure. Recommended interventions include strengthening structural elements, increasing inspection frequency, improving maintenance protocols, and, if necessary, replacing compromised structures. These strategies are critical due to the high risk and significant impact on rail safety and operations, especially in areas prone to natural disasters. The results of this study reinforce the urgency of improving the resilience of bridge infrastructure to earthquake threats to maintain the stability and safety of rail transportation in Indonesia.

Keywords: railway bridge, rating factor, hazard, importance factor, risk.

INTRODUCTION

The train is one of the alternative modes of transportation infrastructure in Indonesia. Given that Indonesia is located in the Ring of Fire, it is crucial to account for the effects of earthquakes (hazards) in the design and operation of railway bridges. The railway bridge is a specific railway structure that serves to extend the railroad over obstacles such as rivers, valleys, straits, and other geographical features [1]. Most of the railway bridges in Indonesia are over 50 years old. One critical reason for assessing the impact of earthquakes is that the seismic design standards in effect at the time of their construction need to be updated or considered in the original design. An earthquake is a geophysical phenomenon involving the abrupt release of energy in the form of seismic waves, resulting in ground shaking at a specific location and lacking a prolonged duration. Earthquakes can be triggered by various factors, including tectonic plate movements, landslides, volcanic activity, explosions, and human-induced activities. The depth of the earthquake’s hypocenter is classified into deep, intermediate, and shallow categories, depending on its distance from the Earth's surface [2]. An earthquake's depth is a key factor in determining its potential destructive intensity. Shallow earthquakes, being closer to the surface, tend to produce higher ground shaking levels and greater damage than more profound seismic events [3]. To manage seismic risks, Indonesia has utilized three official earthquake hazard maps, which have been progressively developed and applied to the design of earthquake-resistant structures and infrastructure since 1983 [4]. Earthquake response considerations are crucial in the structural design process. However, after the structure has been built, it is important to have a periodic maintenance schedule during its service life so that the bridge can last according to plan. Periodic maintenance is also carried out by adjusting the condition value of the bridge structure [5]. A vulnerability assessment with a comprehensive conceptual framework to determine risk is a method that can be used in the actual evaluation of bridge conditions [6]. One of them is physical damage to bridges due to earthquakes that seriously impact infrastructure and cause economic effects on the transportation system [2]. Physical damage also contributes to the loss directly because it impacts safety [7]. Actions that need to be taken to reduce the adverse impacts are identifying hazards and assessing and managing risks [8]. Inspection of bridge structures is crucial for determining which bridges should be prioritized for maintenance, repair, or replacement. As a key aspect of the Bridge Management System (BMS), this process involves reviewing the severity of the damage, environmental conditions, structural geometry, material performance, and load demands [9]. The vulnerability value derived from the Bridge Management System (BMS) is a key factor in calculating the Rating Factor *RF*. The *RF* must typically satisfy the condition $RF \geq 1$, indicating that the structural element safely withstands the applied loads and possesses a reserve capacity beyond the design requirements. Conversely, an $RF < 1$ suggests that the element does not meet the safety criteria [10].

The aim of considering components of the rating factor, earthquake, and importance is Risk Assessment. Risk Assessment serves the purpose of decision-making to plan (1) optimal security measures, (2) maintenance, and (3) countermeasures [11]. Each country needs to improve planning by systematically incorporating risk information and improving safety [12].

RESEARCH METHODS

Methods

Risk analysis is based on assessing the risk levels derived from the Rating factor, Hazard level, and Importance factor. The rating factor is influenced by the vulnerability rating used in this analysis. It is based on the guidelines set by the Bridge Management System (BMS), as stated in Guideline [13]. The survey location can be determined as shown in Figure 1 to Figure 5.

