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Seismic Resistance Evaluation of Highway Bridges under Lateral Load of Earthquake: A Review Study

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ABSTRACT

The structural activity of any structure under horizontal seismic stress will determine its classification for design reasons. Response spectra relevant to the site location, such as proximity to significant active faults, site subsurface conditions, the design earthquake loadings are defined by the ductility modification factor, the structural performance factor, and the determined yearly likelihood of surpassing the design earthquake. After every earthquake, a structural safety assessment must be conducted. The significance of life and material losses underscores the relevance of efforts in earthquake engineering. The primary aims of this work are to examine previous research concerning the seismic resistance assessment of highway bridges subjected to lateral earthquake forces and to analyze and elucidate the seismic design methodologies. The subjects mentioned in this study were bridge structural components which were affected by earthquake action such as piles, piles cap, piers, piers cap and abutments, evaluation of seismic design of bridge supports, damages of bridges due to earthquake load, evaluation methods of seismic resistance such as non-linear static analysis, modal analysis, and demand to capacity ratio.

Keywords: Bridge; pier; abutment; earthquake; pushover method; modal

INTRODUCTION

A bridge is a structure that facilitates movement across an obstruction while maintaining access below. The necessary passage may pertain to a roadway, railway, pedestrian pathway, canal, or pipeline. The barrier to be traversed may be a river, a road, a railway, or a valley. Bridges vary in length from few meters to several kilometers. They rank among the biggest edifices constructed by humanity. The requirements for design and materials are quite stringent. A bridge must possess sufficient strength to bear its own weight in addition to the weight of users and vehicles across it. The construction must also withstand different natural phenomena, like earthquakes, high winds, and temperature fluctuations. Most bridges possess a structure of concrete, steel, or wood, along with an asphalt or concrete roadway for the passage of individuals and automobiles (Acharya & Prasad 2018, Naser, A. 2021, Naser, A. & Wang, Z. 2011, Naser, A. & Wang, Z. 2012).

Presently, earthquakes are natural disasters that compromise the integrity and functionality of structures. The extent of damage an earthquake inflicts on structures depends on the type of building, the nature of the soil, the technology employed for seismic protection, and, importantly, the building's location. The effects of an earthquake on a specific region predominantly depend on the kind of soil in which the building's foundation is constructed, as earthquakes alter ground motion, leading to foundation failure. Earthquakes produce varying shaking intensities across different places, resulting in differential levels of structural damage in structures at these sites. An earthquake is the shaking of the Earth, or alternatively, the release of energy due to the movement of tectonic plates. This natural calamity has several detrimental impacts on the Earth, including ground shaking, landslides, rockfalls from cliffs, state changes, fires, and tidal waves. Earthquake engineering is crucial in contemporary infrastructure design. An earthquake may have a minimal chance of occurrence in some regions; nonetheless, this probability should not be overlooked once a structure is constructed, since even a single seismic event throughout the building's lifespan poses a threat to its occupants. Seismic waves are produced when the Earth's strata vibrate, causing an unanticipated release of energy inside the lithosphere (Shobhit and Sandeep 2021, Klügel, J., & Mualchin, L. 2013, Siqueira et al. 2014).

Geological inspections and historical data allow for the estimation of the locations of significant earthquakes anticipated in the next years. Consequently, earthquake-resistant design profoundly influences the structural design of civil engineering projects. Seismic evaluation is essential for existing buildings in seismic zones, allowing for the assessment of anticipated seismic hazards. Certain factors render the capacity evaluation of structural elements ambiguous, including building type, material degradation, and seismic environment. Typically, the appropriate seismic performance of civil constructions must be assessed following significant earthquakes (Anurag, P. 2018, Rafael, S. 2021, Angulo et al 2020), Wood, J. 2015).

Bridge constructions are a crucial component of lifeline engineering, which may easily lose their traffic functionality when exposed to significant earthquakes. If a bridge is seismically robust, it can either continue operating normally after an earthquake or be repaired to a point where it can be used again with little changes. Ability to concentrate oneself, ability to mitigate injury, and reparability are their primary characteristics. Because of its many benefits, seismic resistance in bridge construction has therefore become a major focus of study in the field of bridge engineering. (Dong & Zhou 2022).

A complete understanding of the predicted site-specific ground vibrations and any abnormalities at or below ground level is essential for seismic bridge design. Experts from academia, industry, and government must launch a long-term study to assess and enhance our geological and seismological design principles so they meet engineering requirements and practical uses. Both current and freshly collected data must be used in the enhancement research. The three suggestions up there specify a framework that these bridge design studies' findings must follow. The nonlinear behavior of the foundation, the absence of uniform progressive yielding of columns, and the nonlinear responses at intermediate expansion joints and bearings all contribute to the complexity of bridge nonlinear dynamics (The National Science Foundation, 1979), Anil, H. & Roy 2012).

The principal aim of seismic design is to guarantee that the bridge can effectively sustain its role in facilitating communication following a seismic occurrence. The feasibility of this will rely on the event's intensity and, by extension, its return period. Bridges must be classified based on their significance and assigned a Risk Factor corresponding to the seismic return period for design considerations. The design of any bridge situated in a region prone to earthquake-induced liquefaction, or positioned over an active fault with a recurrence frequency of 2000 years or fewer, must account for the significant movements that may arise from the settlement, rotation, or translation of piers. Measures should be implemented to limit these impacts, as much as practical and economically feasible, while considering potential societal repercussions. Seismic hazard refers to the intensity of ground motion resulting from seismic activity at a certain site, which may be triggered by a single earthquake or anticipated at a designated frequency of recurrence. Seismic vulnerability refers to the extent of damage a certain structure experiences due to a specified amount of ground motion. Seismic risk refers to the potential harm resulting from a particular earthquake or the anticipated damage at a certain frequency of recurrence. (Agrawal et al. 2012; Pappin, J. 1991)

The seismic design of bridge structures must be conducted according to two levels of evaluation. The initial level, designated as the Safety Evaluation Earthquake (SEE), represents the higher threshold, whilst the subsequent level The lower threshold is indicated by the Functionality Evaluation Earthquake (FEE). Following a seismic safety assessment, the bridge structure must continue to operate. The earthquake load and reaction spectrum must be taken into account in both safety and functioning evaluations. The goals of seismic design for bridges are to keep critical structural components within the elastic range during a safety evaluation earthquake (SEE) and to make sure that the bridges are safe, reliable, serviceable, constructible, and maintainable when they have energy dissipation and isolation devices (Duan & Reno 1999; Caltrans 1999).

OBJECTIVE OF STUDY

The primary aims of this work are to examine previous research concerning the seismic resistance evaluation of highway bridges exposed to lateral earthquake pressures and to analyze and clarify the seismic design methodology.

BRIDGE ELEMENTS

Bridges are important and effective civil engineering projects that use a variety of structural elements. Two groups may be formed from the members. The first kind, known as superstructure, consists of the deck (including walkways), joints, girders (beams), bearings, safety barrier, drainage system, and asphalt surface layer. The foundations (piles and pile tops), piers, and pier caps make up the second group, often known as substructure. An essential part of the transportation engineering system is the bridge. It shows how rivers, valleys, and urban congestion are related. Bridge bearing capacity determines the weight and volume of traffic loads carried by the transportation system. Figure 1 displays the flowchart that lists the components of a bridge structure. Figure 2 illustrates the bridge construction configuration seen in literature (Naser, A. 2018; Mohammed, H. A., & Naser, A. F. 2020; Mohan, A. 2017; Master Wolverine 2024; Usama K. 2022)

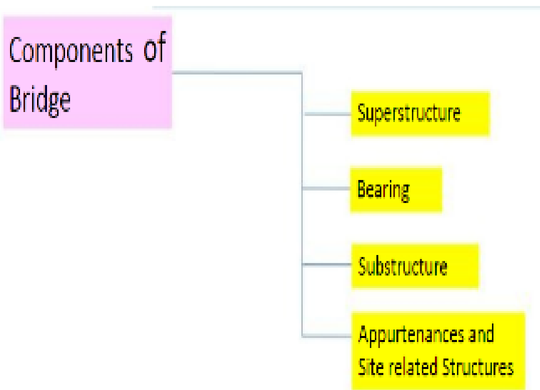


FIGURE 1. Flow chart for components of bridge structure (Master Wolverine 2024)

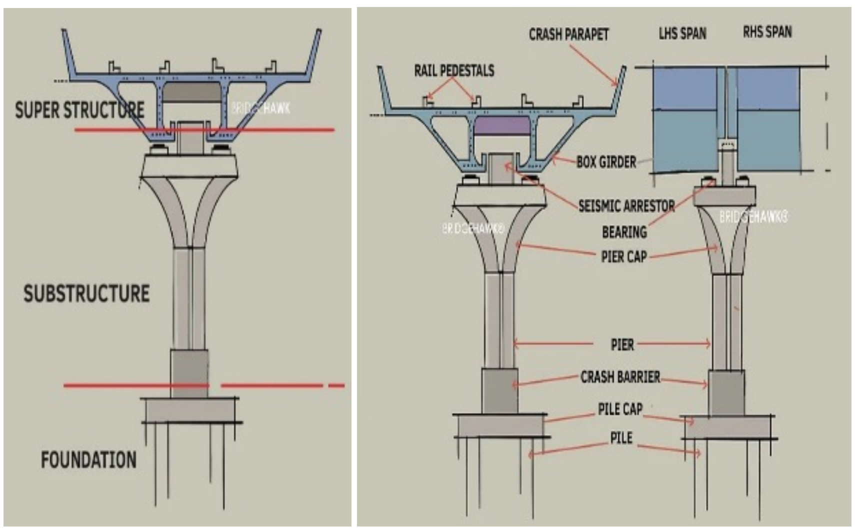


FIGURE 2. The layout of bridge structure in view (Usama k 2022)

PILES AND PILE CAP

Piles are typically employed to support a bridge and provide the foundational base. The piles facilitate the uniform distribution of weight and stresses exerted by the bridge, therefore enhancing its stability and strength. The composition and construction of a pile are contingent upon several elements, including soil type, ground instability, and load-bearing capability limitations. Scouring is also evaluated before to the building of bridges over rivers. Piles are engineered as a collective unit. A single pile top for a pier may accommodate three, four, or more piles. For heavy-duty piers, a single pile cap may accommodate 12 or more piles. A pile cap is a robust reinforced concrete slab erected above a cluster of concrete foundation piles, serving as an integral component of a bridge's deep foundation. Caps enhance the weight transmission capability of the piles. (Amit & Kulkarni 2018).

PIERS AND PIER CAPS

Bridge piers transfer weights from the superstructure to the foundation and support the bridge spans. Piers need to be strong enough to bear weights that are both vertical and horizontal. Piers serve two main purposes: they give bridge spans placed at intermediate points perpendicular support. Its main purpose is to withstand horizontal forces like wind, earthquakes, and hydrostatic pressure while simultaneously transferring the superstructure's vertical stresses to the foundations. Depending on the materials used and the design of the pier's cross-section, different pier types are used while constructing bridges. Piers can be square, circular, solid wall, rectangular, or concrete-filled tubes, and they are frequently constructed of steel or reinforced concrete. The bridge and its weight determine how many piers are needed, which is impacted by factors including girder spacing, pier diameters, and superstructure type. A bridge's pier type should be chosen using geometric, structural, and functional factors. Pier caps are flanged parts of the substructure piers that use bearing pedestals to support the girders. In their design, they frequently make room for the launcher sleeves, seismic arrestors, bearing pedestals, drain holes, and other elements. While Figure 4 shows several pier types. (Usama, k. 2022, Amit & Kulkarni 2018, Al-Hazragi & Lateef 2021, Jinrong, W. 2000). Figure 3 shows piles, pile tops, and piers.

