GeoStruct Innovations
https://www.acadlore.com/journals/GSI

Seismic Performance of Reinforced Concrete Bridge in Pan Borneo Highway Sarawak under the Influence of Seismic Loadings

Alexson Ajah Kanyan*, Ling Hou Jiun

Faculty of Engineering, Universiti Malaysia Sarawak, 94300 Sarawak, Malaysia

* Correspondence: Alexson Ajah Kanyan (72085@siswa.unimas.my)

Received: 01-25-2024 **Revised:** 03-07-2024 **Accepted:** 03-12-2024

Citation: A. A. Kanyan and L. H. Jiun, "Seismic performance of reinforced concrete bridge in Pan Borneo Highway Sarawak under the influence of seismic loadings," *GeoStruct. Innov.*, vol. 2, no. 1, pp. 32–41, 2024. https://doi.org/10.56578/gsi020104.

Abstract: Seismic performance is a critical consideration in the design and assessment of reinforced concrete bridges. Ensuring the structural integrity and safety of bridges under seismic loadings is essential to protect public safety and maintain the longevity of these vital infrastructure components. The objective of this research study was to evaluate the seismic performance of a multi-span reinforced concrete bridge located in Pan Borneo Highway Sarawak. The non-linear static pushover analysis provided valuable insights into the bridge's load resistance. It determined that the bridge could withstand a base shear force of up to 30,130.899 kN before collapsing, indicating its high structural capacity. The capacity curve analysis further demonstrated the ability of bridge to endure spectral accelerations of up to 4.44 g (43.512 m/s^2), indicating its robustness against high-intensity ground motions. In addition, the non-linear static time history analysis considered three ground motions and their effects on the bridge's structural performance. The study highlighted the bridge's sensitivity to different external forces, with varying responses observed under different ground motions. Notably, the recorded joint acceleration and displacement values were found to be within acceptable limits, ensuring immediate occupancy and life safety for bridge users. The research study successfully evaluated the seismic performance of a reinforced concrete bridge in Pan Borneo Sarawak using non-linear time history and pushover analyses. The results demonstrated the bridge's satisfactory capacity to withstand seismic loadings. The utilization of CSIBridge software provided valuable insights into the bridge's structural integrity and behavior under seismic conditions. These findings contribute to the advancement of bridge engineering practices.

Keywords: CSIBridge; Bridge modelling; Nonlinear analysis; Time history; Pushover

1 Introduction

Bridges have been vital throughout history, connecting points over rivers, valleys, and traffic. Initially made of timber, modern bridges are now primarily reinforced concrete. They consist of two main parts: the superstructure (deck slab, pavement, drainage, walls, and girders) and the substructure (piers, cap, and foundations). Some types of reinforced concrete bridges include arch, rigid frame, truss, and girder bridges. Bridges face seismic loadings from earthquakes, which can cause significant damage. The magnitude of an earthquake determines the extent of its destructive power. Sarawak, for example, has experienced several damaging earthquakes due to faults like Mersing, Tinjar, Tubau, and Kalawit. These faults result from the movement of Earth's crust, leading to earthquakes and the formation of mountain ranges [1–3]. Historical records in Sarawak show 35 observed earthquakes ranging from Mw 3.5 to 5.3 in magnitude. Notable events include a MW 5.2 earthquake on February 12, 1994, along the Mersing fault, and another MW 5.2 earthquake on May 1, 2004, along the Tubau fault [2, 4, 5]. These earthquakes registered a VI intensity on the Mercalli scale [6, 7]. To mitigate the risk of structural failure, it is crucial to study how bridge components can withstand seismic loadings from earthquakes.

Sarawak, a state in Malaysia on Bornean Island, has experienced minor damage from local earthquakes [8–10]. Mild earthquakes near Kuching, Samarahan, Bintulu, Bekenu, and Niah caused slight structural damage. Between 1970 and May 2019, around 20 onshore earthquakes with varying intensities (magnitude ¿ 3 Mw) were recorded in Sarawak. Most had magnitudes below 5 Mw, except for those in Batu Niah and Bukit Mersing. Active faults near Niah and Selangau may have caused earthquakes up to a magnitude of 5.4 (Mw). The Tubau Fault Zone is associated with left- lateral strike-slip faults in Niah, while the Mersing Fault Zone is linked to potential right-lateral strike-slip faults in Selangau. The resurgence of ancient faults in Sarawak is likely due to stress from the descent of the Philippine Sea Plate under the Sunda Plate [2, 3].

Earthquakes can damage bridges, causing displacement, cracking, and deformation. The substructure, including embankments, is particularly vulnerable. Studies have shown that earthquakes in places like Lombok, Palu (Indonesia), and Northern Croatia have resulted in disruption, collapse of embankments, cracking of retaining structures, and damage to superstructures [11]. Design flaws and bridge degradation contribute to the damage. Seismic design is crucial for reinforced concrete bridges to withstand earthquakes and ensure safety [12, 13].

