IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

A REVIEW OF THE BRIDGE WITH VARIABLE SPAN LENGTH AND UNEQUAL PIER LENGTH

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ABSTRACT

The analysis and design of bridges with unequal pier lengths and varying span lengths are critical aspects of structural engineering. This review paper provides an overview of methodologies and approaches used in the analysis and design of such bridges. Finite Element (FE) method simulations, force-based and displacement-based methods, and optimization techniques are discussed. The study investigates load distribution, bending moments, and deflections along the bridge deck under diverse loading conditions. Additionally, the review compares traditional and proposed design methodologies, focusing on structural performance, cost efficiency, and construction feasibility. The findings highlight the importance of rigorous analysis and the use of advanced techniques in optimizing the structural efficiency of bridges with unequal pier lengths and varying span lengths. This review serves as a valuable resource for engineers and researchers involved in the design and evaluation of these complex bridge structures, providing insights for improved design strategies and future research directions

Keywords: - Bridges, Pier, T-beam girder, Box girder, Bridge design, Unequal pier lengths, span lengths.

I INTRODUCTION

A bridge is an engineering construction utilised to traverse a physical impediment, including a ravine, road, or body of water, without obstructing the passage beneath. They are integral elements of a transportation network and serve crucial functions in the realm of disaster management. Bridge structures are typically comprised of a reduced number of elements, thereby reducing redundancy. Due to their asymmetrical design, which includes span lengths, pier heights that vary, and occasionally vertical curvature and skew in the superstructure, bridge structures are exceptionally susceptible to damage in the event of significant earthquakes. Bridge damage has significant repercussions on emergency transportation and evacuation operations, including rescue operations, medical services, and firefighting. Such disruptions have an effect on the national economy as a result. A multitude of methodologies are currently undergoing development in order to conduct seismic design for structures. The implementation of force-based design (FBD) is pervasive in the realm of traditional methodologies. In the decades following the 1971 San Fernando earthquake in California, a systematic framework for the seismic design of bridges in the United States was devised by the Applied Technology Council. Furthermore, the California Department of Transportation has developed an innovative methodology for bridge design. Since the Loma Prieta earthquake of 1989, these two approaches founded on FBD principles have been applied internationally to the design of highway structures. The Japan Road Association initiated the revision of highway bridge seismic design specifications in 2002, subsequent to an assessment of the bridges' performance in the wake of the Kobe earthquake in 1995. The FBD method faces a multitude of fundamental challenges, such as determining the fundamental time period of structures, the relationship between strength and rigidity, force reduction factors and code-specified ductility capacity, among others. An innovative methodology known as displacement-based design (DBD) has been developed in response to the inherent challenges associated with the FBD approach. Given the well-established correlation between damage and displacement, this methodology employs displacement as a metric to ascertain seismic demand and quantify the extent of damage, as opposed to relying on the relationship between force and damage. While both the approach and the FBD method share the goal of accomplishing a fundamental design objective, they do so through the utilisation of distinct methodologies. There is presently a restricted selection of design protocols that incorporate displacement-based seismic design methodologies for bridge structures. Significant academic interest has been focused on the shift from force-based to displacement-based seismic design criteria in recent years. The substitute structure method, direct displacement-based design (DDBD), equal displacement approximation, and seismic design criteria all employ distinct approaches to distinction-based design. The DDBD is a widely recognised framework utilised by scientists to assist in the conceptualization of bridges and other structures in alignment with the objectives of performance-based earthquake engineering (PBEE).

1.1 Bridge Pier flow features

The variable effect that bridge pier flow interaction has on the scouring process in Australia has been established in prior research.One of the leading causes of bridge failures is inundation. The majority of Queensland was significantly affected by natural disasters caused by inundation, according to research conducted by Shrestha. A substantial amount of evidence derived from numerous studies indicates that scoures are the principal factor contributing to bridge failures. Analyses are ongoing to determine whether abutment scour contributed to 29 of the 108 bridge failures documented in New Zealand between 1960 and 1984. As a result, the substantial risk that the scour zones encircling bridge abutments present has been predominantly neglected. Consequently, absolute exclusion of structural failure as a plausible outcome is not possible. A number of significant contributors to local scour around bridge piers have been identified in prior research, including bed configuration, fluid properties, pier geometry, bed construction materials, and the passage of time. As a result, specific parameters have an impact on the local scour depth.