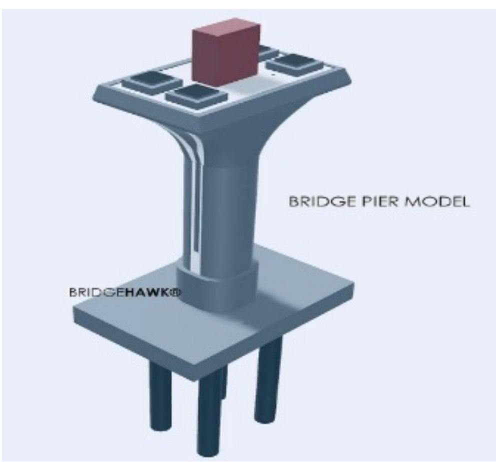


FIGURE 3. Piles, pile caps, and pier (Usama k,2022)

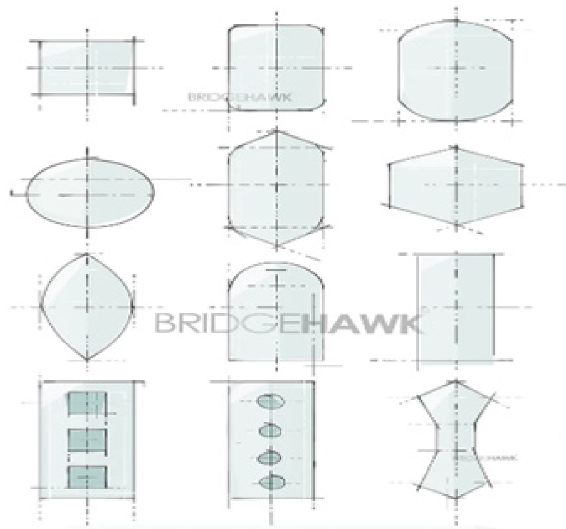


FIGURE 4. Pier types (Usama k. 2022)

ABUTMENT

At bridge termini, abutments are used to support the embankment and transfer loads from the superstructure to the foundation in both vertical and horizontal directions. a substructure that serves as the girders' support framework and can primarily resist lateral stresses on both sides of the bridge. The abutments mark the end of the launch apron. It serves as a retaining wall for the launch apron's backfill.

These constitute the structural connection between the roadway and the bridge framework. They provide support for the launch apron or one edge of an approach slab, while simultaneously supporting the bridge girders on the other side. The majority of highway bridge abutments are fabricated from reinforced concrete. Similar to piers, the most significant maintenance operation for resolving structural issues at abutments is the restoration of concrete surfaces. Two factors impact abutments but not piers: drainage from the approach roadway and earth pressure. Unregulated runoff from the approach may erode the abutment wings and undermine stub abutments, so exposing the foundations. Enhancing drainage at the approach will aid in alleviating this issue. An alternative is to remove the fill and implement a drainage system next to the abutment. This might be a unique backwall drainage system or a segment of drained aggregate from which water is conveyed away. Excavation may facilitate the placement of granular backfill material to alleviate excessive strain on the abutment. Figure 5 illustrates the components of the abutment, whereas Figure 6 depicts its function (Usama k. 2022; Hurt & Schrock 2016; WisDOT Bridge Manual 2024).

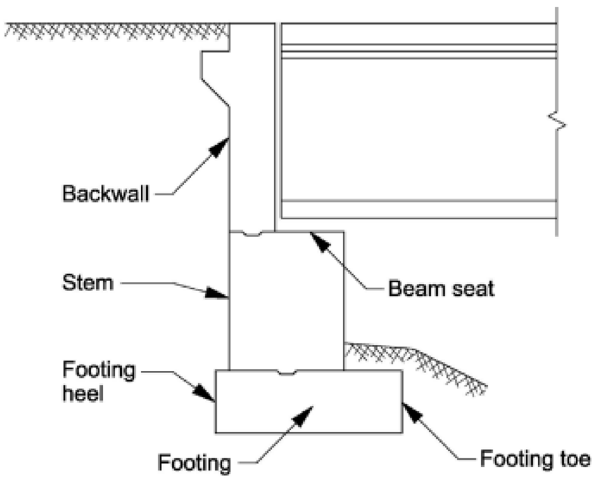


FIGURE 5. Components of abutment (WisDOT Bridge Manual 2024)

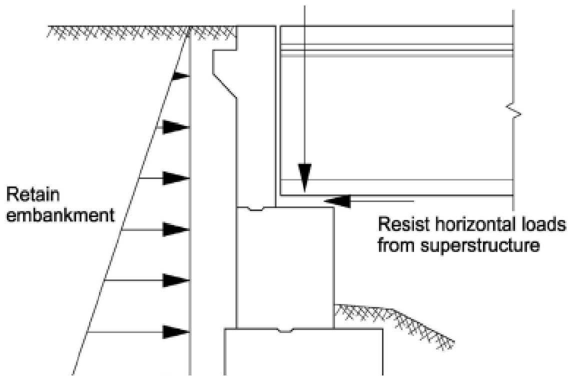


FIGURE 6. Function of abutment (WisDOT Bridge Manua, 2024)

EVALUATION OF BRIDGE SUPPORT SEISMIC DESIGN

When evaluating the seismic design of bridge supports, two metrics can be applied. Capacity and demand are the criteria. All external loads, such as wind, seismic activity, snow, and self-weight (the bridge structure's dead load), are referred to as demand. Capacity refers to a bridge structure's overall capacity to sustain an applied load. Determining whether the structure has enough capacity to meet demands, increasing capacity by altering material properties or the shape and size of the cross section, and identifying structural member failure that happens when demand exceeds capacity are the goals of demand and capacity analysis. To avoid failure, the demand to capacity ratio needs to be kept below or equal to one. Increasing the cross-section of structural components, reducing loads, increasing material strength through replacement, or upgrading the properties of building materials are some ways to do this (Ercan, I., Aydın, B. 2020, Naser et al 2021, Işık et al 2020, Akkar, S & Azak, T. 2018, Transportation 2010, Seonghyeon, M.et al. 2020, Vlašić, A. et al. 2022).

BRIDGES DAMAGES DUE TO EARTHQUAKE

Following every earthquake, significant material and human losses underscore the importance of earthquake engineering work and the need to assess structure safety. One of the stoppages that may be used is determining the seismic danger of a region as a dedicated component of pre-earthquake disaster management. Some flaws in urban areas are revealed by the crucial effect of earthquake events. In general, the amount of damage will either grow or reduce depending on the earthquake level, soil properties, and building type. It becomes clear how important earthquakes are in relation to soil and construction when past earthquake damages are taken into account. Therefore, by identifying the link between these three criteria, the evaluation and design of the buildings become more evocative. To describe how buildings behave during earthquakes and to lessen the damage caused by earthquakes, it is necessary to accurately assess the seismic risk. (Ercan et al 2020, Naser, A. et al 2021, Harirchian & Jadhav 2020, Connor & Alampalli 2024)

Connor & Alampalli. 2024 explained of an earthquake response plan that can be valuable even where earthquakes are not a day-to-day concern. It presented the details of the emergency response plan, Key advantage of the proposed response plan is that it was developed to mesh well with the sponsoring agency's existing staffing and organizational structure. The project report contains a process flowchart, clear lines of responsibility, prioritization methods, reporting forms, list of necessary resources, sample photos of possible earthquake damages, strategies for post-earthquake repairs, and staff training exercises. Further details and technical guidance are available from the authors.

According to Song & Huang, 2015, riverbed erosion causes substantial foundation exposure for a number of bridges located in seismic risk locations. The lateral capacity of pile foundations is significantly reduced by the erosion of nearby soil. When the scour depth above a crucial threshold, the foundation's strength is inadequate to sustain the seismic pressures, the piles are more likely to sustain substantial damage in the event of an earthquake. This study provides a way for analyzing the critical scour depth that impacts a bridge's seismic performance and for comparing the original design of exposed foundation bridges to their risk of earthquake damage. The method determines a bridge's maximum seismic reaction using the tried-and-true response spectrum analysis methodology. Considering the foundation and column strengths in relation to the seismic demand could help one estimate the bridge's collapse probability. A numerical example demonstrates how nonlinear finite element analysis further supports the analytical technique's versatility. Finding the critical scour depth is a breeze using the analytical technique. The findings show that foundation damage during earthquakes may occur at even very small scour depths, even for bridges designed with sufficient seismic resilience. A flow diagram showing the process of estimating the probability of seismic damage to columns and foundations of bridges is shown in Figure 7.

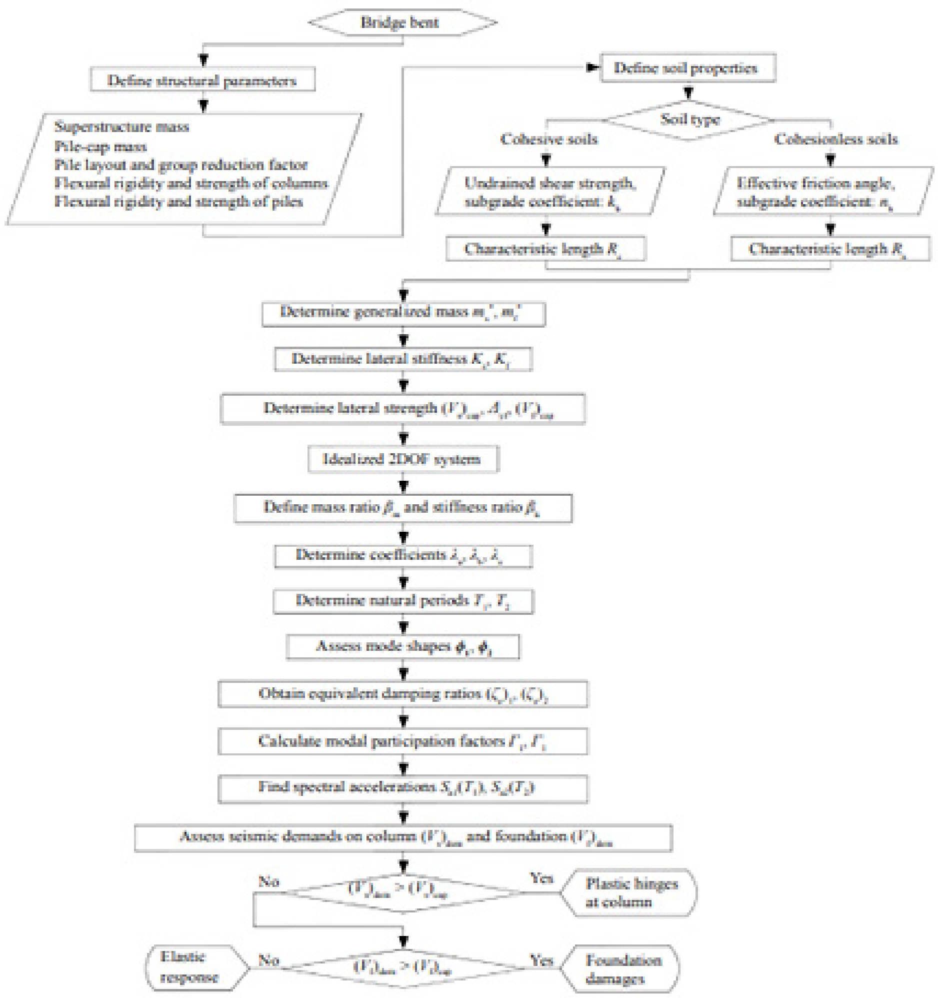


FIGURE 7. Flow chart for assessing the earthquake damage potential of bridge column and foundation (Song & Huang 2015).

Wang, et al 2009 described the damage and the probable causes for nine bridges, including B aihua B Ridge, Xiaoyudong Bridge, Miaoziping Bridge, and Longwei Bridge. The vast majority of highway bridges in the seismically active region are continuous girder bridges with subpar connections between the girders and bridge columns and rubber bearings directly on the cap beam. As a consequence, the bridge girders moved laterally or longitudinally, and after an earthquake, they even fell apart. Although there was not much damage to the bridge columns, some shear or a combination of shear and flexure caused the dam to age to columns, arch ribs, or cap beams. The earthquake loads supported by bridge columns were also reduced as a consequence of poor bearing conditions. The ductility of bridge columns and other structural elements, the design of curved and high-pier bridges, the construction of bearings and measures to keep the girders from collapsing, and site liquefaction, and the stability and strength calculation of bridge abutments are among the recommendations on the seismic design of highway bridges that are based on the lessons learned from the Wenchuan earthquake. It is stressed that careful attention to the structural details design is necessary for the bridge to fulfill its emergency role and prevent collapse in the event of an unplanned, significant earthquake. Bridge damage from earthquakes is seen in Figure 8.

