As per UGC guidelines an electronic bar code is provided to secure your paper

International Journal for Modern Trends in Science and Technology
Volume 12, Issue 07, pages 271-280.
ISSN: 2455-3778 online
Available online at: http://www.ijmtst.com/vol12issue06.html
DOI: https://doi.org/10.5281/zenodo.21651656

Comparative Seismic Assessment of Bridge Pier Configurations Considering Lumped and Consistent Mass Modelling Approaches

Kothapalli Guru Manikanta | Mohammed Parvez Affani

Department of Civil Engineering, Global Institute of Engineering & Technology (A), Affliated to JNTUH, India.
kgmk1506@gmail.com

To Cite this Article
Kothapalli Guru Manikanta & Mohammed Parvez Affani (2026). Comparative Seismic Assessment of Bridge Pier Configurations Considering Lumped and Consistent Mass Modelling Approaches. International Journal for Modern Trends in Science and Technology, 12(07), 271-280. https://doi.org/10.5281/zenodo.21651656

Article Info
Received: 06 July 2026; Revised: 20 July 2026; Accepted: 24 July 2026.

KEYWORDS

RCC Bridge, Bridge Pier, Response Spectrum Analysis, MIDAS Civil, Seismic Analysis, Portal Pier, Hammerhead Pier, Wall-Type.

ABSTRACT

Bridge piers are one of the most critical structural components governing the seismic behavior of reinforced cement concrete (RCC) bridges. The geometry and stiffness of bridge piers significantly influence the overall dynamic response of bridge structures subjected to earthquake loading. This study presents a comparative seismic performance assessment of three widely adopted RCC bridge pier configurations, namely Portal Pier, Hammerhead Pier, and Wall-Type Pier, using MIDAS Civil software. Response Spectrum Analysis was performed in accordance with the provisions of IRC SP:114 to investigate the influence of pier geometry and mass modelling techniques on bridge behavior. Both complete bridge models and simplified pier models subjected to equivalent superstructure reactions were analyzed using consistent mass and lumped mass representations. The seismic performance of each configuration was evaluated using parameters such as base shear, natural time period, seismic coefficient, modal participation, and structural stiffness. The analytical study demonstrates that bridge pier configuration considerably affects the dynamic response of RCC bridges. The complete bridge models provide a more realistic representation of structural behavior, whereas simplified reaction models offer computational efficiency with acceptable engineering accuracy. The findings of this study provide useful guidance for bridge engineers in selecting suitable pier configurations for seismic design and assessment.

I. INTRODUCTION

Bridges play a vital role in transportation networks by providing safe and efficient connectivity between different regions. In earthquake-prone areas, bridge structures are subjected to significant dynamic forces that may adversely affect their structural integrity and serviceability. Historical earthquakes have demonstrated that bridge failures often originate from inadequate seismic performance of bridge substructures, particularly bridge piers. Therefore, understanding the seismic behaviour of different bridge pier configurations has become an essential aspect of modern bridge engineering.

Bridge piers transfer loads from the bridge superstructure to the foundation while resisting vertical loads, lateral forces, and seismic actions. The seismic response of bridge piers depends on several factors, including structural geometry, stiffness, mass distribution, foundation conditions, and interaction between the bridge deck and supporting elements. Different pier configurations exhibit distinct dynamic characteristics, resulting in variations in seismic force distribution, displacement, and vibration behaviour.

Among the various analytical techniques available for seismic evaluation, Response Spectrum Analysis (RSA) is one of the most widely adopted linear dynamic methods because it efficiently estimates the maximum structural response by considering the contribution of multiple vibration modes. The procedure recommended by IRC SP:114 provides a practical framework for evaluating seismic effects in bridge structures and is widely used in engineering practice.

Another important aspect influencing bridge dynamics is the representation of structural mass. In finite element modelling, structural mass may be represented using either consistent mass or lumped mass approaches. The consistent mass method distributes mass throughout structural elements and generally provides a more realistic representation of inertia forces. In contrast, the lumped mass method concentrates mass at nodal locations, reducing computational complexity while maintaining acceptable engineering accuracy for many practical applications.

The present study focuses on a comparative seismic assessment of three commonly used RCC bridge pier configurations: Portal Pier, Hammerhead Pier, and Wall-Type Pier. Numerical models were developed in MIDAS Civil to investigate the influence of pier configuration and mass modelling techniques under identical seismic loading conditions. Both complete bridge models and simplified pier models were analysed to evaluate the effectiveness of different modelling approaches. The study aims to provide practical recommendations for bridge engineers regarding the selection of suitable pier configurations and analytical methods for seismic design.