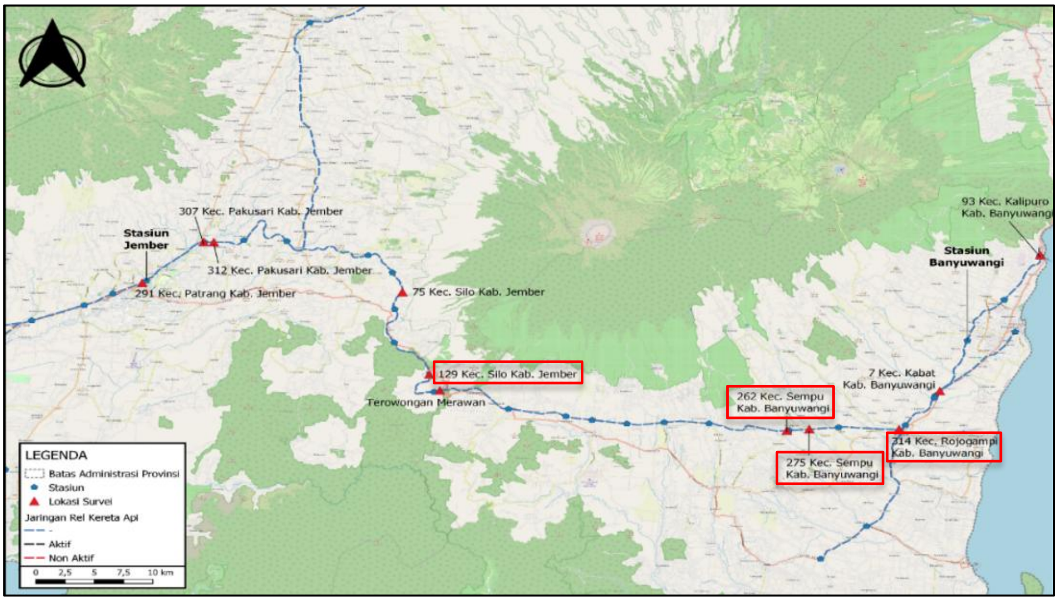

Figure 1. Bridges Location [14]

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Figure 2.
Bridge inspection
(BH – 129)

Figure 3.
Bridge inspection
(BH – 262)

Figure 4.
Bridge inspection
(BH – 275)

Figure 5.
Bridge inspection
(BH – 314)

The survey was conducted by considering various aspects of the damage identified in the structure by the inspection guidelines. The assessment was conducted comprehensively by evaluating the structural elements based on five main parameters: Structure (*S*), Damage (*R*), Quantity *(K*), Function (*F*), and Performance (*P*). The assessment is conducted by giving each parameter a score between 0 and 1. The condition of each structural element is systematically classified into five grading levels, with level 1 indicating the optimal condition and level 5 representing severe deterioration. This assessment methodology is designed to comprehensively evaluate the structural integrity while identifying critical elements that require additional inspection, maintenance, or remedial action.

The specific criteria for each assessment parameter and the scoring process can be seen more clearly in Table 1, which is attached.

Table 1. Bridge Management System Variables and Criteria [13]

Variable	Criteria	Condition Rating
Structure (*S*)	Unsafe	1
	Safe	0
Damage (*R*)	Severe	1
	Not Severe	0
Quantity (*K*)	More than 50%	1
	Less than 50%	0
Function (*F*)	Element not in function	1
	Element in function	0
Performance (*P*)	Effects other elements	1
	Not affect other elements	0
Condition Rating (*CR*) = (*S*+*R*+*K*+*F*+*P*)		0 s/d 5

The condition ratings obtained from the field survey, particularly concerning the superstructure, are processed to derive the condition factors listed in Table 2. Combined with the reduction coefficients from Table 3, these factors are used to calculate the Rating Factor *RF* following the provisions of Guideline No. 3/SE/M/2016, as outlined in the adjusted Equation 1.

Table 2. Factors due to Superstructure Condition [16]

Condition Rating of Superstructure	Factor Superstructure Condition (φ_c)
0	1.00
1	1.00
2	0.90
3	0.70
4	0.30
5	0

Table 3. System Factor of Steel Structure [16]

Element	System Factor of Steel Structure (φ_s)
Flex	0.90
Shear	0.90
Axial Compression	0.85
Tensile Axial to Tensile yield strength	0.90
Axial Tensile to strong Tensile flexure	0.75
Shear Connections	0.75
Bolt Connection	0.75
Full penetration blunt weld connection	0.90
Angle weld and blunt weld connection of partial penetration	0.75

$$RF = \frac{(\varphi_c \varphi_s \varphi M_n) - ɣ_{DL} Mu_{(DL)}}{ɣ_{LL} Mu_{(LL)}} \quad (1)$$