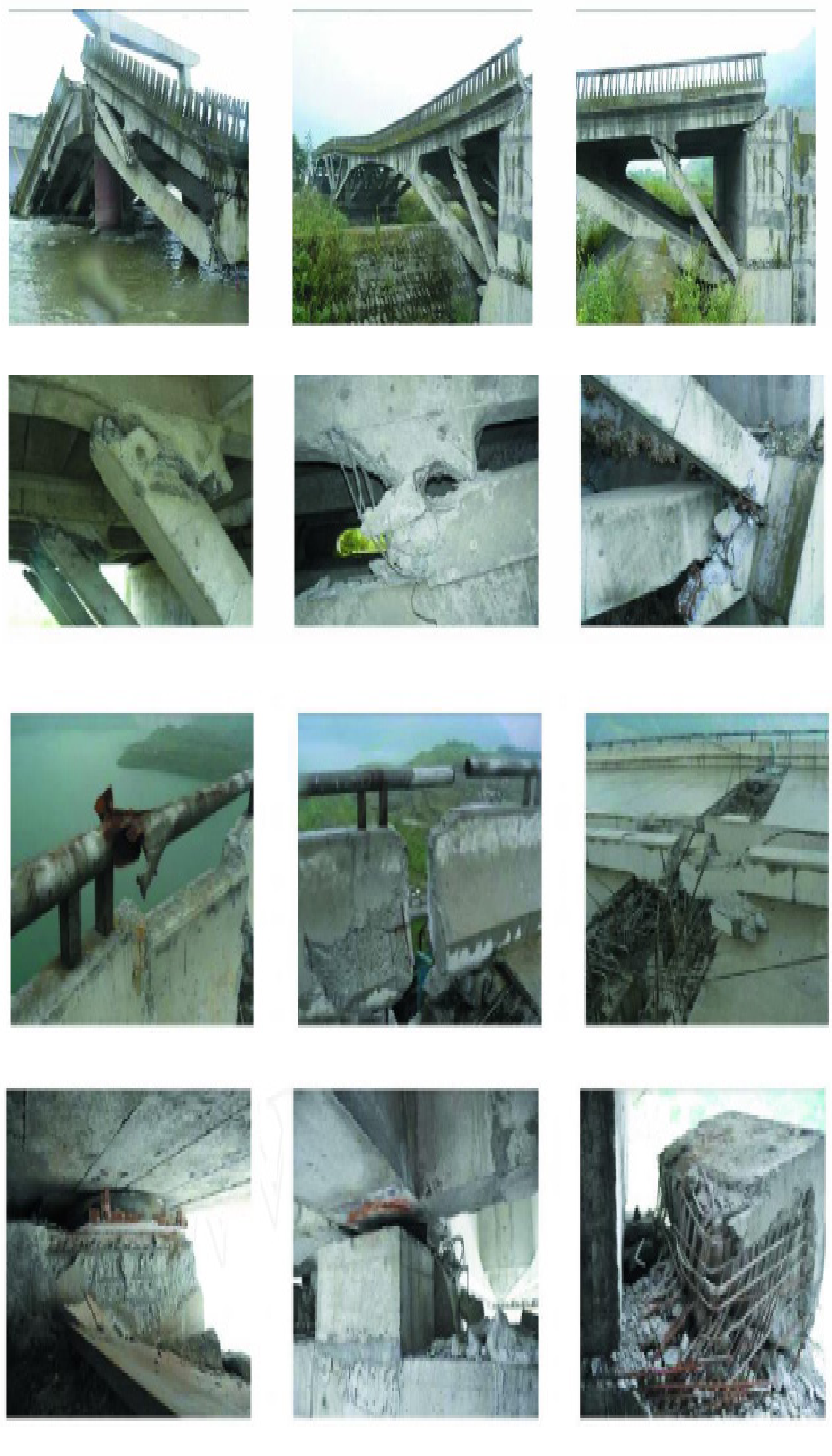


FIGURE 8. Damages of bridges due to earthquake (Wang et al 2009)

There are several forms that earthquake-induced damage to bridges exposed to lateral seismic pressures might take, as explained in Jack & Marc 2000. This chapter's goal is to categorize the many forms of earthquake damage to bridges and, ideally, to identify the sources of this damage. This is a work of incredible craftsmanship. The causes of harm are often the result of a web of interrelated factors. Reconstructing the event often necessitates some conjecture since the pain may obfuscate the specifics of the damage. It may take a thorough investigation to find injuries, and even then, the causes and consequences may not be immediately apparent. It has been determined that the primary cause of the damage is related to the site's general characteristics, the bridge's construction date, and its present situation, among other factors. What follows is a discussion of the consequences of structural arrangement, including skew, redundancy, and curved layouts. What follows is a discussion of unseating superstructures at expansion joints. Before delving into the analysis of bearing and restrainer damage—which impacts several components supported or linked by the superstructure—the chapter starts by describing common forms of damage to the superstructure. In the final part, we describe the damage to the substructure, which includes the foundation. The approach span of the Nishinomiya-ko bridge collapsed in 1995. You can see it in Figure 9. As seen in Figure 10, the Higashi-Nada Viaduct collapsed due to the 1995 Hyogo-Ken Nanbu earthquake. The Bull Creek Canyon Channel Bridge was destroyed in the 1994 Northridge earthquake, as seen in Figure 11. The Route 5/210 intersection has columns that collapsed in the 1971 San Fernando earthquake (Figure 12).

FIGURE 9. Approach span collapse of the Nishinomiya-ko bridge (Jack & Marc 2000)

FIGURE 10. Higashi-Nada Viaduct collapse in the 1995 Hyogo-Ken Nanbu earthquake (Jack & Marc 2000)

FIGURE 11. Bull Creek Canyon Channel Bridge damage in the 1994 Northridge earthquake (Jack & Marc 2000).

FIGURE 12. Damage to the Route 5/210 junction columns caused by the San Fernando earthquake of 1971 (Jack & Marc 2000).

After the earthquakes, Palu and Lombok 2020 looked at risk evaluations for several bridges. 38 bridges have undergone an on-site visual inspection, which has revealed a number of issues. Based on the seriousness of elemental damages and how frequently they occur, a risk analysis was then carried out. According to the study's findings, the approach road's embankment settlement is the area most at danger of seismic damage. Additionally, there is a moderate danger due to the wing wall fissure and superstructure displacement. According to this result, the substructure is the element that is most vulnerable and needs more investigation. Therefore, in order to minimize seismic damage to bridges, especially in areas designated as high seismic zones, it is recommended that heightened design criteria for substructures be established. Bridge element damage statistics after the Lombok and Palu earthquakes are shown in Figure 13, whereas the risk distribution after these seismic events is shown in Figure 14.

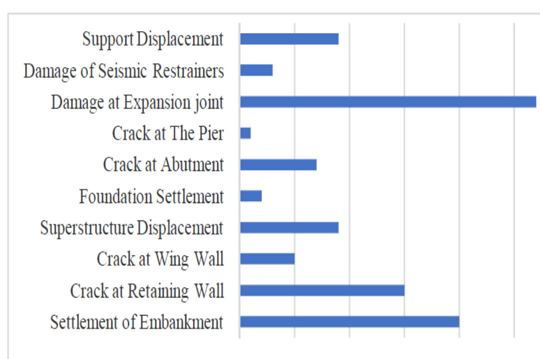


FIGURE 13. Bridge element damage statistics during the Palu and Lombok earthquakes (Palu and Lombok 2020)

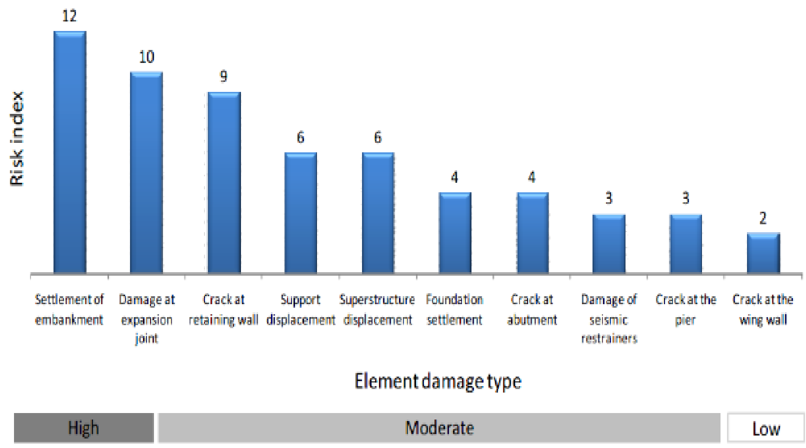


FIGURE 14. Risk distribution after Lombok and Palu earthquake (Palu and Lombok 2020)

Xia & Li, 2012 examined the impact of the Wenchuan, Tangshan, and Yunnan earthquakes on several types of bridges, including simple beam, continuous beam, continuous rigid frame, and arch bridges. Seismic damage to a single system exhibits several features, even if the seismic performance of different bridge systems differs substantially. Because of things like falling, bearing sliding, beam displacement, and collisions between nearby beams at expansion joints, even the simplest beam bridges may be destroyed in an earthquake. Compared to basic support beam bridges, continuous beam bridges have a greater seismic damage ratio and degree. Seismic damage to continuous rigid frame bridges is less obvious compared to near simple beam and continuous beam bridges. Seismic occurrences provide less of a threat to arch bridges. The paper presents a method for selecting an adequate seismic system for a straight-line bridge located in a seismic zone by analyzing earthquake damage and using numerical analysis. Figure 15shows the bridges that were damaged in the earthquake (Xia & Li, 2012).

FIGURE 15. The bridges damaged under earthquake effect in Wenchuan (Xia & Li 2012)

A bridge's damage assessment and seismic evaluation were described in depth in Aye & Shigeishi 2018 explained that the assessment of damage to many bridges impacted by the 2016 Kumamoto Earthquake was the main topic of the first section. Among these bridges, Quite amazing was the Tawarayama Bridge, a plate girder bridge along an active seismic line. The bridge was badly damaged as the epicentres of the earthquake were so near to one another. One reported possibility for damage to this sort of bridge. Parts of the Tawarayama Bridge were inspected during the damage assessment to ascertain the extent of the damage and investigate damage processes and underlying causes. The second section examined the seismic reactions of the Tawarayama Bridge using AVAQUS software, which included beam elements for the structural components. To assess the dynamic reaction of the bridge, the time-history responses were first examined both individually and concurrently utilising both longitudinal and transverse earthquake ground movements. After that, the seismic reactions of Tawarayama Bridge were studied and the behaviour of the lower lateral members was assessed depending on the bending of these members that was seen during the damage assessment. Dynamic response research and field studies show that future bridge construction should include the buckling design of the lower lateral sections. Figure 16 shows Tawarayama Bridges' whereabouts. Figure 17 depicts the Ookirihata Bridge's position. Figure 18 shows Tawarayama Bridge's location and damage evaluation.