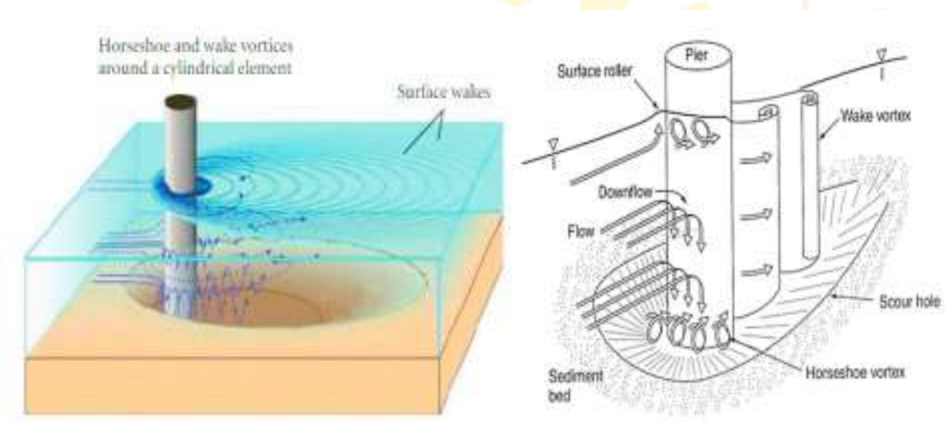

Fig. 1. (a) Schematic of Local scour (b) Scour hole collected due to flow vortices.

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The phenomenon wherein sediment is extracted in the vicinity of bridge foundations, specifically piers or abutments, is referred to as "local scour." A rise in viscosity is observed at the foundation of the bridge as a result of the interaction between water and the sediment that composes its structure. As illustrated in Figure 1(b), the scour crater encircling the bridge foundation is the result of vortices produced by this interaction.

COUNTERMEASURE OF THE BRIDGE LOCAL SCOUR EFFECT

In relation to the confidential inquiry: Bridge structures experiencing localised scour are regarded as posing a significant risk to public safety. Moreover, this phenomenon leads to a matter of concern concerning motor vehicles. In the event that it is inadvertently ascertained that the erosion taking place at a bridge pier has the potential to compromise the bridge's stability once more, a number of preventative measures for the pier should be implemented. As cited in the source, the implemented countermeasures comprised drainage control, approach-channel control, improved bridge modifications, downstream-channel control, and armoring of bridge apertures. Recommendations pertaining to the infill requirements, thickness, extent, edge treatment, interconnectivity, and flexibility of each countermeasure are formulated via engineering research. As the citation suggests, evidence regarding the greatest breadth of the scour apertures at the piers is evidently considered more significant when developing scour mitigation strategies. According to the report, two distinct scour holes formed at L/D = 8 and L/D = 10 after two and seven hours, respectively. Therefore, the utilisation of this report was beneficial in determining the optimal spacing for bridge piers, as it guaranteed the absolute absence of any indications of scour crater overlap. Ripprap is an essential scour countermeasure in situations where its full extent is demanded. The author's arguments unequivocally establish that the upper extent of scour holes at foundations serves as an indicator of the functionality of said holes, in addition to their profundity. In addition, the breadth of the indicative scour crater is calculated utilising the subsequent formula:

$$W_s = d_{se}(K + \cot\theta)$$

K equals 1 under the particular circumstance in which the scour depth (dse) corresponds to the lowest extent of the identified scour trench. Therefore, it can be inferred that the maximum depth of the scour crater in the cohesion-reducing material will consistently vary between 2.07 and 2.8 degrees of subsidence (dse). Conversely, a value of zero for K ensures that the maximum time required to complete a scour crater reaches a range of 1.07 to 1.8 seconds. The maximal diameters of scour apertures between the two pre-existing longitudinal columns of the bridge piers were accurately calculated for a range of L/D values based on the findings of the current investigation. Furthermore, the transparent presentation highlighted the fluctuation in the scour aperture's breadth to accommodate unique spacing between columns. A sequence of laboratory experiments was conducted to investigate the local erosion that takes place near the single and tandem columns of bridge pillars. Furthermore, in regard to the two bridge foundations that were displayed, the columns were parallelly aligned, with an adjustable degree of separation between each column. Furthermore, precise measurements were obtained of the ultimate bed profiles and the geometric properties of the scour apertures at the conclusion of the investigation. Following this, the findings were presented in credible tabular and graphical formats. Through the subsequent acquisition of the laboratory experiment results, it is possible to ascertain the effectiveness of bed shelving in a circular, smooth bridge pier as a preventative measure against local attrition. Additionally, the evaluation of the bed sill's effectiveness was enhanced by its positioning downstream of the pier, as evidenced by the measured distance between the bed sill and the pier. As a result, a comprehensive sequence of experiments spanning from 72 to 75 hours was undertaken in order to ascertain the temporal progression of the scour depths that developed in the vicinity of the bridge foundations. The scour depths were consistently monitored and accurately documented at different time intervals in preparation for subsequent analysis, as previously mentioned. The achievement of the equilibrium scour depth after a period of 72 hours indicates that a longer time period is necessary to attain an equivalent depth in the column downstream. The findings indicated that the bed sill under investigation might have been impacted at some point after the experiment commenced, as the scour cavity detected downstream of the bridge pier experienced significant additional expansion during the interaction with the countermeasure that was implemented. It is indisputable that the efficacy of a particular countermeasure escalates with the reduction in distance between the structures [16]. Furthermore, a bed foundation is integrated in close proximity downstream of the designated jetty to aid in the mitigation of scour area, volume, and depth. Determining the process accountable for the scour concern, selecting an appropriate countermeasure concept, and identifying the most suitable construction method for the chosen countermeasure concept are the phases that are recommended for countermeasure design. As previously mentioned, it is critical to devise a viable countermeasure and evaluate its appropriateness according to suitable standards.
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Hazard of vehicle collision with bridge piers

Comparable to the "seismic hazard," the "vehicle collision hazard" in this context denotes the likelihood and severity of a vehicle colliding with a pier within a specified time period.

Vehicular impact force

The survey was conducted. The primary emphasis of vehicle-pier collision research is the vehicular impact force, denoting the force of contact between the pier and the vehicle. By measuring the magnitude of the impact force, scientists ordinarily ascertain the severity of vehicular impact. After ascertaining the time history and distribution characteristics of the impact force, structural and damage assessments of the structures may be subsequently performed. Measurements derived from field tests. At the moment, experimental investigations pertaining to the impact of sizable vehicles featuring columnar configurations are scarce, specifically those that quantify the impact force. By conducting up to fourteen vehicle collision experiments on RC and steel columns, the reaction times of the columns were determined; nevertheless, the magnitude of the vehicular impact force remained unmeasured. On the basis of the results of ten oblique impact experiments conducted on vertical walls, two primary peaks were identified in the impact force time histories. The observed peaks were indicative of collisions that transpired between the cargo-laden container and the front portion of the vehicle, which contained the engine. A tanker-type tractor-trailer was employed to perform a destructive collision test on an RC pier, without the need for force measurement. In the process of validating the effectiveness of perimeter barriers, frontal collision tests are commonly employed, which involve medium single-unit vehicles. In accordance with Newton's second law, the acceleration at the vehicle's centre of gravity (or at the frame) is computed and employed to determine the impact force of the vehicle during these evaluations. Although there are certain inconsistencies, specifically concerning the initial peak of the impact force, it was ascertained that the impact force calculated utilising this approach is virtually indistinguishable from the wall's contact force. This phenomenon may arise from the vehicle body-mounted accelerometer's limited responsiveness to the collision of stationary objects (e.g., the engine) that precede the vehicle.
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SIGNIFICANCE OF BRIDGES WITH UNEQUAL PIER LENGTHS AND VARYING SPAN LENGTHS