Seismic loading during earthquakes poses a significant threat to reinforced concrete bridges, potentially causing extensive damage. Research studies have provided insights into the behavior of these bridges under seismic conditions. Iliev et al. [14], conducted a study evaluating the seismic performance of a reinforced concrete bridge, which revealed damage to areas such as column ends, the center of the top structure, and abutment regions. Tensile fractures in the columns were attributed to fluctuating tensile and compressive zones and the bending behavior of the concrete. Comparative studies by Shid Moosaavi and Rahai [15] demonstrated that integral and semi-integral bridges exhibit superior seismic performance compared to standard bridges. Integral and semi-integral bridge designs effectively disperse forces over a larger portion of the structure, resulting in reduced displacement and improved behavior during seismic events. Naser [16] investigated the capacity of various types of bridges under seismic loading. The study highlighted that certain bridge types, such as precast I girder, precast T girder, and U steel girder bridges, exhibited vulnerabilities at specific structural members, indicating the need for redesigning those sections to enhance seismic resistance. Moreover, Ajom and Bhattacharjee [17] explored the implications of earthquakes on bridge foundations, focusing on caisson (well) foundations. Their analysis showed that the amplitude of the input motion significantly affects the bending moment and displacement of the well foundation, with higher input motion amplitudes leading to increased surface acceleration amplification.

Non-linear time history analysis is a structural analysis technique that considers the non-linear behavior of a structure and its materials under dynamic loading conditions. Unlike linear analysis, it takes into account the non-proportional response of the structure to applied loads. In this method, the structure is subjected to a series of time-varying loadings, such as earthquakes, wind gusts, or sudden impacts. Advanced numerical methods and algorithms are employed to simulate the structural response over time. Research studies have utilized non-linear time history analysis to evaluate the seismic response of bridges. Mehta and Jivani [18] investigated a curved cable-stayed bridge and found that torsion increased with the degree of curvature, while shear force and bending moment values in an A-shaped pylon with a curved deck showed no significant difference. Research was analyzed on a prestressed I girder bridge and determined that non-linear time history analysis effectively simulated the bridge's damage category under varying intensity levels of seismic loads [19]. Kamal and Gunadi [20] studied toll bridges and observed significant non-linear behavior in their seismic response.

A literature review reveals extensive research on pushover analysis of bridges under seismic loading. Kehila et al. [21] conducted a study developing fragility curves for bridge piers' performance during earthquakes using pushover analysis. The study compared Static Pushover Analysis (SPO) and Dynamic Pushover Analysis (DPO) and found that the DPO curve exhibited greater base shear capacity between initial yield and concrete crushing. This study improved understanding of seismic vulnerability and the response of bridge piers to seismic excitations. Yang et al. [22] utilized pushover analysis to examine the response of bridge piers during earthquakes and its correlation with lateral force distribution patterns. The study emphasized the significant impact of different distribution patterns on pushover analysis results, emphasizing the need for careful selection to accurately assess seismic performance. Patil et al. [23] evaluated the performance of T- girder, I-girder, and Box-girder concrete bridges under seismic loads using pushover analysis. Their study revealed that the bridge models were inadequate in resisting the common intensity range of 0.8 to 1.0 PGA (g) before collapsing.

2 Methodology

The methodology of the study involved the use of CSIBridge software to perform nonlinear static pushover analysis and nonlinear static time history analysis [24]. CSIBridge is a widely used software tool for advanced structural analysis and design.

This analysis was carried out to determine the maximum lateral load capacity of the structure and identify potential weak points or failure modes. This analysis helped assess the structure's overall performance and understand its response under lateral loading conditions. Flowchart of analysis is as shown in Figure 1.

2.1 Nonlinear Static Pushover Analysis

In this analysis, the structure was subjected to a series of dynamic loadings over time, such as earthquakes or wind gusts. CSiBridge facilitated the simulation of the structure's behavior under these dynamic loadings, considering the non-linear behavior of the materials. Flowchart of analysis is as shown in Figure 2.