STRUCTURE OF PAPER

The paper is organized as follows: In Section 1, the introduction of the paper is provided along with the structure, important terms, objectives and overall description. In Section 2 we discuss Literature Review. In Section 3, 4 & 5 we have the Research Gap, Objective of Study and Problem Statement respectively. Section 6 & 7 shares information about the Methodology , Results & Discyssion respectively. Section 8 tells us about the Conclusion. Section 9 & 10 tells us about the Limitation of Study & future scope respectively and concludes the paper with acknowledgement and references.

II. LITERATURE REVIEW

Bridges Bridge engineering has undergone significant advancements in seismic design due to the increasing occurrence of earthquakes and the need for resilient transportation infrastructure. Earthquake-induced failures have highlighted the importance of understanding the dynamic behaviour of bridge substructures, particularly bridge piers, which play a crucial role in transferring loads from the superstructure to the foundation while resisting seismic forces. Consequently, numerous researchers have investigated the influence of pier geometry, structural stiffness, analytical modelling techniques, and seismic design methodologies on bridge performance.

Priestley, Seible, and Calvi[1] established the principles of performance-based seismic bridge design by emphasizing ductility, energy dissipation, and capacity design concepts. Their work demonstrated that proper detailing of bridge piers significantly improves seismic resistance and minimizes structural damage during strong ground motions.

Chopra[2] presented the theoretical framework of structural dynamics and Response Spectrum Analysis (RSA), explaining that RSA provides a practical and reliable method for estimating the maximum dynamic response of structures subjected to earthquake excitation. Compared with equivalent static analysis, RSA considers modal participation and natural vibration characteristics, leading to more realistic prediction of seismic forces.

The Indian Roads Congress introduced IRC SP:114–2018[3], which provides detailed recommendations for seismic analysis and design of road bridges. The code recommends Response Spectrum Analysis for important bridge structures and specifies procedures for evaluating seismic forces, response reduction factors, damping ratios, and modal combinations. Similarly, IRC:112–2020[4] provides comprehensive guidelines for the design of reinforced concrete bridge components, including provisions for material properties, serviceability, and ultimate limit state design.

Researchers have extensively studied the influence of bridge pier configuration on seismic response. Portal piers are recognized for their high redundancy and balanced lateral load distribution because of their twin-column arrangement connected by a cross beam. Hammerhead piers are widely adopted due to their simple construction, economical design, and satisfactory structural behaviour under moderate seismic loading. Wall-type piers possess comparatively higher lateral stiffness, making them suitable for long-span bridges and urban flyovers where displacement control is essential.

Mass modelling techniques have also received considerable attention in finite element bridge analysis. Wilson[5] demonstrated that consistent mass matrices provide a more accurate representation of structural inertia by distributing mass throughout finite elements, whereas lumped mass matrices simplify computations by concentrating mass at nodal locations. Although both approaches generally predict similar global structural behaviour, consistent mass modelling produces improved accuracy in modal analysis, particularly for flexible bridge structures.

Recent advancements in finite element software have enabled engineers to perform sophisticated bridge analysis using realistic structural models. MIDAS Civil has become one of the most widely adopted bridge analysis software packages because it provides integrated tools for static analysis, moving load analysis, modal analysis, response spectrum analysis, construction stage analysis, and nonlinear structural evaluation. The software enables accurate modelling of bridge decks, bearings, piers, and support conditions within a three-dimensional finite element environment.

Recent research has focused on improving bridge seismic assessment through advanced numerical modelling techniques. Studies published in recent years have reported that bridge pier geometry significantly influences natural vibration characteristics, seismic force distribution, and lateral displacement. Other investigations have highlighted that realistic mass representation improves the prediction of modal properties and dynamic response, particularly in multi-span bridge systems. Researchers have also demonstrated that complete bridge models provide more accurate seismic behaviour by considering the interaction between the bridge superstructure and substructure, although simplified pier models remain useful for preliminary design because of their reduced computational effort.

Despite the considerable amount of research available, most studies evaluate either a single bridge pier configuration or a single analytical modelling technique. Comprehensive comparisons involving Portal Pier, Hammerhead Pier, and Wall-Type Pier under identical bridge geometry, loading conditions, and seismic parameters while simultaneously investigating complete bridge modelling, simplified reaction-based modelling, consistent mass modelling, and lumped mass modelling remain limited. The present study addresses this gap through a systematic comparative seismic assessment using Response Spectrum Analysis in MIDAS Civil based on IRC recommendations.