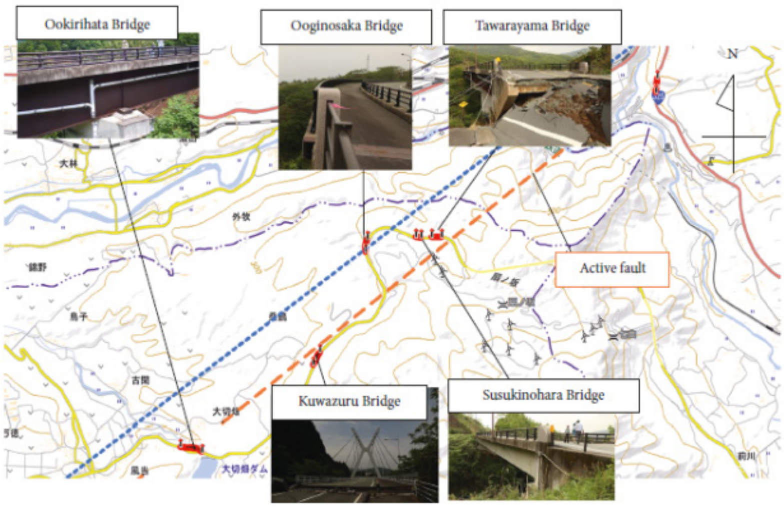
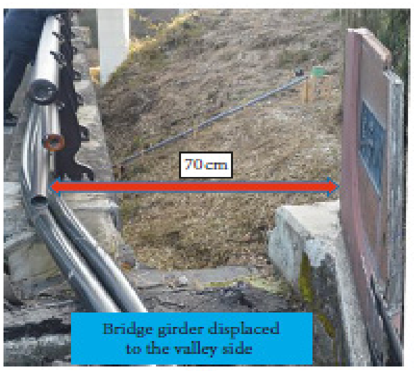


FIGURE 16. Location of bridges in Tawarayama
(Aye, Kasai, & Shigeishi 2018)



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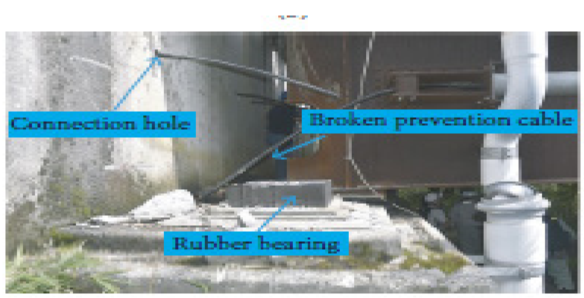

(c)

FIGURE 17. Displacement in Ookirihata Bridge
(Aye & Shigeishi 2018)

FIGURE 18. Location and damage of Tawarayama Bridge (Aye & Shigeishi 2018)

Bas et al 2024 presented a summary of the damage observed in bridges in the regions affected by the 6 February 2023 Kahramanmaras, Turkiye earthquake sequence. A bridge database was developed based on the observations from multiple reconnaissance groups that visited the bridges. These reconnaissance groups collectively visited 140 individual bridges that were subjected to various intensities of ground shaking. The severity of the observed damage ranged from no damage to total collapse. The types of damage to bridge components mainly included cracking and shifting of abutments, failure of pier cap shear blocks, shifting or dislodging of bearing pads, cracking of girders and loss of prestress, plastic hinging at pier bases residual pier drift, and distress to deck surfaces, handrails, and carried utilities. Recorded and estimated seismic intensity measures are presented for each bridge site, and statistical information and correlations were developed considering the intensity of shaking, bridge parameters, and observed damage. Observations from a few visited sites are presented as case studies to illustrate the common failure mechanisms. The bridge database and presented results are expected to serve as a reference for further analysis, such as statistical verification, correlation, or damage estimations, and discussion regarding the mitigation of the observed vulnerabilities of bridges in Turkiye and those with similar construction worldwide. Figure 19 shows the damages of Hatay Stadium Bridge.

FIGURE 19. Damages of Hatay Stadium Bridge
(Bas et al 2024)

FIGURE 20. Damages in Tohma Bridge in Malatya province (Bas et al 2024)

EVALUATION METHODS OF SEISMIC RESISTANCE OF BRIDGES

In contrast to the modern seismic design code for bridges (RPOA-2008), which uses fragility curves, the Algerian Highways Bridge was developed using an outdated static technique based on the seismic coefficient approach, and Kehila & Remki 2018 assessed the seismic performance of the bridge piers for this bridge. In light of the revised RPOA2008 standard, this research assesses the effectiveness of bridge piers that were constructed using the seismic coefficient approach. These curves were produced by evaluating the reactions of the selected bridge piers using static pushover analysis and nonlinear time history analyses. IDA stands for incremental dynamic analysis. Thirty ground motion data points are used to evaluate the engineered bridge piers' effectiveness. The proposed bridge piers are subjected to analytical fragility studies using probabilistic seismic demand models (PSDM). In order to forecast how well the bridge piers would function under different intensities of ground motion, fragilities were developed based on the maximum drift in the piers throughout four distinct damage phases (slight, moderate, substantial, and collapse). Fragility analysis is used to evaluate how changing the reinforcing strength affects the seismic performance of designed bridge piers. The fragility data show that the RPOA2008 performs better than the traditional design pier and has a lower chance of breaking. Figure 21 illustrates the bridge configuration, whereas Figure 22 presents the response spectra, depicting the dispersion of peak ground accelerations.

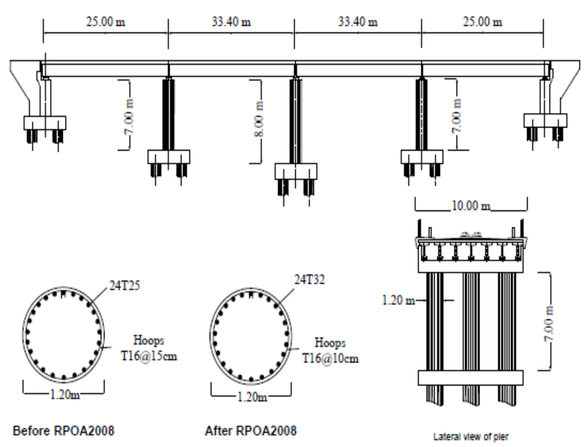

FIGURE 21. The bridge configuration, whereas Figure 22 presents the response spectra, depicting the dispersion of peak ground accelerations (Kehila & Remki 2018)

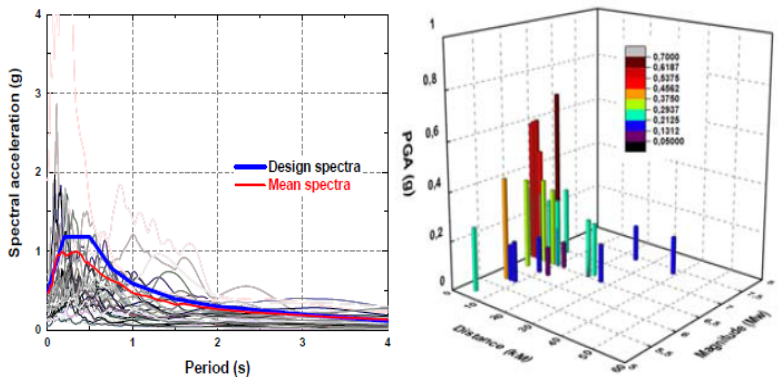

FIGURE 22. Response spectra - distribution of peak ground accelerations (Kehila & Remki 2018)

In order to investigate the seismic performance of a concrete bridge pier model under severe shaking, Al-Aayedi & Shamkhi 2020 performed two shaking model tests. Throughout the testing, the displacement and seismic reaction of the model were recorded. Experimental analysis was conducted in this study to determine the seismic performance of concrete bridge piers. Important factors that have been studied include acceleration response, seismic displacements, settling of the bridge pier model, and failure processes. A few of the results included the seismic displacement of the bridge pier model, the acceleration response as characterized by temporal acceleration and acceleration response spectra, and the failure cause during shaking. According to the findings, the acceleration amplification is most pronounced at the highest point of the bridge pier. Because of the powerful movement, the seismic displacement increases suddenly. The mechanism of overturning failure at the heel of the bridge pier was proven in tests 1 and 2. Figure 23 shows the layout of the shaking table model and associated equipment. In Figure 24 we can see the regions of input motion's frequency and time-acceleration.

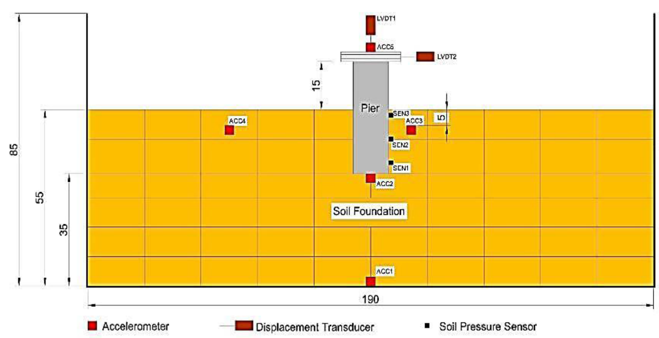

FIGURE 23. Shaking table model layout with instruments (Al-Aayedi & Shamkhi 2020)

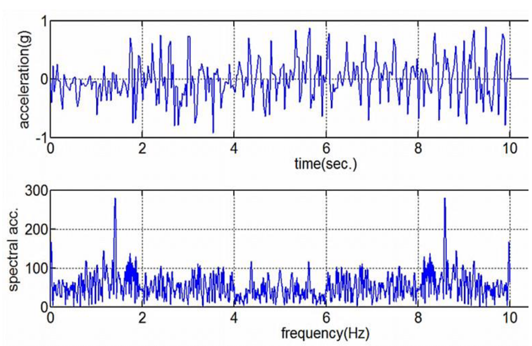

FIGURE 24. Time-acceleration and frequency domain of the input motion (Al-Aayedi & Shamkhi 2020)

The study cited in Pettorruso & Quaglini 2024 looked into The possibility of less complex methods using less computational resources for assessing straight, We compare the results of Multi-Span Bridges with those of Nonlinear Time History Analysis (NLTHA) to get a sense of the predicted accuracy. The study takes into account the unique characteristics of Italy's bridge inventory by analyzing three bridge archetypes with simply-supported or continuous-deck design. In order to find the standard solution, the bridges are subjected to a battery of tests, starting with nonlinear dynamic analyses and progressing through linear dynamic analyses, response spectrum analysis, and nonlinear static analyses like modal pushover analysis (MPA) and equivalent static analysis. Finally, the research concludes with a comparison of the evaluated techniques, outlining the pros and cons of each method. Figure 25 shows the chosen bridge piers. You may see elastic spectra that adhere to the IBC standards in Figure 26.

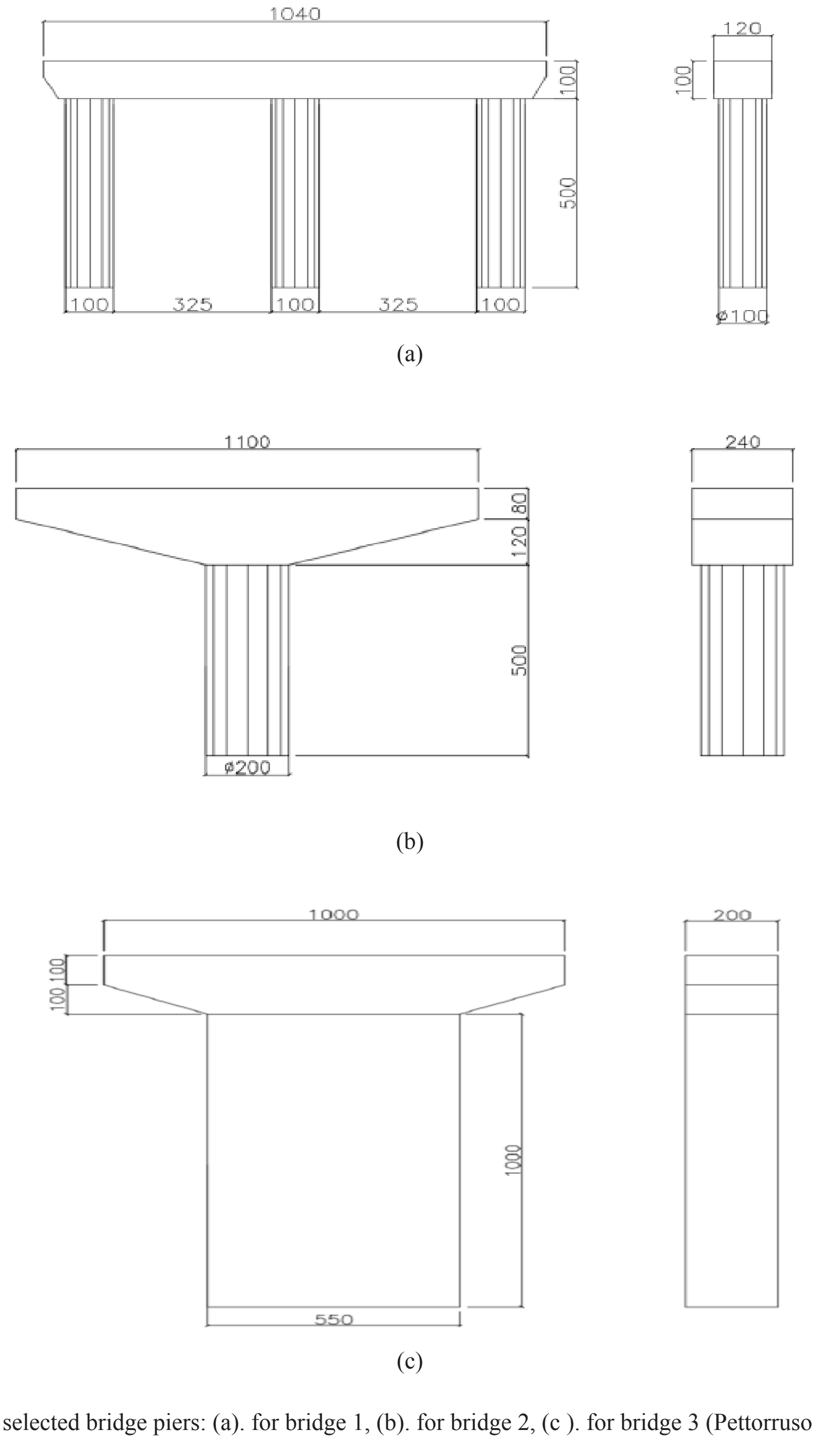

FIGURE 25. The selected bridge piers: (a). for bridge 1, (b). for bridge 2, (c). for bridge 3 (Pettorruso & Quaglini 2024).