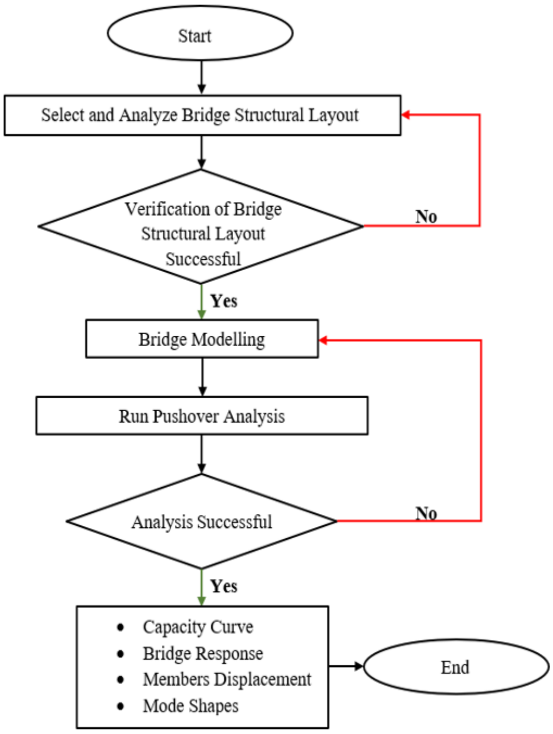

Figure 1. Nonlinear static pushover analysis flowchart

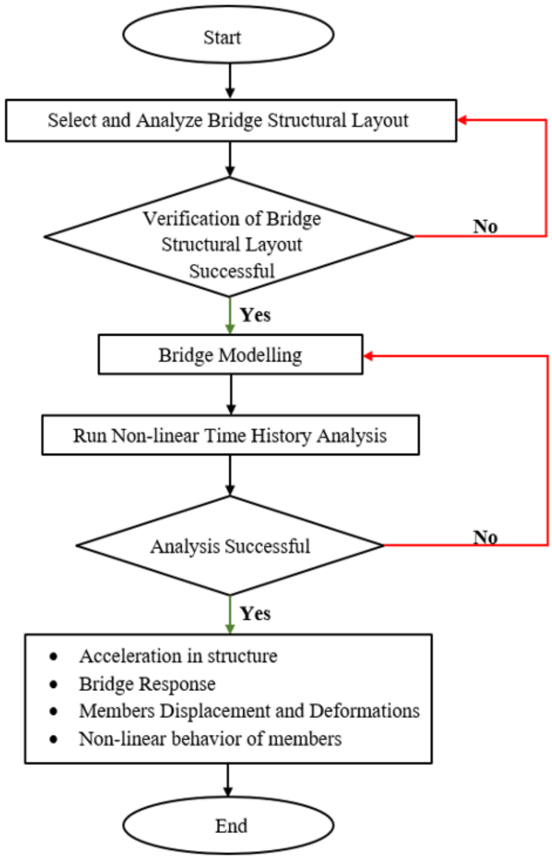

Figure 2. Nonlinear static time history analysis flowchart

2.2 Modelling

The modelling steps are illustrated in Figure 3, which outlines the step-by-step block diagram of the process. The generated bridge model is as shown in Figure 4.

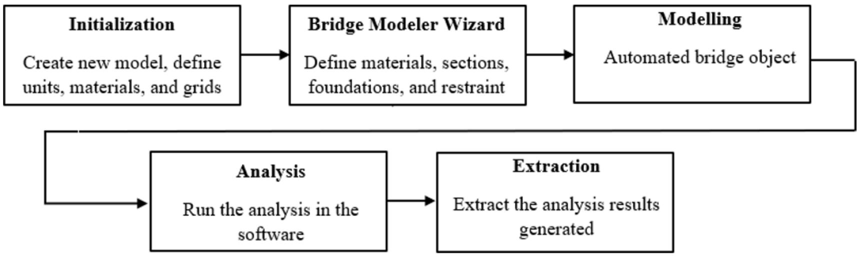

Figure 3. Systematic block diagram

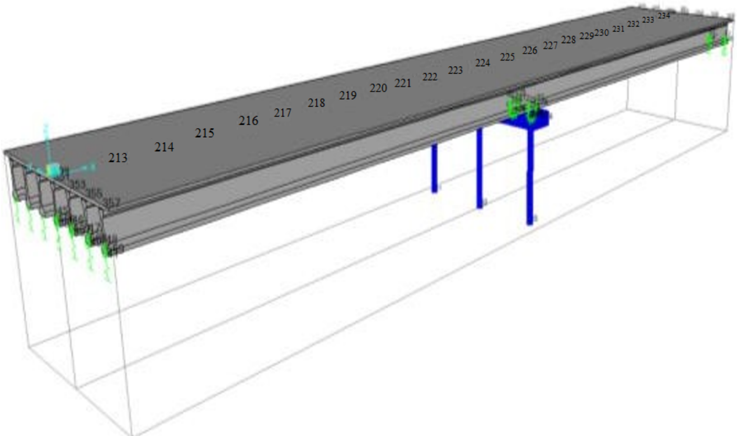

Figure 4. Bridge model

3 Results and Discussion

3.1 Nonlinear Static Pushover Analysis

The provided pushover curve from the analysis (Figure 5) illustrates the response of a structure to increasing displacement. Initially, the structure exhibits a linear elastic response with minimal displacement and negligible base force. As the displacement increases, the structure enters its elastic range, showing a proportional increase in base force. At a certain point, the structure exceeds its elastic limit and enters the yielding stage, with a significant increase in displacement and a decrease in base force. Post-yield, the structure reaches a stable behavior with minor fluctuations in displacement and a roughly constant base force. It then progresses towards ultimate failure, characterized by a gradual increase in displacement and a decrease in base force. The structure eventually reaches a residual strength state, where further displacement has minimal effect on the base force. In subsequent steps, the displacement increases significantly, indicating substantial damage and a distinct post-residual behavior. Overall, the pushover curve summarizes the structural response from the linear elastic range to yielding, progressive failure, and residual strength.