Prior survey findings The structures that span the length of the bridge may exhibit varying degrees of rigidity, which could lead to significant irregularities. A considerable body of academic literature and reports have been devoted to the topic of bridges that display significant irregularity along their complete length, as previously delineated. A considerable amount of scholarly focus has been previously directed towards a particular classification of multispan reinforced concrete bridges, which demonstrate varying degrees of irregularity and regular and irregular configurations. In the past twenty years, this specific classification of bridges has significantly contributed to the development of innovative principles concerning seismic analysis and bridge construction. This category of bridges includes "B213," an exceptionally irregular RC continuous span single-column bend highway viaduct with unequal pier heights. The disputed bridge is widely recognised and referred to as "the reference bridge" (Ispra bridge). The enclosed bridge segment, which is illustrated in Figure 1, spans a distance of 200 metres and consists of four spans that are equivalent in nature. The fourteen-meter-wide superstructure is reinforced by three intermediate structures, which vary in height by fourteen, twenty-one, and seven metres, respectively, as illustrated in Figure 1. Additionally, it is linked to the abutments. The cross-sectional characteristics of the hollow rectangular piers remain unchanged. The manner in which the short or unyielding pier is engineered has a substantial effect on the configurational irregularity of the bridge. An inquiry is necessary into the crucial aspect of ascertaining the location of the deck bulk in relation to the assumed connection between the deck and pier, which in the course of analysis and design is deemed unreliable. Prior research has examined fundamental and monolithic connections, as depicted in Figure 2. To enhance rotational motion, it is customary to incorporate a hinge connecting the superstructure and pier during the design phase. This assumption fails to consider the influence of the vertical load, which generates a stationary limit moment incapable of rotation (determined by multiplying the vertical load by the distance between supports). A multitude of ongoing research initiatives that contribute to Eurocode 8 (PREC8) have documented preliminary investigations into this particular bridge, as well as a great number of other common and uncommon configurations. A report that has been published provides a concise summary of the subjects investigated throughout the research process that backed Eurocode 8. The European Laboratory for Structural Assessment (Elsa) oversaw the 1995 testing of six large-scale (1:2·5) bridge specimens as an element of the programme.According to the authors, this event served as a pivotal moment in subsequent inquiries concerning the seismic properties of irregular structures, thus constituting a significant historical landmark. Instead of centering on the seismic response of the reference bridge when it was in a singular irregular or regular configuration, which was previously mentioned, an extensive collection of scholarly literature and technical reports has been dedicated to its various configurations thus far. Anthology of recent print publications

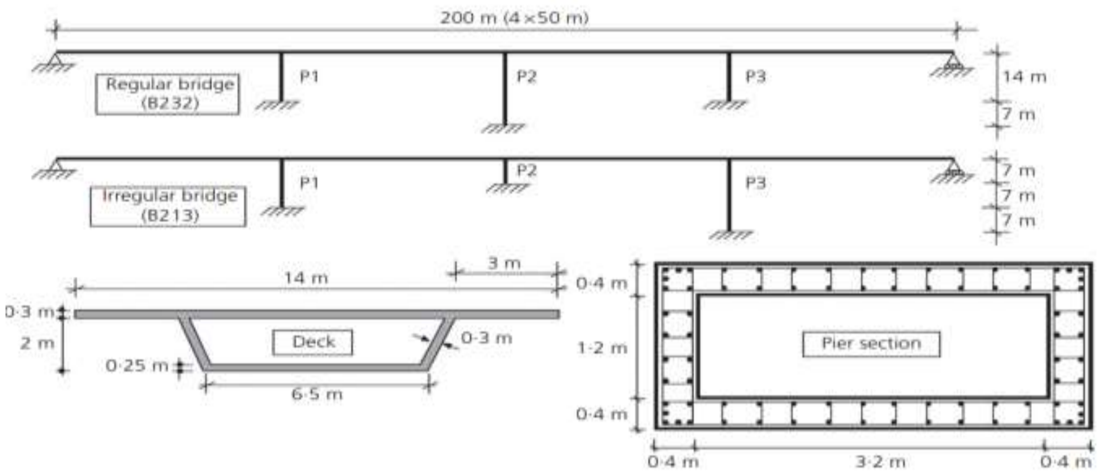

Figure 1. Details and general configuration of the 'reference bridge'

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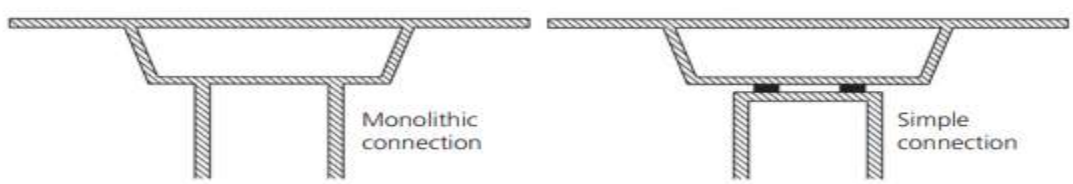