III. RESEARCH GAP

Although considerable research has been conducted on the seismic analysis of reinforced cement concrete (RCC) bridges, most published studies primarily focus on the seismic performance of individual bridge pier configurations or a single modelling approach. Limited studies have performed a comprehensive comparison of different pier configurations under identical loading conditions while simultaneously evaluating the influence of structural mass modelling techniques and analytical idealization.

Most existing investigations evaluate Portal, Hammerhead, or Wall-Type piers independently, making it difficult for bridge designers to identify the most suitable pier configuration for specific seismic conditions. Furthermore, previous studies generally employ either a complete bridge model or a simplified pier model without assessing the accuracy and applicability of both approaches within the same analytical framework.

The influence of lumped mass and consistent mass modelling on the seismic behaviour of RCC bridge piers has also received comparatively less attention in practical bridge engineering applications. Since mass representation directly affects modal characteristics, natural vibration periods, and seismic force distribution, understanding its influence is important for achieving reliable analytical results.

Therefore, there is a need for a systematic comparative study that evaluates Portal, Hammerhead, and Wall-Type bridge piers using identical bridge geometry, loading conditions, material properties, and seismic parameters while comparing complete bridge modelling with simplified reaction-based modelling using both consistent and lumped mass approaches.

The present study addresses this research gap by performing a comprehensive seismic assessment using MIDAS Civil based on Response Spectrum Analysis in accordance with IRC SP:114 recommendations.

IV. OBJECTIVES OF STUDY

The primary objective of this research is to evaluate and compare the seismic behaviour of different reinforced cement concrete bridge pier configurations subjected to earthquake loading using finite element analysis.

The specific objectives are as follows:

1. To develop three-dimensional finite element models of Portal Pier, Hammerhead Pier, and Wall-Type Pier using MIDAS Civil.
2. To perform Response Spectrum Analysis in accordance with IRC SP:114 provisions for seismic loading.
3. To compare the influence of Consistent Mass and Lumped Mass modelling techniques on structural response.
4. To investigate the difference between Complete Bridge Models and Simplified Pier Models subjected to equivalent superstructure reactions.
5. To evaluate the seismic performance of different bridge pier configurations based on:
    - Base Shear
    - Seismic Coefficient
    - Natural Time Period
    - Modal Characteristics
    - Structural Stiffness
6. To identify the advantages and limitations of each bridge pier configuration for practical seismic bridge design.
7. To provide recommendations for selecting suitable bridge pier configurations under earthquake loading conditions.

V. PROBLEM STATEMENT

Bridge structures located in seismic regions are frequently subjected to dynamic earthquake forces that may cause excessive displacement, structural damage, and even collapse if not properly designed. The seismic response of bridge structures depends largely on the stiffness, geometry, and dynamic characteristics of bridge piers.

Although Portal, Hammerhead, and Wall-Type bridge piers are extensively used in bridge construction, limited comparative information is available regarding their seismic performance under identical bridge geometry and loading conditions. In addition, the influence of structural modelling techniques, including complete bridge modelling, simplified reaction-based modelling, consistent mass modelling, and lumped mass modelling, has not been comprehensively investigated.

Hence, an analytical study is required to compare the seismic response of these bridge pier configurations using Response Spectrum Analysis and identify modelling approaches that provide reliable and efficient seismic assessment.

VI. METHODOLOGY

A. Overview of the Study

The present research investigates the seismic behaviour of three reinforced cement concrete (RCC) bridge pier configurations using finite element modelling and Response Spectrum Analysis (RSA). The study was carried out using MIDAS Civil software in accordance with the provisions of IRC SP:114–2018. The primary objective was to evaluate the influence of bridge pier geometry and mass modelling techniques on the seismic performance of bridge structures.

A comparative approach was adopted in which Portal Pier, Hammerhead Pier, and Wall-Type Pier configurations were analysed under identical loading conditions, material properties, and seismic parameters.

Two modelling techniques, namely Complete Bridge Modelling and Simplified Pier Modelling using equivalent superstructure reactions, were considered for each pier configuration. Furthermore, both Consistent Mass and Lumped Mass approaches were employed to investigate the effect of mass representation on structural response.

B. Bridge Geometry and Structural Configuration

A single-span reinforced concrete bridge having a span length of **30 m** was considered for the analytical investigation. The bridge superstructure consisted of a reinforced concrete U-girder deck supported on elastomeric bearings resting over RCC bridge piers. The height of each pier was maintained at **20 m** to ensure uniformity during comparison.