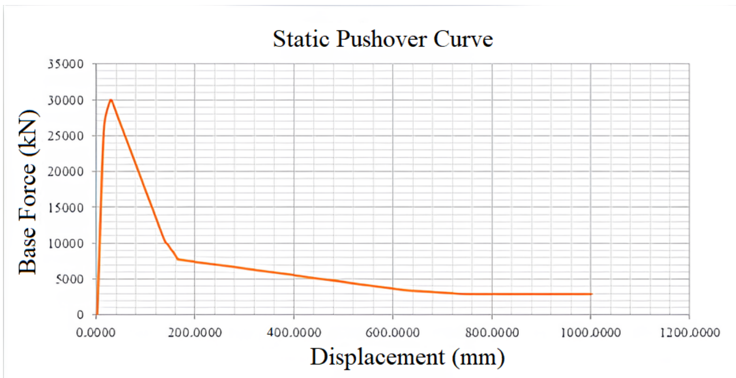

Figure 5. Static pushover curve

The pushover analysis results were presented using the ATC-40 Capacity Spectrum (Figure 6), a graph representing the bridge's capacity to resist seismic forces at different spectral acceleration levels. The highest point on the curve was found to be at 4.435793 g (43.6 m/s^2), indicating the maximum spectral acceleration that the bridge can withstand without exceeding its capacity. This value demonstrates the bridge's robustness and its ability to resist significant seismic forces. The ATC-40 Capacity Spectrum provides engineers and designers with a visual representation of the bridge's response to varying ground motion intensities, allowing them to ensure the bridge's safety and reliability during seismic events. The analysis concluded that the bridge has the ability to withstand spectral accelerations up to the highest point on the capacity spectrum. In summary, the nonlinear static pushover analysis, coupled with the ATC-40 Capacity Spectrum, revealed that the bridge can withstand spectral accelerations up to 4.435793 g (43.6 m/s^2). This information is crucial for designing and evaluating bridges in areas prone to earthquakes, ensuring that the structures are built to withstand the expected ground motions and maintain their structural integrity.

3.2 Nonlinear Time History Analysis

Nonlinear tie history analysis is a complex analytical method used to evaluate a system's structural reaction to seismic events. This analysis simulates dynamic forces on the structure using Upland, Gulf, and Borrego ground motions shown in Figure 7, Figure 8 and Figure 9, respectively. The Sarawak Response Spectrum is used to match these ground vibrations. Each ground motion was scaled to match Sarawak's maximum PGA of 1.0 g (9.82 m/s^2). The following figures showed ground motions graphically.

For the analysis, three critical joints (Figure 10) were chosen to be analyse. These joints were connecting the column to the cap beam. If these joints fail, it may induce failure or collapse of the bridge structure. The elastic response spectra is shown in Figure 11.