Figure 2. Different deck-to-pier connections

LITERATURE REVIEW

Zhanfei Wang et.al (2021) An assessment was performed to determine the seismic response of steel tubular bridge foundations integrated into a continuous girder bridge system with five spans. A comparative analysis is undertaken to examine the performance of partially concrete-filled steel tubular (PCFST) and hollow steel tubular (HST) structures when subjected to different eccentricities of the ground and superstructure.The findings indicate that the eccentricity of the superstructure significantly increases the transverse displacement of HST piers, whereas its effect on the longitudinal displacement is negligible. Yield strength is achieved in HST foundations via the mechanisms of local fracturing and tension concentration. On the contrary, PCFST foundations demonstrate restrained buckling as a result of the substantial enhancements in ductility and bearing capacity induced by the concrete in-fill. The findings derived from this research suggest that the integration of PCFST foundations might enhance the bridge system's seismic performance.

Jawalkar, Prof. G.C. et.al (2021) investigates the buckling phenomenon in thin members subjected to axial load and biaxial bending, known as the 'P∇' effect, resulting in excessive bending moments and yielding at maximal deflection points. The study aims to develop a bending moment equation using beam column theory and analyze the performance of bridge piers with solid and hollow circular sections. Optimization involves substituting solid sections with combinations of solid and porous sections within limits. A comparison study assesses behaviors under axial, longitudinal, and transverse forces, conceptualizing piers as columns under biaxial moment and axial load, with second order analysis necessary for precise force calculations considering the buckle effect.

Nailiang Xiang et.al (2020) In mountainous regions where multispan continuous bridges with unequal height structures are prevalent, seismic response is emphasised. For earthquake protection, exterior concrete shear keys are typically employed; however, this practice may result in atypical seismic reactions and substantial rotations of the superstructure. Substituting yielding steel dampers for shear keys would result in more consistent movement of the superstructure and more equitable seismic loads on the substructure, according to the study. By employing deterministic and probabilistic dynamic analyses, the efficacy of this design approach is verified, thereby guaranteeing that these bridges will exhibit a consistent and equitable seismic performance.

M. A. Hoque et.al (2020) When examining multispan bridges with unequal pier heights, force-based seismic design (FBD) and displacement-based seismic design (DBD) were compared. A comparison is made between the conventional FBD method and the DBD method, which utilises acceleration and displacement response spectra to incorporate direct displacement-based (DDBD) and alternative-to-direct displacement-based (ADBD) approaches. The findings indicate that DBD techniques produce more minimal base incisions when compared to FBD techniques. Specifically, ADBD techniques produce more condensed member sections while employing a conservative design strategy. This investigation provides a significant addition to the current body of knowledge regarding seismic design methodologies for irregularity-containing multispan bridges.

Denis DAVI (2014) compared structural analysis methods, including force-based and displacement-based modal spectral analysis, push-over analysis, and non-linear dynamic time-history analysis, from Eurocode 8-2 and the bridge seismic design literature. The approaches employed in this research concern a fictitious reinforced concrete pier-deck bridge spanning 306 metres in length, constructed in a seismically active area of France, utilising prestressed concrete. Furthermore, it establishes a distinction between Eurocode 8-2 and the previous French seismic regulations known as "AFPS92" and puts forth suggestions for improving Eurocode 8-2 by implementing similar theoretical and practical frameworks.

Gopal Adhikari et.al (2010) The efficacy of the direct displacement-based seismic design (DDBD) method, which was initially devised for bridges characterised by short to moderate spans, was assessed with respect to straight long span bridges that incorporate distinctive features such as elevated piers, irregular spans, and heights. The findings suggest that the present DDBD approach demonstrates a diminished capacity to accurately represent displacement and base shear requirements in comparison to nonlinear dynamic analysis. Parametric studies have validated an extension proposed on the basis of enhanced mechanics that incorporates pier mass into the estimation of base shear demand and a modal combination rule into the estimation of displacement demand. Moreover, this novel methodology provides engineers with the capacity to alter the distribution of strength at prospective locations of plastic hinges.