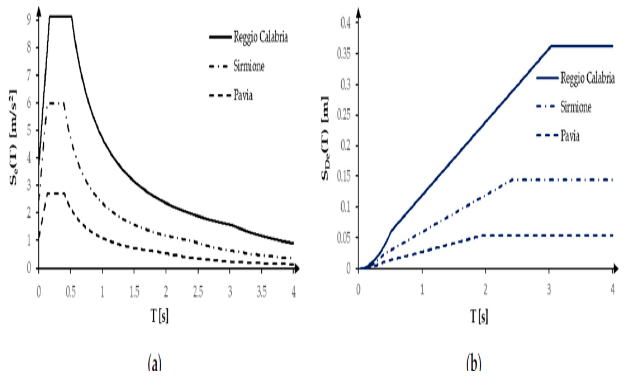

FIGURE 26. Elastic spectra according to IBC: (a). Acceleration, (b). Displacement (Pettorruso & Quaglini 2024)

Suwal & Jamarkattel 2023 examined if adding steel jacketing to the bridge pier would enhance its seismic performance. The steel casing's thickness is the altered variable. Pushover, or displacement-controlled nonlinear static analysis, is used to evaluate a bridge pier's capability. To determine the bridge's seismic demand, a temporal load history is applied to the structure. By graphing the fragility curve, the improvement of the bridge structure after Steel Jacketing is applied is evaluated. CSI Bridge V20.2.0 is used to simulate the bridge. The strain values obtained from the pushover research are used to define the different damage phases. The likelihood of surpassing certain PGA thresholds under predetermined damage scenarios is calculated using capacity and demand measurements. The First Order Second Order Method (FOSM) is used to generate the fragility curve. The study shows that the bridge's failure susceptibility dropped from 28.22% to 14.24% at a 1.0g PGA when jacketing was applied for significant damage. Similarly, the failure probability decreased from 16.93% to 7.22% at 1.0 PGA due to the bridge's vulnerability to collapse damage condition after jacketing. The model of global finite elements is shown in Figure 27. The pushover curve is shown in Figure 28.

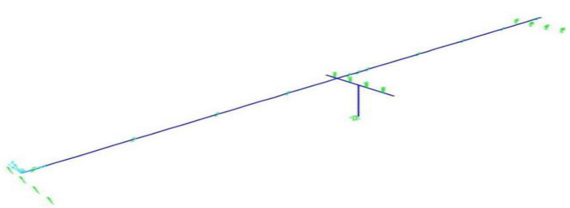

FIGURE 27. Global Finite Element Model (Suwal & Jamarkattel 2023)

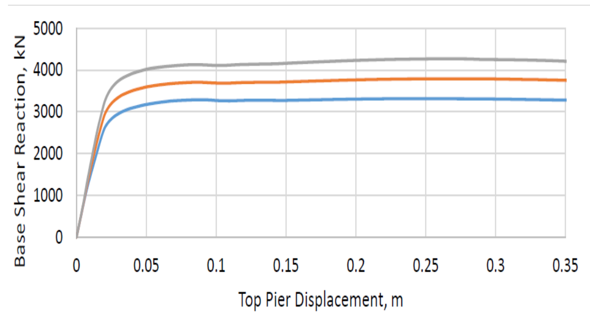

FIGURE 28. Pushover Curve (Suwal & Jamarkattel 2023)

Gönen & Soyöz 2022 proposed a comprehensive reliability-oriented seismic evaluation methodology utilizing analytical modeling, laboratory experimentation, and probabilistic analysis. It suggests performance limit states and looks at the idea of measures of success. This technique is used in an old Turkish masonry arch bridge. Using a thorough 3D finite element model, probabilistic nonlinear analyses are conducted to methodically evaluate the uncertainties in seismic input and material characteristics. The distributions of demand and capacity are generated by integrating the data with the proposed limit state definitions. The First-Order Reliability Method and Monte Carlo simulation distributions are used to evaluate the dependability indices and likelihood of exceedance for every limit state. For decision-making purposes, especially in relation to the design of intervention techniques and post-earthquake scenarios, the proposed probabilistic assessment method will offer a realistic way to obtain more reliable information on the expected seismic performance of masonry arch bridges. Figure 29 shows the position of the bridge, the plan view, and the North Anatolian Fault line. See the bridge's size and finite element mesh in Figure 30. The limit states and the results of the MPP analysis are shown in Figure 31. Figure 32 shows the average PO curve's performance limit states and the CM node's transverse drift. (Gönen & Soyöz 2022)

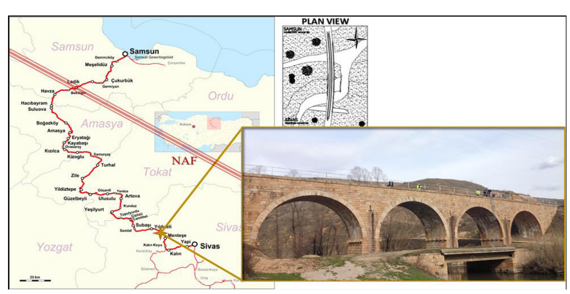

FIGURE 29. The Location of the Bridge, plan view, and North Anatolian Fault line (Gönen & Soyöz 2022)

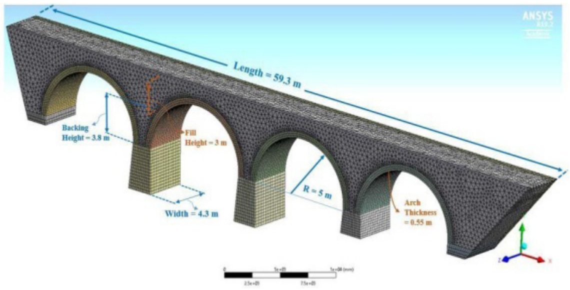

FIGURE 30. Dimensions and the FE mesh of the bridge (Gönen & Soyöz 2022)

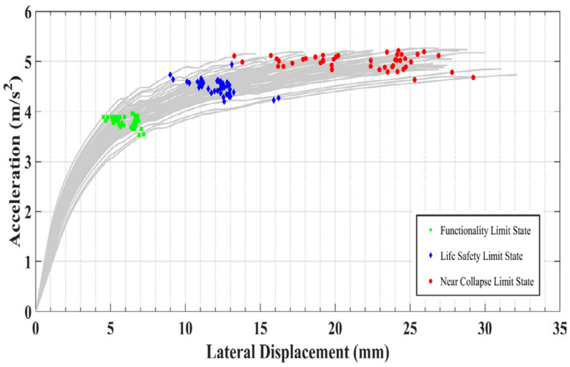

FIGURE 31. MPP analysis results and the limit states (Gönen & Soyöz 2022)

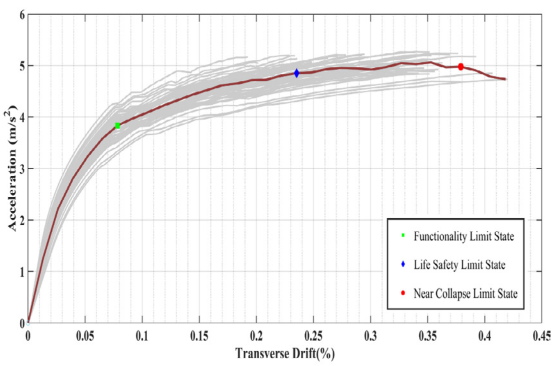

FIGURE 32. Transverse drift of the CM node and the performance limit states corresponding to the average PO curve (Gönen & Soyöz 2022)

Mosleh & Varum, 2020 used the use of analytical fragility curves, the seismic vulnerability of highway concrete bridges constructed before to 1990 was assessed. The elements that are evaluated include concrete compressive strength, reinforcement yield strength, lap splices, span length, and column height. For every group of bridge specimens exposed to varying intensities of seismic ground vibrations, nonlinear response history assessments using 3D models were carried out. Using the displacement ductility requirement of the piers as a performance parameter, this research examines how the kind of earthquake fault affects the seismic vulnerability of bridges. In order to support future seismic-risk reduction efforts, fragility curves are used to evaluate the seismic susceptibility of common concrete bridge types in Iran using this value. The chosen set of seismic recordings comes from reversal fault and strike-slip seismic sources. Compared to bridges exposed to strike-slip accelerograms, those exposed to reverse fault recordings exhibit higher pier demands and greater seismic susceptibility. The seismic susceptibility of bridge piers is significantly impacted by span length, lap splice, column height, and seismic fault type, according to research. The results are essential for determining which retrofit techniques are most important for the most seismically susceptible bridges. A three-dimensional finite element model is shown in Figure 33.

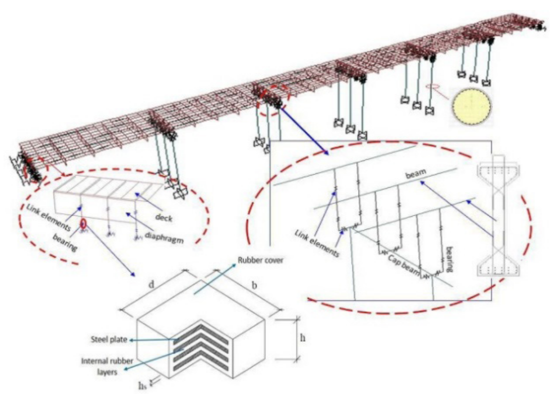

FIGURE 33. Three-dimensional finite-element model (Mosleh & Varum, 2020)

Siddique & Hossain 2020 Discovered that the contribution of seismic forces escalates markedly for bridges situated in inferior site classes, with the proportion of earthquake force to dead load increasing from 7.4% to 16.7% for site classes SC and SD, respectively. The impact of an earthquake of equivalent magnitude on bedrock is exacerbated on a bigger scale in inferior soils. Consequently, inferior soils experience more intense shaking during an earthquake hazard event. The design column section is significantly bigger for bridges constructed in inferior site classes due to their exposure to elevated seismic stresses. The enlarged column sections diminish the bridge's flexibility and increase its rigidity. The contributions of seismic forces are determined to be greater. The impact of seismic forces may vary significantly among bridges constructed in different eras. The ratios of seismic displacement demand to capacity markedly increase for bridges situated in inferior site classifications. Bridges situated in inferior site classes will have subsoil conditions beneath their piers that are substandard, resulting in the structure confronting more intense ground shaking and elevated seismic demands. Both bridges situated in site classes SC and SD, adequately designed for seismic stresses, meet the seismic performance objectives. The demand capacity ratios vary based on different combinations of column sections and steel ratios. Consequently, it is essential to assess the performance of a bridge before concluding the design. Figure 34 presents the precise dimensions of the bridge in question, as illustrated in Figure 35. The elastic response spectrum for SC soil in Sylhet is presented, together with Figure 36, which illustrates the elastic response spectrum for SD soil in Sylhet.