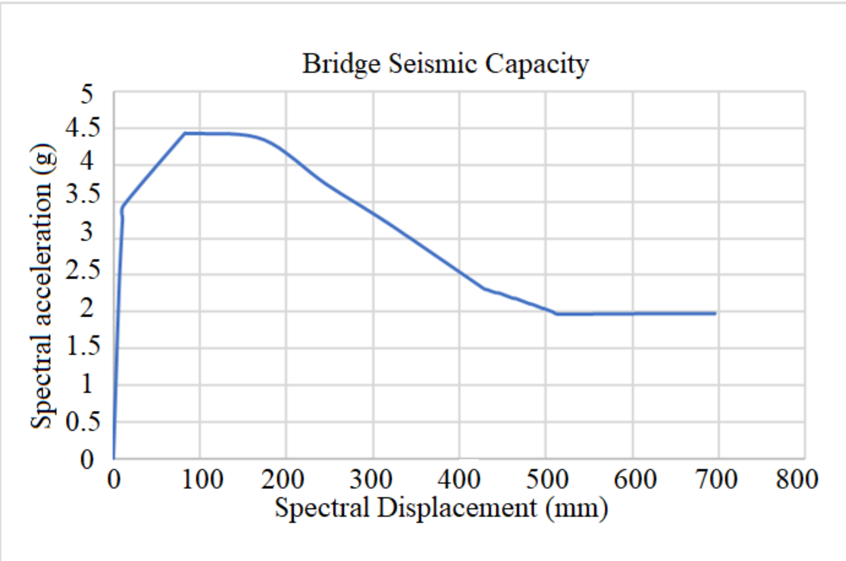

Figure 6. Bridge seismic capacity

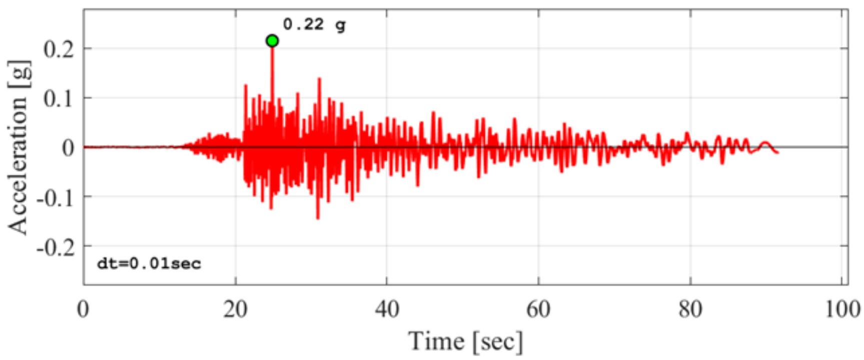

Figure 7. Upland ground motion

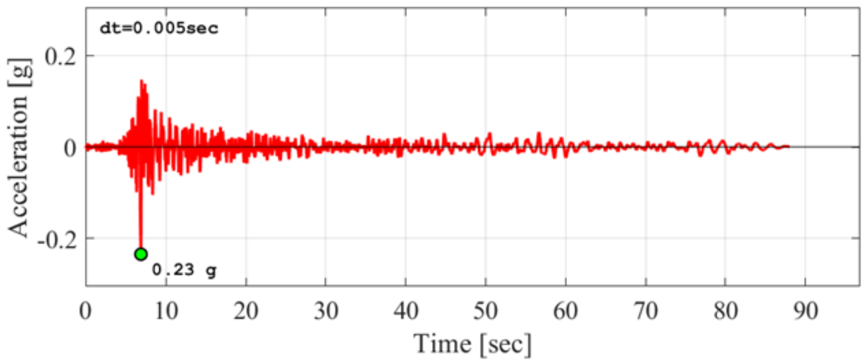

Figure 8. Gulf of California ground motion

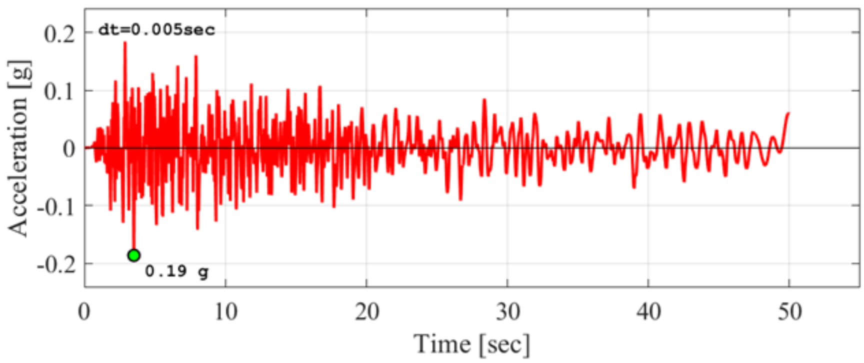

Figure 9. Borrego ground motion

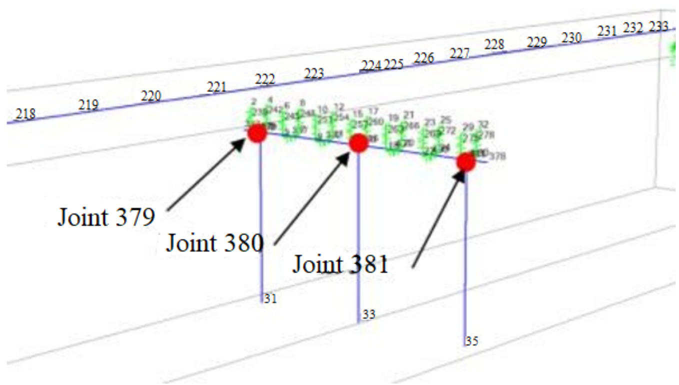

Figure 10. Critical joints

Table 1. Joint acceleration

Ground Motion	Direction	Maximum Acceleration	
		m/s^2	g
	x-direction	3.99098	0.4064
Upland	y-direction	0.00281	0.0003
	z-direction	1.42999	0.1456
Gulf	z-direction	2.36488	0.2408
	y-direction	0.00358	0.0004
	z-direction	1.71913	0.1751
Borrego	x-direction	3.23223	0.3291
	y-direction	0.0032	0.0003
	z-direction	1.63382	0.1664

Based on Table 1, the maximum acceleration values vary greatly. In Upland ground motion, the x-direction has the maximum joint acceleration, 0.4064 g (3.99098 m/s^2), whereas the y and z-directions have smaller accelerations, 0.003 g (0.00281 m/s^2) and 0.1456 g (1.42999 m/s^2). In the Gulf ground motion, the x-direction has the maximum joint acceleration 0.2408 g (2.36488 m/s^2), the z-direction 0.1751 g (1.71913 m/s^2), and the y-direction 0.004 g (0.00358 m/s^2). Finally, in Borrego ground motion, the x- direction again has the maximum joint acceleration 0.3291 g (3.23223 m/s^2), followed by the z-direction 0.1664 g (1.63382 m/s^2) and the y-direction 0.003 g (0.0032 m/s^2). In all three directions, the Upland ground motion has the highest maximum joint acceleration values. Gulf ground motions have lower joint acceleration values than Upland and Borrego ground motions. Borrego has the lowest joint acceleration values.