Mohammad Abbas et.al (2015) The seismic behaviour of a multiframe concrete box-girder viaduct that displays a spectrum of altitudinal irregularities (ranging from highly irregular to regular) can be assessed through the utilisation of fragility curves. Anxious conditions that emerge during catastrophes and are exacerbated by irregular topographical features and long span junctions are the subject of this study. Comprehensive nonlinear time-history analyses conducted on three-dimensional finite-element models demonstrate that the degree of altitudinal irregularity increases proportionally with the instability of the bridge. Component fragility parameters, which incorporate uncertainties associated with materials, structural geometries, and earthquake impacts, have identified the unseating of the in-span hinge location as the element with the highest susceptibility.

Hossein Rezaei et.al (2019) The effects of hammering and irregularity on concrete box-girder bridges with varying altitudinal irregularities were investigated by employing probabilistic seismic assessment. The objective of this research is to examine the impact of pressure on seat-type abutments and in-span hinges of multi-frame bridges. This inquiry takes into account various factors, including variations in materials, geometries of structures, and seismic activity. The inquiries encompass an analysis of the impact of gap size on engineering demand parameters (EDPs), a comparison of pounding force across bridge irregularities of varying degrees, and an examination of the correlations between pounding force and earthquake parameters. The research calculates the likelihood that a striking incident will not occur in bridges that are not continuous, as well as examines the consequences of such an occurrence on neighbouring bridge segments. The findings underscore the substantial influence that the magnitude of the gap exerts on the passive deformation, impacting force, and base shear of abutments. The correlation between gap size and EDPs is nevertheless attenuated by substructure irregularities. The correlation between pounding force and structural/seismic parameters is assessed in the study's conclusion, with particular attention given to the influence of adjacent frame period ratios on earthquake type and pounding probability.

Athanasios Agalianos et.al (2017) utilised two swaying isolation concepts to investigate the seismic performance of a flyover bridge situated on the Attiki Odos motorway in Athens, Greece: (a) rocking pier-footing assemblies on soil and (b) rocking piers on foundations. A 5-span system is analysed in relation to conventionally designed bridges, with a focus on surface foundations in deep clay. For static pushover and non-linear dynamic analyses involving 20 selected ground motions that exceed design levels, 3D numerical models are utilised. In five out of ten instances, the conventional system fails, whereas the swaying piers design endures with only minor deformations in eight out of ten. Even greater safety margins are observed for rocking footings, which endure any circumstance with enhanced durability and diminished structural damage. Conversely, stress concentrations at the bases of swaying foundations indicate the necessity for specialised design, in contrast to rocking footings which experience increased settlements but no residual rotations.

M. Shahria Alam et.al (2019) This study examined the feasibility of retrofitting energy dissipation devices onto a pre-existing bridge that had lead rubber bearings (LRBs) for reinforcement. The objective was to reduce the displacement hazards that are commonly associated with period elongation. Yielding steel cables (YSCs), friction dampers (FDs), viscous dampers (VDs), and superelastic shape memory alloy cables (SMAs) are all examples of retrofit measures.Fault sensitivity analyses compare the effectiveness of isolation bearing damage prevention measures in bridge structures so as not to increase their vulnerability. The results suggest that SMAs demonstrate superior efficacy compared to FDs, VDs, and YSCs with regard to residual superstructure displacement reduction and recentering performance.