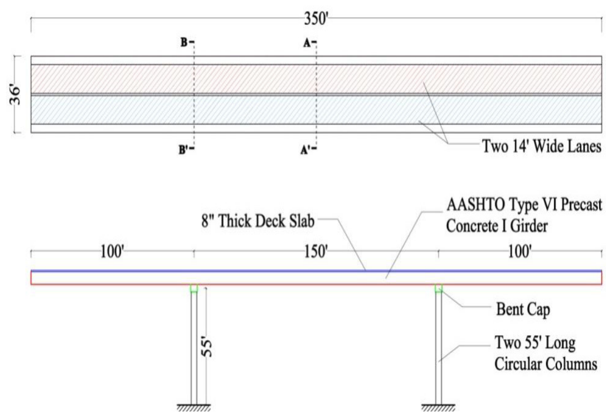

FIGURE 34. Detailed dimensions of the bridge under consideration (Siddique & Hossain 2020)

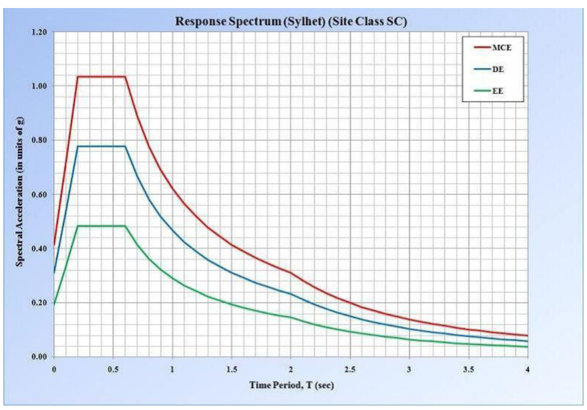

FIGURE 35. Elastic response spectrum for SC soil in Sylhet (Siddique & Hossain 2020)

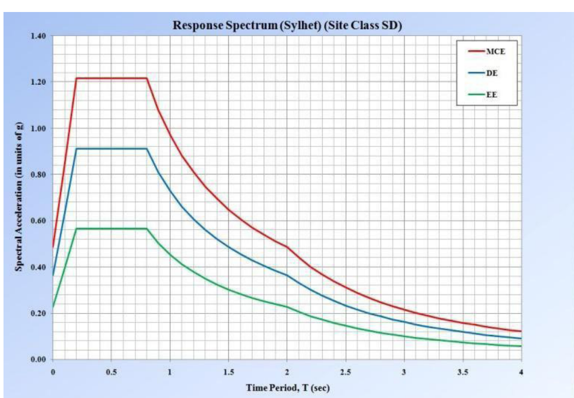

FIGURE 36. Elastic response spectrum for SD soil in Sylhet (Siddique & Hossain 2020)

Jaaz et al 2021 varied the locations and numbers of piers to assess the seismic performance of two bridge structures under earthquake impacts. The simply supported I girder bridge demonstrated a higher structural capacity than the continuous box girder bridge, which, based on the D/C ratio data, can sustain seismic stresses. The continuous box girder bridge had a greater seismic demand and a poorer structural capacity in comparison to the simply supported I girder bridge. Two bridge types with progressively more piers were found to have seismically sound designs that could sustain seismic pressures in area class B. Adding more piers has a significant impact on the seismic design of bridge structures by increasing displacement capacity, force capacity, and reducing seismic demand, which lessens the impact of earthquake forces on the structural elements of the bridges, according to the results of non-linear static analysis (pushover method). The simply supported I girder bridge showed a greater longitudinal capacity than the continuous box girder bridge. Continuous box girder bridges perform better than simply supported I girder bridges in terms of transverse capacity. The displacement-based performance ratings declined as the number of bridge support piers increased. Figure 37 displays the natural frequency of the box girder bridge, and Figure 38 follows. Natural frequency of an I-girder bridge.

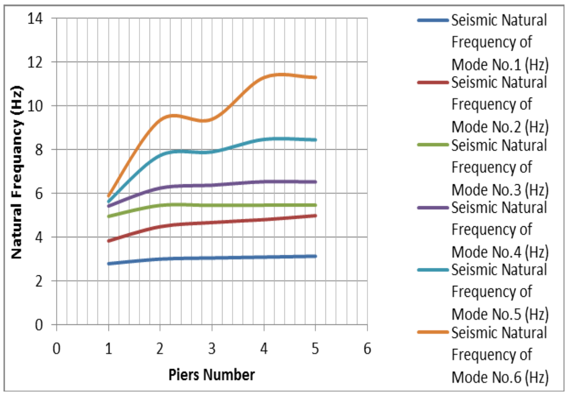

FIGURE 37. Natural frequency of box girder bridge (Jaaz et al 2021).

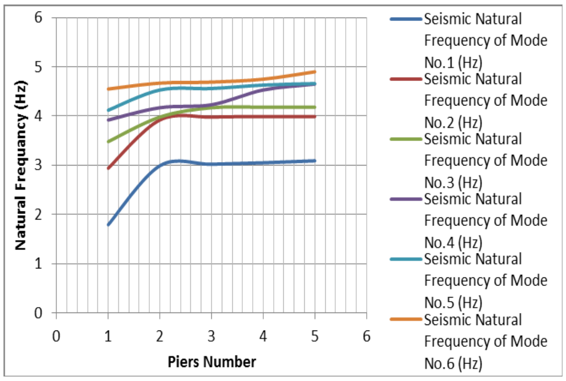

FIGURE 38. Natural frequency of I girder bridge (Jaaz et al 2021)

Naser 2022 optimized and evaluated The seismic resilience of bridge piers through the implementation of various cross-sectional shapes and dimensions for bridge supports subjected to seismic forces. Two seismic design methodologies were used in the process of optimization and evaluation. The yielding point and the demand to capacity ratio (DCR) were the methods used. According to the demand to capacity ratio (DCR) statistics, all pier models' DCR values rose as pier cross-sectional dimensions grew until eventually dropping below 1.0. This implies that increasing the size improves the bridge supports' ability to sustain seismic stresses in both longitudinal and transverse directions. Solid wall piers exhibited a lower DCR value than models, indicating that they are suitable for bridge support design to tolerate lateral earthquake loads, exhibiting adequate stiffness and capacity under seismic stresses. The yielding points rose as pier dimensions expanded in both transverse and longitudinal directions, according to the performance point data. The ratings between support No. 1 and support No. 4 were the highest.

When compared to alternative pier types, the solid wall form of piers showed higher yielding points, suggesting improved seismic capacity and increased resilience to earthquake pressures. This research recommended that bridge constructions be designed to resist seismic loads using a third model for each kind of pier. When building bridge constructions in seismically active areas, this research advises using solid wall piers as supports. Bridge models are shown in Figure 39. The force yielding points for bridge support models in the longitudinal direction are shown in Figure 40. The displacement yielding points for bridge support models in the longitudinal direction are shown in Figure 41.

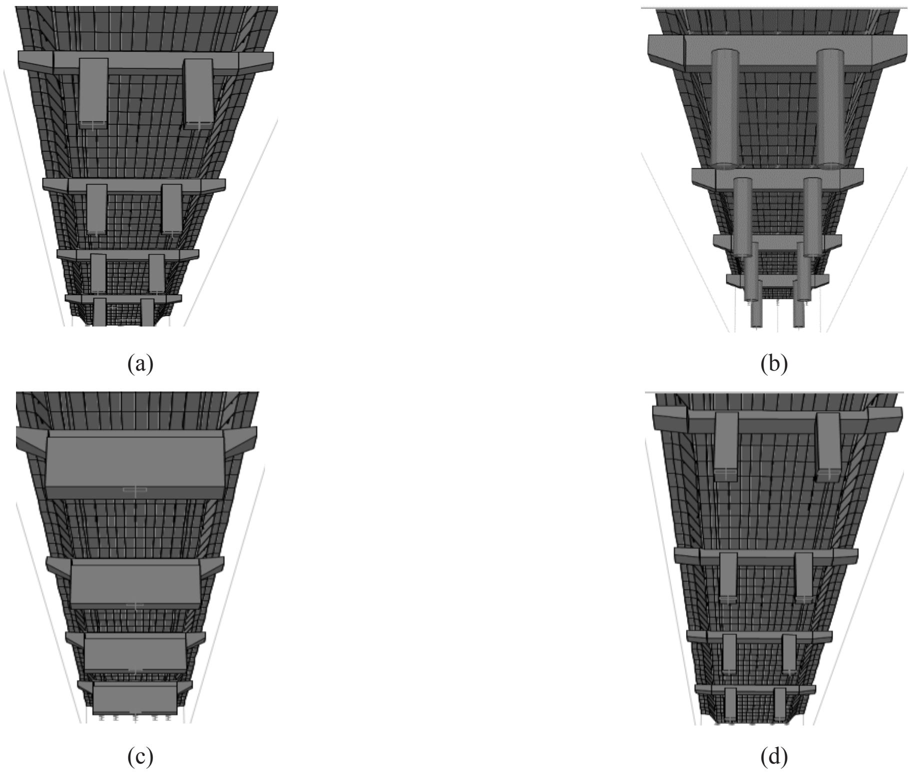

FIGURE 39. Bridges models : (a). Square pier form, (b). Circle pier form, (c). Solid wall pier form, (d). Rectangular pier form (Naser 2022).

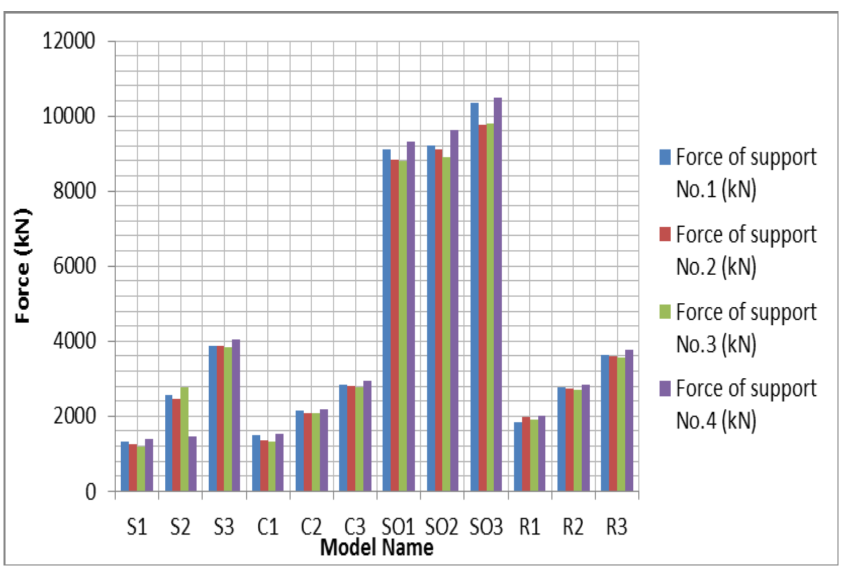

FIGURE 40. Force yielding points in longitudinal direction for bridges supports models (Naser 2022)

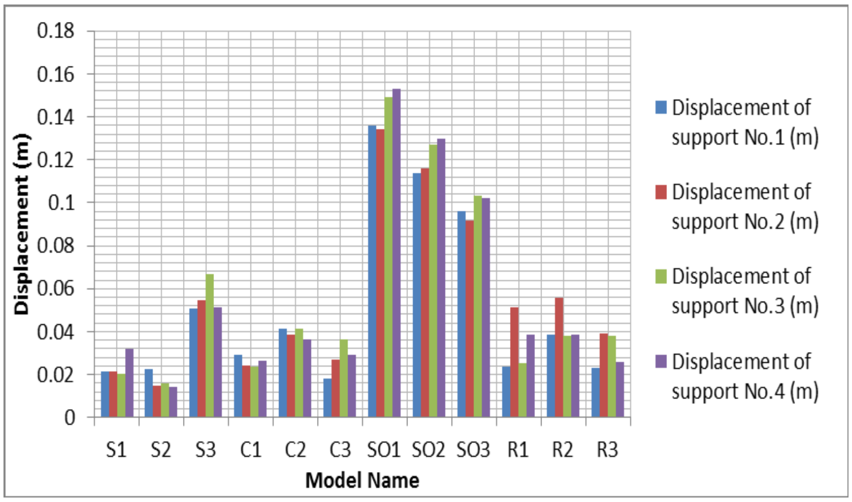

FIGURE 41. Displacement yielding points in longitudinal direction for bridges supports models (Naser 2022)

Naser A. 2022 assessed the structural components' capacity to sustain loads in a range of bridge types under seismic stress. The results of the seismic modal analysis indicated that under seismic stress, the box girder bridge, precast T girder bridge, and U steel girder bridge displayed higher natural frequency values than other bridge constructions. The pushover investigation in the transverse direction revealed that bend No. 2, which is located in the center of the superstructure, had more displacement than bends No. 1 and No. 3.