The maximum displacement values in millimetres (mm) represent the displacement of joints during an earthquake. The maximum joint displacement values in the x-direction for the three ground motions are Borrego (179.56992 mm), Upland (140.13486 mm), and Gulf (24.44953 mm) shown in Table 2. These data imply that Borrego ground motion causes the joints to experience the most lateral x-direction movement in the seismic event, while Gulf experiences the least. In the y- direction, Upland, Gulf, and Borrego recorded 0.00067, 0.00069, and 0.00067 mm, respectively. The y-direction displacements show limited lateral movement perpendicular to the x-direction. The three ground movements have similar maximum joint displacement values in the vertical z- direction. Borrego, Upland, and Gulf have the greatest values.

The Gulf, Borrego, and Upland base shear values mentioned above are useful. In earthquakes, base shear values in kilonewtons (kN) reflect the overall lateral force a structure's foundation must sustain. These values can help determine each structure's seismic performance and advise design and construction decisions. The three ground motions' greatest base shear values in the x-direction are Gulf (0.0003966 kN), Borrego (0.0003285 kN), and Upland (0.0002894 kN). Gulf experience higher lateral forces than the other two ground motions in the x-direction. Borrego has the highest y-direction base shear value (1630.3244 kN), followed by Upland (1496.31372 kN) and Gulf (1436.53136 kN). This shows that the structure experience lowest lateral forces in the y-direction in Gulf ground motion, while Borrego ground motion is the largest. In the vertical z-direction, Upland has the highest base shear (4222.14399 kN), followed by Borrego (4142.34539 kN) and Gulf (3812.61414 kN) shown in Table 3. This means structures analysed with Upland ground motion have the highest vertical forces and Gulf ground motion the lowest. Base shear in all directions in nonlinear static time history analysis is less than base shear in pushover analysis. Since it can withstand 30,130.899 kN of base shear force, the bridge will not collapse.

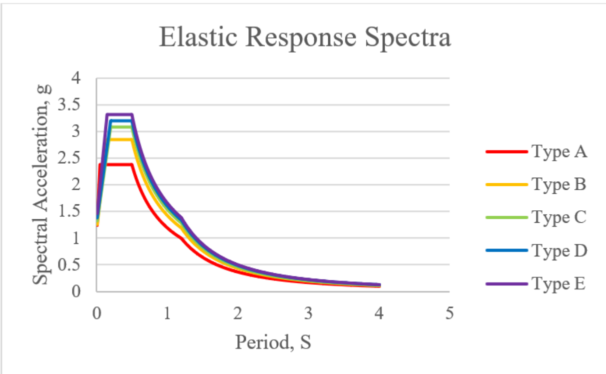

Figure 11. Elastic response spectra

Table 2. Joint displacements

Ground Motion	Direction	Maximum Displacement (mm)
Upland	x-direction	140.13486
	y-direction	0.00067
	z-direction	0.35388
Gulf	x-direction	24.44953
	y-direction	0.00069
	z-direction	0.32974
Borrego	x-direction	179.56992
	y-direction	0.00067
	z-direction	0.35448

Table 3. Base shear of bridge

Ground Motion	Direction	Base Shear (kN)
Upland	x-direction	0.000289
	y-direction	1496.314
	z-direction	4222.144
Gulf	x-direction	0.000397
	y-direction	1436.531
	z-direction	3812.614
Borrego	x-direction	0.000329
	y-direction	1630.324
	z-direction	4142.345

Table 4. Test results of classification

Ground Motion	Pier	Axial Force (kN)
Upland	Pier 1	315.33
	Pier 2	316.33
	Pier 3	315.33
Gulf	Pier 1	294.01
	Pier 2	294.93
	Pier 3	294.01
Borrego	Pier 1	315.93
	Pier 2	316.92
	Pier 3	315.93

The findings of the study present the maximum axial forces observed at three different piers (Pier 1, Pier 2, and Pier 3) under three different ground motion (Upland, Gulf, and Borrego) shown in Table 4. These results are crucial in assessing the structural integrity and load-bearing capacity of the piers during seismic events. It is observed that the maximum axial forces vary slightly between the different ground motion scenarios and piers. The axial forces for Pier 1 range from 294.01 kN to 315.93 kN, Pier 2 ranges from 294.93 kN to 316.92 kN, and Pier 3 ranges from 294.01 kN to 315.93 kN From the results, there is a similar trend across the different ground motion scenarios. Generally, Pier 2 tends to experience slightly higher axial forces compared to Piers 1 and 3, which have relatively similar values.

4 Conclusions

At the end of the research, the bridge structural components are found to be able to withstand seismic loadings with the magnitude up to 1.0 g. The non-linear static pushover analysis of the bridge model has shown that it has a capacity to resist a base shear force of up to 30,130.899 kN before collapsing. The capacity curve reveals that the bridge can withstand spectral acceleration (g) of up to 4.44 g (43.6m/s^2). The deformed shape of the selected step in the analysis demonstrates the progressive failure of flexural hinges.

In the non-linear static time history analysis, it is observed that the structural performance of the bridge varies depending on various factors, including the ground motion. Different ground motions yielded different results, indicating the sensitivity of the bridge's response to different external forces. The highest recorded joint acceleration and displacement are 0.4064 g (3.99 m/s^2) and 179.57 mm, respectively. The joints tend to accelerate and displace in the x-direction.