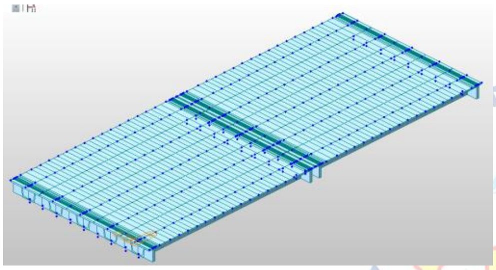


Fig.1 Superstructure Resting on Piers

Three different pier configurations were analysed:

- **Portal Pier:** Consisting of two vertical columns connected by a transverse beam providing improved redundancy and lateral stability.

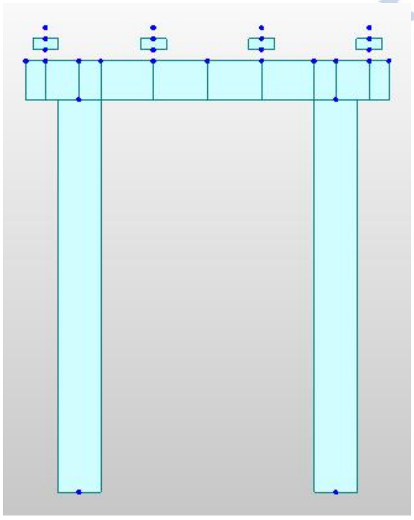


Fig 2. Portal Pier

- **Hammerhead Pier:** Consisting of a single circular/rectangular column supporting a wide pier cap, commonly adopted for highway bridges.

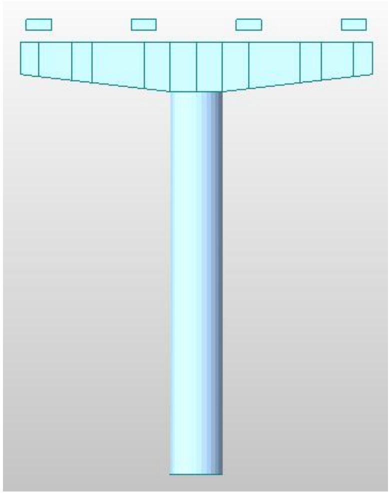


Fig 3. Hammer Head Pier

- **Wall-Type Pier:** A solid reinforced concrete wall section providing high lateral stiffness and reduced structural deformation.

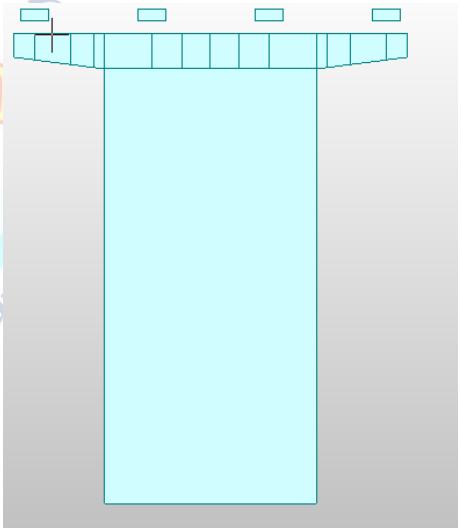


Fig 4. Wall Type Pier

All geometric dimensions were kept identical except for the pier configuration so that the influence of pier geometry alone could be evaluated.

C. Material Properties

All structural members were assumed to be constructed using **M45 grade reinforced concrete**. Material properties were assigned according to **IRC:112–2020** recommendations.

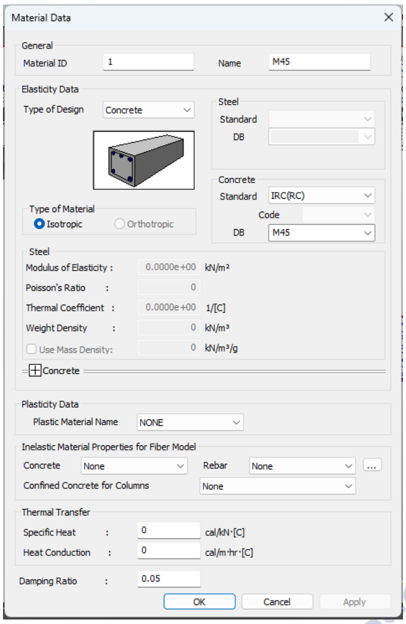


Fig 5. Definition of Material Properties

The following properties were adopted:

Property	**Value**
Grade of Concrete	M45
Density	25 kN/m³
Poisson's Ratio	0.20
Modulus of Elasticity	As per IRC:112
Damping Ratio	5%

The bridge deck, pier cap, and pier sections were modelled using appropriate beam and plate elements available in MIDAS Civil.