The Precast I girder bridge exceeded the maximum transverse displacement value and showed a greater longitudinal displacement in the longitudinal direction than earlier bridge constructions. Bent No. 2 is the crucial structural component, according to the demand and capacity ratio analysis. Demand/capacity ratios for precast I girder, precast T girder, and U steel bridges, in particular, exceed or approach 1.0, suggesting a possible failure risk at bent No. 2 for these bridge types. In order to change the bents of various bridge types, it was necessary to increase the number of piers, use high-strength materials when building bents, and increase the diameters of piers and pier tops. According to the analysis of internal forces, of all the bridge constructions, bent No. 2 experienced the highest levels of axial force, horizontal shear, and bending moment. The results of the pushover investigation and the demand/capacity ratio were consistent with the superior force values of the precast I girder bridge, precast T girder bridge, and U steel bridge models when compared to other models. The seismic design curve is shown in Figure 42. Seismic natural frequencies for bridge models across the first six mode forms are shown in Figure 43 (Naser A. 2022)

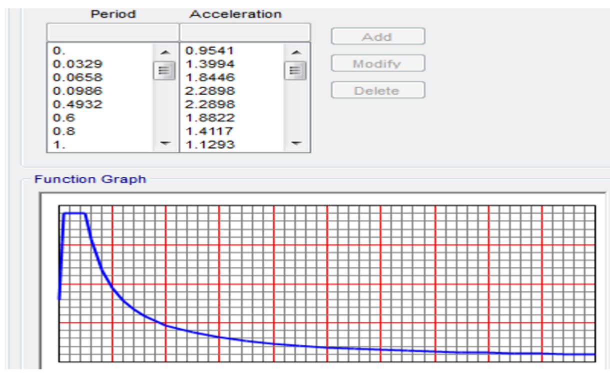

FIGURE 42. The seismic design curve (Naser A. 2022)

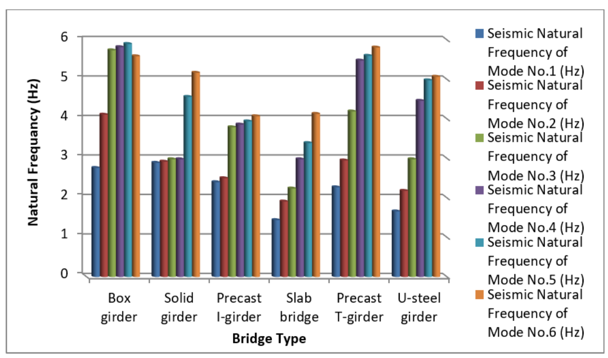

FIGURE 43. Seismic natural frequency for bridges models of first six modes shapes (Naser A. 2022)

NON-LINEAR STATIC METHOD (PUSHOVER)

Non-linear static method (pushover method) is a very employed method in the assessment of seismic design of bridges structures to resist the earthquake action. Pushover analysis consists of a lateral load that pushes the structure in incremental steps; calculating the state of equilibrium in each of them, as well as the corresponding internal forces and the displacements of the nodes, it consequently describes the elastic and plastic behavior of each structural element and its non-linear hinges. This method is highly effective for assessing the seismic safety of both new and existing structural elements. Numerous approaches exist for the use and implementation of the non-linear static analysis method (pushover analysis). These approaches encompass various load patterns, the incorporation of higher modes, adaptive load patterns, and force versus displacement management. All these efforts are directed towards obtaining a capacity curve that provides a reliable indication of the structure's seismic behavior. This strategy can be advantageous when an existing structure lacks earthquake resistance capacity. (Shehu, R. 2021, European Committee for Standardization. 2014, Ismaeil, M. 2018 ,Naser et al 2021) .

The capacity curve is created using a novel, straightforward, and useful technique known as the Pushover method. It is then compared to the seismic demand curve to ascertain the structure's performance point. This establishes the foundation for performance-based design, a seismic design methodology. Nonlinear statics analysis Pushover analysis assumes that the response of a multi-degree of freedom (MDOF) structure may be approximately represented by an analogous single-degree of freedom (SDOF) system. According to studies, the first mode of vibration dominates the structure's motion, indicating that the response is primarily governed by a single mode of vibration whose configuration stays consistent throughout the earthquake. The capacity curve in Figure 44 and the identification of the system's performance point (Sa-Sd) are outcomes of the pushover technique. The determination is made by superimposing two curves: the response spectrum in Figure 45 represents the seismic demand, while the structural strength capability is shown by the other curve. One of the representative parameters indicating the progression of damage levels in a structure or structural element is the damage index (DI). This index is standardized and discretized into a series of values ranging from '0', indicating that the structure has suffered no structural damage, to '1', indicating that the structure has reached its maximum capacity and structural instability near rupture or total collapse. For example, if DI > 1, the building has completely collapsed and is unrecoverable; however, if DI = 0.7, the building is considered recoverable and can be preserved with appropriate reinforcement measures. There are four levels or degrees of damage: low, moderate, significant, and very significant. The damage index is defined with respect to lateral displacement as follows: (Jamil & Cherraj 2023; Cosenza & Ramasco 1993; Ghobarah & Biddah 1999; Powell & Allahabadi 1988)

$$\mathbf{DI}=\frac{\delta m-\delta y}{\delta u-\delta y} \quad (1)$$

δm: the maximum displacement in the nonlinear zone (performance
point).
δy: the elastic displacement (without damage).
δu: the ultimate displacement (total collapse).

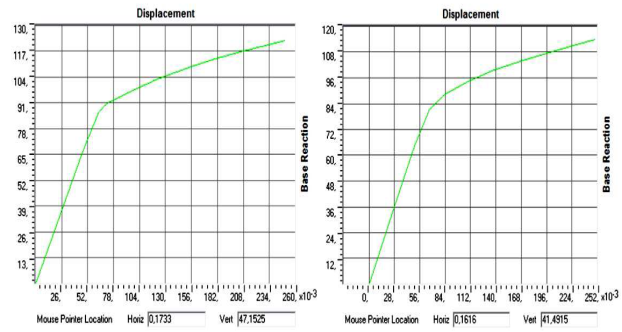

FIGURE 44. Capacity curve in x and y direction (Jamil & Cherraj 2023)

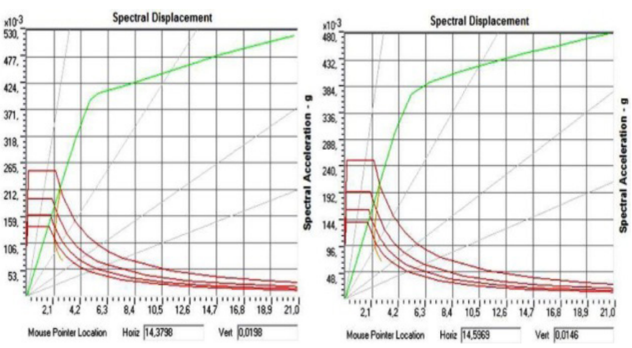

FIGURE 45. The performance point (direction X-X and Y-Y) (Jamil & Cherraj 2023)

BRIDGE BENTS' DEMAND TO CAPACITY RATIO

The Applied Technology Council (ATC) was the first to suggest the demand to capacity ratio (D/C). The ability of structural components to tolerate the pressures and displacements brought on by seismic activity is contrasted with the internal forces and displacements obtained from an elastic analysis for design earthquake requirement. The structural component is at danger of failure and has to be modified when the demand-to-capacity ratio is greater than one. Therefore, for structural elements with sufficient ability to support earthquake stresses from all directions, this ratio has to be less than 1.0. When ductility is evaluated inside the section, a section ductility requirement of 2 or 3 may be associated with the demand-to-capacity ratio. Recent developments in earthquake response research have led to a more thorough analysis of the demand to capacity method. The main issue with using this approach is that non-linear behavior prevents a correlation between the member and the structural ductility parameter. (Jaaz, et al., 2021, Naser, A. 2022, Sonawane et al., 2013, Kenneth,T. & Yahya, C. 2001).

SEISMIC MODAL ANALYSES

Seismic modal analysis is conducted on bridge structures under their self-weight, subjected to seismic loads, to determine demand values such as natural frequencies and mode shapes. It is utilized in the design and study of civil structures to enhance natural mode frequencies and forms, as well as to ascertain dynamic features. It may be incorporated into the response spectrum analysis, a method extensively utilized for the construction of civil structures under typical conditions or seismic activity. The aim of this method is to provide swift estimations of the maximum reaction without necessitating response history analysis (Ozel, A. 2016; Nikolaos et al. 2015; Fragiadakis, M. 2013).

Using modal analysis on a bridge allows for a more precise evaluation of the structure's integrity and structural sufficiency monitoring. Important factors for bridge design, assessment, and condition evaluation include natural frequency, mode shape, and seismic loads. One may assess a bridge's capacity, appropriateness, and structural integrity by using these data, especially the seismic loads and natural frequency. These characteristics have a significant impact on the bridge's resistance to lateral pressures, which may be caused by seismic activity. Bridges' natural frequency and mode shape are important dynamic features. Consequently, a study of the mode shape and natural frequency is required. The amount of the seismic load delivered to a bridge will be determined by a modal analysis that makes use of the two anticipated dynamic features. (Mardhiyah & Bangun 2023, Akbari & Maalek 2018; Cao & Chen 2018; Cui & Che 2021).

FUTURE DIRECTION

It is important to develop experimental tests before and after earthquake load to reduce the damage due to seismic load. Numerical design and analysis by using different new engineering software is significant to improve the design of structural members of bridges.

CONCLUSION

The aim of this study was to examine topics related to the design of seismic resistance and assessment of bridge constructions subjected to lateral loads from earthquakes. This study elucidated that an earthquake is the vibration of the Earth's layers, resulting in an unforeseen release of energy within the Earth's lithosphere, which generates seismic waves. Geological assessments and historical documentation allow for the estimation of potential locations for significant earthquakes in the forthcoming years. Consequently, earthquake-resistant design profoundly influences the architectural planning of civil structures. This study focused on bridge structural components impacted by seismic activity, including piles, pile caps, piers, pier caps, and abutments. It assessed the seismic design of bridge supports, the damage to bridges resulting from earthquake loads, and evaluation techniques for seismic resistance, such as non-linear static analysis, modal analysis, and demand-to-capacity ratio. The seismic resistance of bridge structures must be assessed prior to and following seismic events.

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DECLARATION OF COMPETING INTEREST

None

REFERENCES

Acharya, N. and Prasad, V. 2018. Design and detailing of earthquake resistant RC bridge structure. *International Journal of Creative Research Thoughts* 6(2): 982-1008.

Agrawal, A. K., Liu, H., Imbsen, R. A., & Zong, X. 2012. Seismic design considerations, volume I, technical approaches and results, Volume II, Appendices II-VIII (No. FHWA-NJ-2010-006). New Jersey. Dept. of Transportation.

Akbari, R., Maadani, S., & Maalek, S. 2018. On the fundamental natural frequency of bridge decks: Review and applications. *Proceedings of the Institution of Civil Engineers-Structures and Buildings* 171(12): 931-945.

Akkar, S., Azak, T., Can, T. O. L. G. A., Çeken, U., Demircioğlu Tümsa, M. B., Duman, T. Y., & Zülfikar, Ö. 2018. Evolution of seismic hazard maps in Turkey. *Bulletin of Earthquake Engineering* 16: 3197-3228.

Al-Aayedi, H. K., Aldefae, A. H., & Shamkhi, M. S. 2020, June. Seismic performance of bridge piers. In *IOP Conference Series: Materials Science and Engineering* 870(1): 012069. IOP Publishing.