Notably, the values of joint acceleration, displacement, and base shear obtained from the time history analysis are very low, indicating that the bridge can withstand seismic excitation of 1.0 g magnitude. The maximum base shear obtained in the z-direction of the Upland ground motion is 4,222.44 kN, which is less than the base shear for collapse determined in the non-linear static pushover analysis. Therefore, the base shear induced by the ground motion will not cause failure in the bridge.

Furthermore, the pier's axial force ranges from 294.01 kN to 316.92 kN for different ground motions. These axial force values remain relatively consistent across the ground motions analyzed. The objectives of modeling and analyzing the behavior of a reinforced concrete bridge in Pan Borneo Highway Sarawak using non-linear time history and pushover analysis, as well as studying the effects of displacement and peak ground acceleration and investigating the seismic performance of the bridge subjected to seismic loadings, have been successfully achieved.

Through the utilization of CSIBridge software, the bridge model was effectively constructed and analyzed using both non-linear static pushover and time history analysis methods. The capacity of the bridge to resist base shear force before collapse was determined, providing valuable insights into its structural integrity. The capacity curve revealed the bridge's ability to withstand high levels of spectral acceleration.

By conducting the non-linear static time history analysis, the response of the bridge to various ground motions was studied. It was observed that different ground motions resulted in varying structural performance, highlighting the influence of external factors on the bridge's behavior. The recorded joint acceleration and displacement values demonstrated the bridge's ability to endure seismic excitation of a magnitude up to 1.0 g (9.82 m/s^2).

The investigation of the bridge's seismic performance yielded significant findings. The maximum base shear obtained was analyzed and found to be lower than the base shear for collapse determined in the non-linear static pushover analysis. This indicates that the induced base shear from seismic forces will not lead to failure in the bridge. Furthermore, the consistent range of pier axial forces across different ground motions suggests a stable and reliable performance of the bridge under seismic loadings.

In conclusion, based on the non-linear static pushover and time history analyses, it can be inferred that the bridge exhibits a satisfactory capacity to withstand the applied loads and ground motions. The bridge demonstrates resilience and remains within acceptable limits in terms of joint acceleration, displacement, and axial force. Other than that, modeling and analysis using CSIBridge software have provided valuable insights into the behavior and seismic performance of the multi-span reinforced concrete bridge in Pan Borneo Highway Sarawak. The study successfully achieved its objectives and contributes to a better understanding of the bridge's response to displacement, peak ground acceleration, and seismic loadings.

Author Contributions

Conceptualization, methodology, software, validation, formal analysis; investigation, A.A.K and L. H. J.; data curation, writing—original draft preparation, A.A.K; writing—review and editing, A.A.K and L. H. J.; visualization, L. H. J; supervision, A. A. K.

Data Availability

Not applicable.

Acknowledgements

The authors would like to acknowledge the University Malaysia Sarawak (UNIMAS) for the courtesy of giving every resource to complete the research.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] R. Ahmadi, I. A. Najar, A. F. Abdullahi, M. Norazzlina, H. Hamza, and N. A. Najar, "Computational investigation of soil liquefaction susceptibility based on standard penetration test value of miri district (Sarawak, Malaysia)," *Int. J. Adv. Sci. Technol.*, vol. 29, no. 7, pp. 2735–2748, 2020.

[2] R. Ahmadi, M. H. A. M. Suhaili, I. A. Najar, M. A. Ladi, N. A. Bakie, and A. F. Abdullahi, "Evaluation on the soil flexibility of the largest HEP Dam Area in East Malaysia using 1-D equivalent linear analysis," *Int. J. Adv. Sci. Eng. Inform. Technol.*, vol. 11, no. 4, pp. 1535–1542, 2021. https://doi.org/10.18517/ijaseit.11.4.12281

[3] I. A. Najar, R. B. Ahmadi, M. A. H. Jamian, H. B. Hamza, A. Ahmad, and C. H. Sin, "Site-specific ground response analysis using the geotechnical dataset in moderate seismicity region," *Int. J. Mech.*, vol. 16, no. 1, pp. 37–45, 2022. https://doi.org/10.46300/9104.2022.16.5

[4] I. A. Najar, R. B. Ahmadi, H. Hamza, N. B. M. Sa'don, and A. Ahmad, "First order seismic microzonation of Miri district of Sarawak Malaysia using AHP-GIS platform," *Test Eng. Manag.*, vol. 83, no. April, pp. 13 918–13 928, 2020.