In Guideline [15], *RF* represents the Rating Factor, which determines whether a structural element can safely withstand the applied loads, with values of $RF \geq 1$ indicating sufficient reserve capacity and structural safety. The parameter φ_c is the reduction factor associated with the condition of the superstructure, reflecting the degree of deteriorations. The factor φ_s accounts for the system's structural characteristics, particularly for steel structures, while φ denotes the LRFD (Load and Resistance Factor Design) reduction factor, ensuring safety under different loading conditions. The nominal moment capacity, M_n, represents the theoretical strength of the structural element before failure, derived from material properties and geometry. Meanwhile, $M_{u\ (DL)}$ and $M_{u\ (LL)}$ are the ultimate design moments due to dead and live loads, respectively, calculated based on load combinations prescribed by design codes. The load factors ɣ are applied to dead and live loads to account for load magnitudes and distribution uncertainties. Together, these parameters provide a comprehensive framework for assessing the reliability of structural elements under combined loading scenarios, ensuring compliance with safety standards and design specifications.

A similar approach to determining *RF* can also be applied to shear capacity evaluation. In this case, the formula adapts to account for the nominal shear capacity V_n, and the design shear forces from dead and live loads are $V_{u\ (DL)}$ and $V_{u\ (LL)}$. The modified formula is expressed as Equation 2

$$RF = \frac{(\varphi_c \varphi_s \varphi V_n) - ɣ_{DL} V_{u(DL)}}{ɣ_{LL} V_{u(LL)}} \quad (2)$$

This approach is particularly critical for bridge assessments, where safety, durability, and functionality are paramount. The factor rating value only consists of 2 categories where a level description is added to help; for the category, a Rating Factor more than or equal to 1 is declared good or level 1, and a Rating Factor less than 1 is declared less good or level 2, as can be seen in Table 4.

Table 4. Level Rating Factor [15]

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Rating Factor	Level
$RF \geq 1$	1
$RF < 1$	2

The next step is to calculate the earthquake hazard value for each bridge using data from the lini.binamarga.pu.go.id website. This process requires the input of the bridge's geographical coordinates in longitude and latitude format. The resulting output is the S_{D1} value, which indicates the spectral acceleration response at one second, essential for evaluating the seismic behavior of the bridge. The accuracy and suitability of the S_{D1} values obtained need to be confirmed through additional calculations based on national standards [16]. This standard provides detailed guidelines for calculating and assessing seismic parameters in the Indonesian region. The S_{D1} values that have been obtained are then compared and adjusted to the earthquake zone calcification criteria set out in [16], as referenced in Table 5. This process aims to identify the specific seismic zone in which the bridge is located, allowing a more precise assessment of the potential seismic risks that may affect the stability and integrity of the bridge structure.

Table 5. Seismic Zone Based on S_{D1} Value[16]

Coefficient of acceleration (S_{D1})	Seismic Zone
$S_{D1} \leq 0.15$	1
$0.15 < S_{D1} \leq 0.30$	2
$0.30 < S_{D1} \leq 0.50$	3
$S_{D1} > 0.50$	4

The next step involves determining the importance factor of the bridge, which is based on its operational significance, as illustrated in the provisions outlined in the [16], as illustrated in the accompanying table 3.

Table 6. Importance Factor Based on the Operational importance of the bridge [16]

Condition	Importance Factor
An important or very important bridge	1.05
Typical bridge	1.00
Less important bridge	0.95

Data Analysis

The risk R is determined by multiplying the rating factor RF with 2 as a maximum value and 1 as a minimum value. Next is seismic zone H, which has a maximum value of 4 and 1 as the minimum. Last, the factor importance I is 1.05 for the maximum value and 0.95 as the minimum value, producing a total risk level. The value of each component is normalized, as shown in Equation 2, which is a modified formula based on the regulation issued by the Badan Nasional Penanggulangan Bencana (BNPB), No. 02 of 2012.

$$R = \left(\frac{RF}{RF_{max}} \times \frac{H}{H_{max}} \times \frac{I}{I_{max}}\right)^{\frac{1}{n}} \quad (3)$$

The risk results are categorized as outlined in Table 7, with the categories and range values adjusted accordingly to reflect the specific conditions of the assessment.