Al-Hazragi, A. & Lateef, A. M. 2021. Behaviour of uniaxial reinforced concrete columns strengthened with ultra-high-performance concrete and fiber reinforced polymers. *Tikrit Journal of Engineering Sciences* 28(2): 54-72.

Amit, K., & Kulkarni, M. 2018. Parametric study of bridge piers. *International Research Journal of Engineering and Technology* 5(1): 656-660.

Angulo, C., Díaz, K., Gutiérrez, J. M., Prado, A., Casadey, R., Pannillo, G. & Vielma, J. C. 2020. Using BIM for the assessment of the seismic performance of educational buildings. *Int. J. Saf. Secur. Eng.* 10(1): 77-82.

Anil, K., Huabei, L., & Roy, A. 2012. Seismic design considerations Volume I: Technical Approaches and Results, Final Report. Report No. FHWA-NJ-2010-006, Federal Highway Administration US Department of Transportation Washington, DC USA.

Anurag, D. P. 2018. Performance based seismic evaluation of medium rise 3D bare frame. *Journal of Emerging Technologies and Innovative Research* 5(9): 227-232.

Aye, M. N., Kasai, A., & Shigeishi, M. 2018. An investigation of damage mechanism induced by earthquake in a plate girder bridge based on seismic response analysis: case study of Tawarayama bridge under the 2016 Kumamoto earthquake. *Advances in Civil Engineering* 2018(1): 9293623.

Bas, S., Hunt, J., Gencturk, B., Jampole, E., Sonmezer, Y. B., Chancellor, B., ... & Sezen, H. 2024. Seismic performance and damage assessment of bridges during the 2023 Kahramanmaras, Türkiye earthquakes (M w= 7.8, M w= 7.6). *Earthquake Spectra* 40(4): 2339-2363.

Caltrans. 1999. Guidelines for generation of response-spectrum-compatible rock motion time history for application to Caltrans toll bridge Seismic retrofit projects, Caltrans Seismic Advisory Board, California Department of Transportation, Sacramento, CA.

Cao, L., Liu, J., & Chen, Y. F. 2018. Theoretical and numerical study on the natural frequencies of bridges with corrugated steel webs. *Structures* 15: 224-231.

Connor, J. S., & Alampalli, S. 2024. A plan for assessing the damage to highway bridges after an earthquake. In Bridge Maintenance, Safety, Management, Digitalization and Sustainability (pp. 3329-3336). CRC Press. and Sustainability-Jensen, Frangopol & Schmidt: 3329- 3336. DOI: 10.1201/9781003483755-394.

Cosenza, E., Manfredi, G., & Ramasco, R. 1993. The use of damage functionals in earthquake engineering: a comparison between different methods. *Earthquake Engineering & Structural Dynamics* 22(10): 855-868.

Cui, J., & Che, A. 2021. Calculation method of natural characteristics of beam element considering initial state. In *IOP Conference Series: Earth and Environmental Science* 676(1): 012140. IOP Publishing.

Dong, H., Han, Q., Du, X., & Zhou, Y. 2022. Review on seismic resilient bridge structures. *Advances in Structural Engineering* 25(7): 1565-1582.

Duan, L., & Reno, M. 1999. *Performance-Based Seismic Design Criteria for Bridges*. Structural Engineering Handbook Ed.

European Committee for Standardization. 2014. Design of Structures for Earthquake Resistance—Part 1; Eurocode 8: CEN: Brussels, Belgium, Volume 3.

Fragiadakis, M. 2013. Response spectrum analysis of structures subjected to seismic actions. *Encyclopedia of Earthquake Engineering*, 3-18.

Ghobarah, A., Abou-Elfath, H., & Biddah, A. 1999. Response-based damage assessment of structures. *Earthquake Engineering & Structural Dynamics* 28(1): 79-104.

Gönen, S., & Soyöz, S. 2022. Reliability-based seismic performance of masonry arch bridges. *Structure and Infrastructure Engineering* 18(12): 1658-1673.

Harirchian, E., Jadhav, K., Mohammad, K., Aghakouchaki Hosseini, S. E., & Lahmer, T. 2020. A comparative study of MCDM methods integrated with rapid visual seismic vulnerability assessment of existing RC structures. *Applied Sciences* 10(18): 2-24. https://doi.org/10.3390/app10186411.

Hurt, M. A., & Schrock, S. D. 2016. *Highway Bridge Maintenance Planning and Scheduling*. Butterworth-Heinemann.

Işık, E., Büyüksaraç, A., Ekinci, Y. L., Aydın, M. C., & Harirchian, E. 2020. The effect of site-specific design spectrum on earthquake-building parameters: A case study from the Marmara Region (NW Turkey). *Applied Sciences* 10(20): 7247. https://doi.org/10.3390/app10207247.

Ismaeil, M. 2018. Seismic capacity assessment of existing RC building by using pushover analysis. *Civil Engineering Journal* 4(9): 2034-2043.

Jaaz, H. A. G., Naser, A. F., Mohammed, H. A., & Mohammed, A. A. 2021. Earthquake resistance optimization and evaluation of bridge piers structural form and dimensions based on demand to capacity ratio and yielding points of force-displacement. *Mathematical Modelling of Engineering Problems* 8(6): 945-954. https://doi.org/10.18280/mmep.080614.

Jack, P. M., & Marc, O. 2000. Earthquake damage to bridges. In *Bridge Engineering Handbook*, edited by Wai-Fah Chen and Lian Duan. CRC Press.

Jamil, Z., Jamil, Y., Nasla, S., Gueraoui, K., & Cherraj, M. 2023. Application of the nonlinear static analysis method of pushover on an existing building in the city of Al Hoceima, Morocco. *JP Journal of Heat and Mass Transfer* 36: 167-179.

Jinrong, W. 2000. *Piers and Columns. Bridge Engineering Handbook*, Ed. Wai-Fah Chen and Lian Duan, Boca Raton: CRC Press.

Kehila, F., Kibboua, A., Bechtoula, H., & Remki, M. 2018. Seismic performance assessment of RC bridge piers designed with the Algerian seismic bridges regulation. *J. Earthquakes Struct* 15(6):701-713.

Kenneth, T., Yahya, C. 2001. Capacity-demand index relationships for performance based seismic design, Structural Engineering Research Report, Report #NDSE-01-02, Department of Civil Engineering and Geological Sciences University of Notre Dame, Notre Dame, Indiana, USA.

Klügel, J., & Mualchin, L. 2013. Earthquake engineering needs and seismic hazard assessment. In Earthquake Resistant Engineering Structures: IX (Vol. 132, pp. 47-67). WIT Press.

Mardhiyah, A., Tarigan, J., & Bangun, E. P. 2023. Application of modal analysis of earthquake force and natural frequency tanjung baru bridge. *IOP Conference Series: Earth and Environmental Science* 1244(1): 012004. IOP Publishing.

MasterWolverineMaster1139. 2024. Civil Engineering. University of Technology Sydney. https://www.cliffsnotes.com/study-notes/20020589.

Mohammed, H. A., & Naser, A. F. 2020. Mathematical assessment of vehicles types and loads influences on the structural performance parameters of concrete and steel bridges. *Journal of Engineering Science and Technology* 15(2): 1254-1266.

Mohan, A. S. 2017. The structural behavior of horizontally curved pre-stressed concrete box girder bridges. Doctoral dissertation, Thesis of the Doctor Degree of Philosophy, Submitted to School of Computing, Science and Engineering University of Salford, United Kingdom.

Mosleh, A., Jara, J., Razzaghi, M. S., & Varum, H. 2020. Probabilistic seismic performance analysis of RC bridges. *Journal of Earthquake Engineering* 24(11): 1704-1728.

Naser, A. F. 2018. Optimum design of vertical steel tendons profile layout of post-tensioning concrete bridges: FEM static analysis. ARPN *Journal of Engineering and Applied Sciences* 13(23): 9244-9256.

Naser, A. F. 2021. Analysis the effect of super-elevation on static and dynamic properties of horizontal curved concrete bridge by finite element. *Journal of Engineering Science and Technology* 16(5): 3669-3686.

Naser, A. F. 2022. Comparative study of seismic design for different bridges structures. *Jurnal Kejuruteraan* 34(1): 59-71.

Naser, A. F., Mohammed, H. A., & Mohammed, A. A. 2021. Seismic design assessment of bridge piers location effect on the structural capacity of supports under earthquake action. *International Journal of Safety and Security Engineering* 11(2): 143-153.

Naser, A.F and Wang, Z. 2011. Field damage inspection and static load test analysis of Jiamusi highway prestressed concrete bridge in China. *Advanced Materials Research* 163-167: 1147–1156.

Naser, A.F. and Wang, Z. 2012. Experimental monitoring of the strengthening construction of a segmental box girder bridge and field testing of external prestressing tendons anchorage. *Frontiers of Structural and Civil Engineering* 6(3): 308–320.

Nikolaos, N., John, H., & Konstantinos, D. 2015. Modal analysis. Encyclopedia of Earthquake Engineering.

Ozel, A. 2016. Seismic design of a prestressed concrete bridge. Thesis of Master Degree, University of New Orleans.

Pappin, J. W. 1991. Earthquake engineering in regions of low seismicity. Bull. NZ.

Pettorruso, C., & Quaglini, V. 2024. Comparison of linear and nonlinear procedures for the analysis of the seismic performance of straight multi-span RC bridges. *Buildings* 14(2):464.

Powell, G. H., & Allahabadi, R. 1988. Seismic damage prediction by deterministic methods: concepts and procedures. *Earthquake Engineering & Structural Dynamics* 16(5): 719-734.

Putra, R., & Riyono, W. A. 2020. Risk analysis of seismic bridge damage: Case study after Lombok and Palu earthquake. In E3S Web of Conferences (Vol. 156, p. 03008). EDP Sciences.

Shehu, R. 2021. Implementation of pushover analysis for seismic assessment of masonry towers: Issues and practical recommendations. *Buildings* 11(2): 71.

Shehu, R. 2021. Implementation of pushover analysis for seismic assessment of masonry towers: Issues and practical recommendations. *Buildings* 11(2):71.

Shobhit Gajbhiye, Sandeep Gaikwad. 2021. Seismic effects on different structural members. *International Journal for Research in Applied Science & Engineering Technology* 9(VII): 1481- 1485.

Siddique, A. F. A., & Hossain, T. R. 2020. Seismic performance evaluation of bridge piers resting on different soil classes. In Paper presented at IABSE-JSCE Joint Conference on Advances in Bridge Engineering-IV.

Siqueira, G. H., Tavares, D. H., Paultre, P., & Padgett, J. E. 2014. Performance evaluation of natural rubber seismic isolators as a retrofit measure for typical multi-span concrete bridges in eastern Canada. *Engineering Structures* 74: 300-310.

Sonawane, M. B., Dubey, S. K., & Deodhar, S. V. 2013. An analytical approach to demand-capacity method. *International Journal of Advanced Technology in Civil Engineering* 2(1):17-23.

Song, S. T., Wang, C. Y., & Huang, W. H. 2015. Earthquake damage potential and critical scour depth of bridges exposed to flood and seismic hazards under lateral seismic loads. *Earthquake Engineering and Engineering Vibration* 14(4):579-594.

Suwal, R., & Jamarkattel, B. 2023. effect of steel jacketing thickness on seismic performance of bridge. *SCITECH Nepal* 17(1): 1-11.

The National Science Foundation, 1979. Proceedings of a Workshop on Earthquake Resistance of Highway Bridges, Applied Technology Council, Palo Alto, California 94306. USA.

Usamak. 2022. Components of bridges. https://www.thebridgehawk.com/post/components-of-a-bridge.

Wang, D., Guo, X., Sun, Z. G., Meng, Q., Yu, D., & Li, X. 2009. Damage to highway bridges during Wenchuan earthquake. *Journal of Earthquake Engineering and Engineering Vibration* 29(3): 84-94.

WisDOT Bridge Manual. 2024. Chapter 12 – Abutments.

Wood, J. H. 2015. Earthquake design of bridges with integral abutments. In 6th International Conference on Earthquake Geotechnical Engineering.

Xia, X. S., Chen, X. C., & Li, X. 2012. Analysis of bridge earthquake damage and reasonable aseismic systems. *Advanced Materials Research* 433: 4782-4787.