[5] R. Ahmadi, I. A. Najar, A. F. Abdullahi, and T. Galin, "Response spectra for moderate seismic area - application to miri district of sarawak, malaysia," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1101, no. 1, p. 012020, 2021. https://doi.org/10.1088/1757-899x/1101/1/012020

[6] I. A. Najar, R. Ahmadi, Y. K. A. Khalik, S. N. L. Taib, N. B. M. Sutan, and N. H. B. Ramli, "Soil suffusion under the dual threat of rainfall and seismic vibration," *Int. J. Des. Nat. Ecodynamics*, vol. 18, no. 4, pp. 849–860, 2023. https://doi.org/10.18280/ijdne.180411

[7] R. Ahmadi, A. Ahmad, A. Abdullahi, I. Najar, and M. Suhaili, "A framework on site-specific probabilistic seismic hazard assessment of tabung haji hotel and convention centre in kuching, sarawak, malaysia," *Procedings of WCDM in IIT Mumbai India*, no. Feb, 2019.

[8] B. Ahmad and I. A. Najar, “Comparative seismic analysis of EL centro and Japan earthquakes using response spectra method,” *Int. J. Curr. Eng. Technol.*, vol. 6, no. 5, pp. 1859–1864, 2016.

[9] S. A. Y. B. W. A. Aziz and I. A. Najar, “Seismic capacity using finite element analysis: A case study of Murum Powerhouse,” *Acadlore Trans. Geosci.*, vol. 2, no. 2, pp. 70–79, 2023. https://doi.org/10.56578/atg020202

[10] I. A. Najar, R. Ahmadi, Y. K. A. Khalik, N. Z. Mohamad, M. A. H. Jamian, and N. A. Najar, “A framework of systematic land use vulnerability modeling based on seismic microzonation: A case study of Miri district of Sarawak, Malaysia,” *Int. J. Des. Nat. Ecodynamics*, vol. 17, no. 5, pp. 669–677, 2022. https://doi.org/10.18280/ijdne.170504

[11] I. A. Najar, R. B. Ahmadi, M. A. H. Jamian, H. B. Hamza, A. Ahmad, and C. H. Sin, “Site-specific ground response analysis using the geotechnical dataset in Moderate Seismicity Region,” *Int. J. Mech.*, vol. 16, pp. 37–45, 2022. https://doi.org/10.46300/9104.2022.16.5

[12] J. Huang, “Earthquake damage analysis of concrete gravity dams: Modeling and behavior under near-fault seismic excitations,” *J. Earthq. Eng.*, vol. 19, no. 7, pp. 1037–1085, 2015. https://doi.org/10.1080/13632469.2015.1027019

[13] D. L. Lau, A. Tang, and J. R. Pierre, “Performance of lifelines during the 1994 Northridge earthquake,” *Can. J. Civ. Eng.*, vol. 22, no. 2, pp. 438–451, 1995. https://doi.org/10.1139/l95-052

[14] A. Iliev, D. Stefanov, and D. Dimitrov, “Nonlinear time history analysis of a reinforced concrete bridge,” in *Xth International Scientific Conference On Architecture And Civil Engineering (ARCIVE)*, Varna, Bulgaria, May 29 2021.

[15] S. Shid Moosavi and A. Rahai, “The performance of integral and semi-integral pre-tensioned concrete bridges under seismic loads in comparison with conventional bridges,” *AUT J. Civil Eng.*, vol. 2, no. 2, pp. 219–226, 2018.

[16] A. Naser, “Comparative study of seismic design for different bridges structures,” *J. Kej*, vol. 34, no. 1, pp. 59–71, 2022.

[17] B. E. Ajom and A. Bhattacharjee, “ICOVP,” in *13th International Conference on Vibration Problems*, IIT Guwahati, India, 2017.

[18] A. H. Mehta and D. K. Jivani, “A seismic assessment of curved cable-stayed bridges,” *Int. J. Dars. Inst. Eng. Res. And Emg Tech.*, vol. 11, no. 1, pp. 34–42, 2022.

[19] R. Kurniawan, “Seismic vulnerability assessment of three spans Girder Bridge in Kuranji-Padang by developing fragility curve,” *IOP Conf. Ser.: Earth Environ. Sci.*, vol. 708, no. 1, p. 012006, 2021.

[20] R. Kamal and R. Gunadi, “Analysis of bridge structure with non-linear time history method,” *IOP Conf. Ser.: Earth Environ. Sci.*, vol. 732, no. 1, p. 012012, 2020.

[21] F. Kehila, A. Kibboua, H. Bechtoula, and M. Remki, “Seismic performance assessment of RC bridge piers designed with the algerian seismic bridges regulation,” *Earthq. Struct.*, vol. 15, no. 6, pp. 701–713, 2018.

[22] Y. Yang, D. Jiao, and H. Song, “Pushover analysis in different lateral force distribution patterns of bridge piers,” *IOP Conf. Ser.: Earth Environ. Sci.*, vol. 647, no. 1, p. 012023, 2021.

[23] D. Patil, R. Bhargava, and R. Khare, “Performance-based seismic evaluation of different concrete bridges,” *Int. J. Appl. Eng. Res.*, vol. 14, no. 11, pp. 2799–2805, 2019.

[24] S. K. Ben, R. Ahmadi, R. A. Bustami, and I. A. Najar, “Numerical investigation of seismic hazard and risk of murum hydro-electric dam (MHEP),” in *International Conference on Dam Safety Management and Engineering*. Singapore: Springer Nature Singapore, 2023, pp. 855–869.