Table 7. Criteria for risk levels [17]

Range	Description	Control type
0.484 – 0.613	Low	Administrative
0.613 – 0.742	Mid	Technical
0.742 – 0.871	High	Substitution
0.871 – 1.000	Extreme	Elimination

Risk mitigation categories are considered regarding the risk control hierarchy in the [18] standard. This standard provides systematic guidance in risk management with the primary objective of reducing the impact of disasters on occupational safety and health. This hierarchy of controls consists of several sequential levels, ranging from the least effective to the most effective. The order of the hierarchy is the elimination, substitution, technical, administrative, and finally, the use of personal protective equipment (PPE), which can be seen in Figure 6. [18]

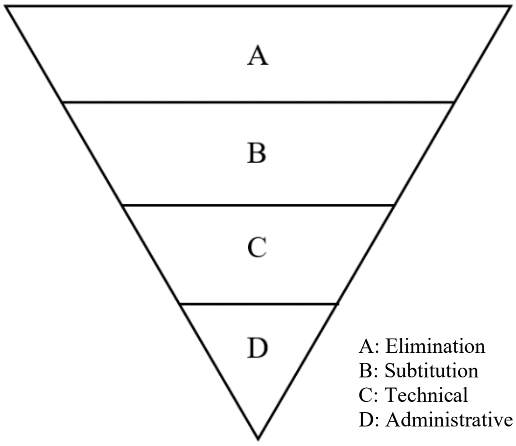

Figure 6. The hierarchy of risk control [18]

Elimination involves eliminating the risk, the most effective method of handling risk. If elimination is impossible, the second step is substituting the risk with something less dangerous. The third step, technical, is an effort to minimize risk by modifying the infrastructure or using certain technologies. The fourth step, administrative, is an action in the form of training, work procedures, and policies to reduce risk exposure. Finally, the use of PPE, but the use of PPE, in this case, is quite complicated because the passengers are always changing, and the number is not fixed, so the last step of using PPE needs to be considered.

RESULT AND DISCUSSION

The direct survey result at the location produced similar condition values in the four bridges reviewed, where the four bridges experienced some corrosion on the steel elements caused by anti-rust paint that had peeled off in several parts. Each bridge component is evaluated based on predefined criteria, resulting in the corresponding bridge condition rating, as presented in Table 8**.**

Table 8. Superstructure Condition Rating

Bridges	**Element**		**Level 1**
	Code	**Description**	**CR**
BH – 129	2.400	Superstructure	3
BH – 275	2.400	Superstructure	3
BH – 262	2.400	Superstructure	2
BH – 314	2.400	Superstructure	3

Furthermore, the calculation of rating factors consisting of the Nominal Moment M_N of the cross-section obtained from calculations based on SNI 1729: 2020, design moment of Dead Load *DL*, Live Load *LL*, Additional Load *DW,* Impact Load *IM* on one of the bridge elements and also factors used such as condition factors φ_c based on the condition of the superstructure, system factors φ_s taken in the form of bending, LRFD resistance factors φ, and LRFD load factors which can be seen in Table 9 and also applied in Tabel 10, the shear strength components are incorporated into the analysis, where the Nominal Shear Strength V_n is calculated as the capacity of the cross-section to resist shear forces, by **SNI 1729:2020**. The design shear forces under Dead Load *LL* and Live Load *LL*, Additional Load *DW,* and Impact Load *IM* are obtained through structural modeling under relevant load combinations. The value taken is the element with the smallest factor rating.

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Table 9. Rating Factor by Moment

Bridge	Factor Reduction			Nominal Moment	Momen Design				Rating Factor	RF Risk
	φ_c	φ_s	φ		DL	LL	DW	IM		
BH – 129	0.70	0.90	1.00	3167.1	77.96	743.85	12.87	227.52	1.074	1
BH – 275	0.70	0.90	1.00	3442.5	57.91	566.20	9.9	84.24	1.78	1
BH – 262	0.90	0.90	1.00	3167.1	55.96	363.63	5.70	73.33	3.49	1
BH – 314	0.70	0.90	1.00	3442.5	57.91	566.20	9.9	84.25	1.78	1

Table 10. Rating Factor by Shear

Bridge	Factor Reduction			Nominal Shear	Shear Design				Rating Factor	RF Risk
	φ_c	φ_s	φ		DL	LL	DW	IM		
BH – 129	0.70	0.90	1.00	2633	29.28	225.08	3.7	61.63	3.13	1
BH – 275	0.70	0.90	1.00	2862	18.83	228.88	3.23	24.36	3.89	1
BH – 262	0.90	0.90	1.00	2633	22.19	117.06	2.02	26.203	8.15	1
BH – 314	0.70	0.90	1.00	2862	18.83	228.88	3.23	24.36	3.89	1

The Seismic zone level for each bridge was obtained from the website *lini.binamarga.pu.go.id,* also based on the Indonesian **earthquake map and SNI 2833:2016, seen in Table 11.**

Table 11. Bridges Seismic Zone

Bridge	Seismic Zone
BH – 129	4
BH – 275	4
BH – 262	4
BH – 314	4

Risk analysis is carried out by calculating the value of the bridge condition and the earthquake value on the bridge. The risk level can be seen in Table 12.