Literature survey

Table 1 . Literature survey previous paper

Author	Title	Methods	Parameters	Results
Zhanfei Wang et.al (2021)	Seismic Performance of Steel Tubular Bridge Piers in a Five-Span Continuous Girder Bridge System	- Finite Element Analysis (FEA) - Comparison of Hollow Steel Tubular (HST) and Partially Concrete-Filled Steel Tubular (PCFST) Piers - Varying Superstructure Eccentricities - Different Ground Motions	- Superstructure Eccentricities - Displacement in Longitudinal and Transverse Directions - Yield Strength and Ductility of HST and PCFST Piers	- HST piers show minimal displacement in longitudinal direction, increase in transverse direction - HST piers reach yield strength with stress concentration - PCFST piers exhibit higher ductility and bearing capacity
Jawalkar, Prof. G.C. et.al (2021)	Buckling Phenomenon in Thin Members Subjected to Axial Load and Biaxial Bending	- Development of Bending Moment Equation using Beam Column Theory - Comparison of Solid and Hollow Circular Sections - Optimization with Solid and Porous Sections within Limits	- Bending Moment Equation - Structural Analysis of Bridge Piers - Comparison of Solid and Hollow Sections	- Yielding at maximal deflection points - Stress concentration and local buckling in HST piers - PCFST piers exhibit restrained buckling due to concrete in-fill - SMAs show higher ductility and bearing capacity
Nailiang Xiang et.al (2020)	Yielding Steel Dampers for Seismic Response Improvement in Multispan Continuous Bridges	- Proposal of Yielding Steel Dampers to Replace Concrete Shear Keys - Deterministic and Probabilistic Dynamic Analyses	- Seismic Response in Multispan Continuous Bridges - Effectiveness of Yielding Steel Dampers	- SMAs retrofitted bridge shows improved seismic performance - Yielding Steel Dampers provide uniform superstructure movement and balanced seismic demands - Enhanced seismic resilience and reduced structural damage
M. A. Hoque et.al (2020)	Comparative Analysis of Displacement-Based Seismic Design and Force-Based Seismic Design for Multi-Span Bridges with Unequal Pier Heights	- Comparison of Displacement-Based Seismic Design (DBD) with Force-Based Seismic Design (FBD) - Evaluation of Direct Displacement-Based (DDBD) and Alternative-to-Direct Displacement-Based (ADBD) Approaches - Use of Acceleration and Displacement Response Spectra	- Base Shear Calculations - Member Section Design Efficiency - Comparison of DBD and FBD Methods for Multi-Span Bridges	- DBD methods yield smaller base shears than FBD - ADBD provides a more conservative design approach - Improved understanding of seismic design methods for bridges with irregularities
Denis DAVI (2014)	Structural Analysis Methods Comparison for Seismic Design of Prestressed Concrete Deck Bridge	- Comparison of Eurocode 8-2 and Bridge Seismic Design Literature - Modal Spectral Analysis, Push-over Analysis, Non-linear Dynamic Time-History Analysis	- Structural Analysis Methods from Eurocode 8-2 and Bridge Seismic Design Literature - Application to Prestressed Concrete Deck Bridge	- Force-Based and Displacement-Based Methods - Improved understanding of seismic design methods - Theoretical and Practical Comparisons of Eurocode 8-2 and AFPS92
Gopal Adhikari et.al (2010)	Enhanced Direct Displacement-Based Seismic Design for Straight Long Span Bridges	- Analysis of Direct Displacement-Based (DDBD) Procedure - Mechanics-Based Extension - Parametric Studies	- Straight Long Span Bridge Analysis - Enhanced DDBD Procedure - Precise Force Calculations	- Current DDBD lacks accuracy in capturing displacement and base shear demands - Proposed enhanced mechanics-based extension improves accuracy and provides flexibility in strength allocation

Mohammad Abbas et.al (2015)	Seismic Behavior of Multiframe Concrete Box-Girder Viaduct with Altitudinal Irregularity	- Investigation of Seismic Behavior using Fragility Curves - Nonlinear Time-History Analyses	- Bridge Fragility with Altitudinal Irregularity - Component Fragility Parameters	- Increased bridge fragility with greater altitudinal irregularity - In-span hinge location unseating as most vulnerable component - Study considers uncertainties in earthquake effects and structural materials

CONCLUSION

In conclusion, Considerable insights into enhancing the seismic performance of multispan bridges containing a variety of irregularities can be gleaned from the literature review. Studies on steel tubular bridge piers highlight the advantages of partially concrete-filled piers (PCFST) over hollow steel tubular piers (HST), showcasing higher ductility and bearing capacity. Investigations into buckling phenomena in thin members offer optimized solutions through combinations of solid and porous sections, enhancing structural efficiency. Proposals for yielding steel dampers and alternative displacement-based seismic design methods contribute to more uniform superstructure movement and economical member sections. Retrofitting existing bridges with energy dissipation devices like super elastic shape memory alloy cables (SMAs) proves effective in reducing displacement risks. Moreover, analyses of bridge fragility and seismic behavior under altitudinal irregularities emphasize the importance of precise force calculations and flexible design approaches. These findings collectively advance seismic design strategies, ensuring enhanced resilience and reduced damage potential for multi-span bridge systems.

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