Table 12. Bridges Risk Level

Bridge	Seismic Zone	Rating Factor	Importance	Risk	Description
BH-129	4	1	1	0.7809	High
BH-275	4	1	1	0.7809	High
BH-262	4	1	1	0.7809	High
BH-314	4	1	1	0.7809	High

The risks resulting from analyzing four railway bridges at various locations revealed that all had high-risk scores. The results suggest that all surveyed bridges need special attention to prevent potential accidents. Considering the threat also comes from the region's high level of earthquake vulnerability, quick and effective mitigation measures are needed.

a. Risk Assessments

The survey included a thorough evaluation of the physical condition of the bridge structure and environmental factors. Risk scores were calculated based on the field observations, and the results showed that all bridges were in the high category, meaning there is a significant risk of structural failure or other serious problems. The geographic location of these four bridges is in an earthquake-prone zone, which magnifies the potential hazards.

b. High-Risk Factors

Some of the factors that cause high-risk values include:

(a) The age of the structure, where the average bridge surveyed has a fairly high service life, and even though maintenance has been carried out, there is still damage due to age.
(b) Environment and earthquake exposure: the surveyed bridge area is high for earthquakes and other exposures, such as floods, that overload the structure, triggering damage and even partial or complete collapse.
(c) Poor maintenance of some bridges was found to have a long maintenance history and no recent maintenance.

c. Impact

The risk of collapse on these bridges is a serious concern, especially in the presence of potential earthquakes. If an earthquake were to occur, bridges already in a vulnerable condition are at risk of structural failure in the form of a collapse. Bridge collapses can cause massive accidents and loss of life. In addition, railway operations will be disrupted due to the closure of lanes affected by bridge damage, causing economic losses.

d. Recommendations

Some of the steps that need to be taken to reduce risk include:

(a) Inspection and Maintenance, which is carried out in detail using technology to identify and repair defects that are not visualized,
(b) The Schedule of Maintenance, which needs to be improved, especially on preventive repairs and replacement of components that are damaged or too old,
(c) Reinforcement of the structure, where possible, with modern construction techniques and appropriate materials to improve the durability of the structure,
(d) Replacement, carried out if it is found that the bridge is no longer structurally feasible, then a long-term replacement plan needs to be prepared and implemented as soon as possible.

CONCLUSION

The results of this risk analysis highlight a critical issue for stakeholders managing railway infrastructure. While the factor rating values for the four surveyed railway bridges are classified as good, the overall risk level is still categorized as high. This elevated risk is attributed to the location of these bridges in a highly earthquake-prone zone and their importance within the railway network, which amplifies the potential consequences of structural failure. These findings demand urgent attention and action, as ignoring the risks could result in catastrophic outcomes, including severe structural damage, substantial economic losses, service interruptions, and, most tragically, the loss of human life. To address these risks, it is imperative to implement swift and effective preventive measures. These could include retrofitting the bridges with advanced seismic reinforcement technologies to withstand earthquake forces, employing structural health monitoring systems to assess the condition of bridge components regularly, and integrating early warning systems to provide timely alerts for seismic activity. Additionally, a robust and consistent maintenance schedule should be established to ensure the ongoing integrity of the bridge structures. Upgrading the design of the bridges to enhance their resilience to seismic forces, particularly in light of increasing earthquake frequency and intensity, is also crucial for long-term safety. Collaboration among key stakeholders is essential for the success of these initiatives. Transport authorities, railway companies, civil engineers, and disaster management agencies must work together to prioritize safety without compromising operational efficiency. Policymakers also have a critical role in allocating sufficient funding and resources to support these risk-reduction efforts, recognizing the vital importance of railway bridges in maintaining connectivity and economic stability. Moreover, public awareness campaigns can educate communities on the importance of infrastructure safety, fostering collective support for necessary interventions and investments.

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REFERENCES

[1] Suwandi. (2021). *Pengenalan Jembatan* (W. T. Adi, Ed.; Edisi Revisi). Deepublish.

[2] Mardhiyah, A., Tarigan, J., & Sitanggang, E. S. Y. (2022). Studi Literatur: Pengaruh Gempa Terhadap Jembatan. *RADIAL*, *10*(1), 46–59.

[3] Arvin, M., Beiki, P., Hejazi, S. J., Sharifi, A., & Atashafrooz, N. (2023). Assessment of infrastructure resilience in multi-hazard regions: A case study of Khuzestan Province. *International Journal of Disaster Risk Reduction*, *88*. https://doi.org/10.1016/j.ijdrr.2023.103601

[4] Pusat Penelitian dan Pengembangan Perumahan dan Permukiman, Badan Penelitian dan Pengembangan, & Kementerian Pekerjaan Umum dan Perumahan Rakyat. (2017). *Peta Sumber dan Bahaya Gempa Indonesia*.

[5] Sugeng, & Rosadi, H. (2011). Interpretasi Citra SRTM dan Analisis Seismotektonik untuk Mengetahui Penyebab Rel Kereta Api Patah di Resort 6.6 Prambanan akibat Pengaruh Gempa 27 Mei 2006. *Proseding Seminar Nasional Kebumian 2011*.

[6] Moret, W. (2014). *Vulnerability Assessment Methodologies: A Review of the Literature*.

[7] Joshi, D., Takeuchi, W., Kumar, N., & Avtar, R. (2024). Multi-hazard risk assessment of rail infrastructure in India under local vulnerabilities towards adaptive pathways for disaster resilient infrastructure planning. *Progress in Disaster Science*, *21*. https://doi.org/10.1016/j.pdisas.2023.100308

[8] Hao, M., & Nie, Y. (2022). Hazard identification, risk assessment and management of industrial system: Process safety in mining industry. *Safety Science*, *154*. https://doi.org/10.1016/j.ssci.2022.105863

[9] Aflatooni, M., Chan, T., David, T., & Thilakarathna, I. (2012). Classification of Railway Bridges Based on Criticality and Vulnerability Factors. In R. R (Ed.), *Proceedings of the 2012 Australasian Structural Engineering Conference.* (pp. 1–8). Engineers Australia.

[10] Zaeni, M. R., Ambari, S. F., Sudarsono, I., & Mulyawati, F. (2022). *Analisis Nilai Kapasitas Jembatan Eksisting Menggunakan Metode Rating Factor*. https://doi.org/10.26760/rekaracana

[11] Andrić, J. M., & Lu, D. G. (2016). Risk assessment of bridges under multiple hazards in operation period. *Safety Science*, *83*, 80–92. https://doi.org/10.1016/j.ssci.2015.11.001

[12] Koks, E. E., Rozenberg, J., Zorn, C., Tariverdi, M., Vousdoukas, M., Fraser, S. A., Hall, J. W., & Hallegatte, S. (2019). A global multi-hazard risk analysis of road and railway infrastructure assets. *Nature Communications*, *10*(1). https://doi.org/10.1038/s41467-019-10442-3

[13] Kementrian Pekerjaan Umum dan Perumahan Rakyat Direktorat Jendral Bina Marga. (2022). *Pedoman Bidang Jalan dan Jembatan - Pemeriksaan Jembatan*.

[14] Pusat Studi Transportasi dan Logistik. (2024). *Laporan Risiko pada Bangunan Jembatan dan Terowongan Jalur Kereta Api*.

[15] Kementrian Pekerjaan Umum dan Perumahan Rakyat. (2016). *Pedoman Penentuan Bridge Load Rating untuk Jembatan Eksisting*.

[16] Badan Standardisasi Nasional. (2016). *Standar Nasional Indonesia Perencanaan jembatan terhadap beban gempa (SNI 2833:2016)*. www.bsn.go.id

[17] Dalezios, & Nicolas R. (2017). *Environmental Hazards Methodologies for Risk Assessment and Management* (Vol. 16). Water Intelligence Online. https://doi.org/10.2166/9781780407135

[18] International Organization for Standardization. (2018). *ISO 45001 Occupational health and safety management systems — Requirements with guidance for use*. www.iso.org