D. Bearing Modelling

The connection between the bridge deck and supporting piers was represented using elastic link elements simulating elastomeric bearings.

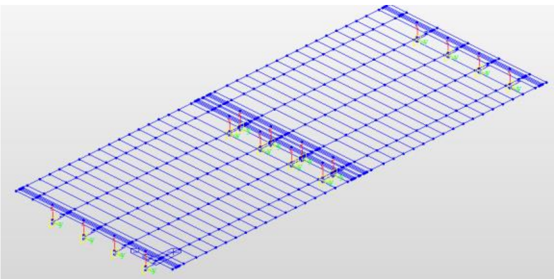


Fig 6. Elastic Links (Bearings)

The bearings were assumed to provide:

- High vertical stiffness for efficient load transfer.
- Finite longitudinal stiffness.
- Finite transverse stiffness.
- Rotational flexibility wherever applicable.

This modelling approach provides a realistic representation of bridge behaviour during earthquake excitation.

E. Loading Considered

The following loading conditions were considered during analysis:

- Self-weight (Automatically generated)
- Superimposed Dead Load (SIDL)
- Wearing Course Load
- Seismic Load obtained through Response Spectrum Analysis

The load combinations were prepared according to the provisions of IRC bridge design guidelines.

F. Seismic Parameters

Dynamic analysis was performed using the Response Spectrum Method based on IRC SP:114–2018.

The adopted seismic parameters are summarized below:

Parameter	**Value**
Seismic Zone	III
Importance Factor (I)	1.20
Response Reduction Factor (R)	2.50
Soil Type	Medium
Damping Ratio	5%

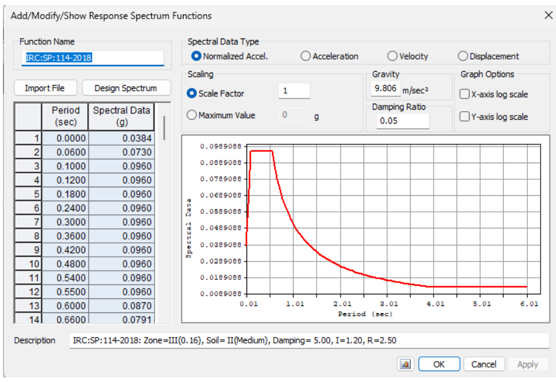


Fig 7. Response Spectrum

The Complete Quadratic Combination (CQC) method was used for modal combination since closely spaced vibration modes were expected.

G. Finite Element Modelling

The bridge models were developed using MIDAS Civil. For each pier configuration, four analytical models were generated:

1. Complete Bridge Model – Consistent Mass
2. Complete Bridge Model – Lumped Mass
3. Simplified Pier Model – Consistent Mass
4. Simplified Pier Model – Lumped Mass

Thus,

Total Models Analysed = 3 × 4 = 12 Numerical Models

Case	Pier Type	Superstructure	Mass Type
1	Portal	Full Model	Consistent
2	Portal	Full Model	Lumped
3	Portal	Reaction Model	Consistent
4	Portal	Reaction Model	Lumped
5	Hammerhead	Full Model	Consistent
6	Hammerhead	Full Model	Lumped
7	Hammerhead	Reaction Model	Consistent
8	Hammerhead	Reaction Model	Lumped
9	Wall	Full Model	Consistent
10	Wall	Full Model	Lumped
11	Wall	Reaction Model	Consistent
12	Wall	Reaction Model	Lumped

This comprehensive modelling approach enabled direct comparison of pier configurations under identical analytical conditions.

H. Dynamic Analysis Procedure

The seismic assessment was carried out in two stages.

First, Eigenvalue Analysis was performed to determine:

- Natural frequencies
- Fundamental time period
- Mode shapes
- Modal participation factors

Subsequently, Response Spectrum Analysis was performed to obtain:

- Base Shear
- Seismic Coefficient (Ah)
- Modal Response
- Structural Stiffness Characteristics

The analytical results obtained from all twelve models were compared to identify the influence of pier geometry and modelling assumptions on seismic performance.

I. Evaluation Parameters

The seismic performance of each bridge model was assessed using the following response parameters:

- Base Shear
- Seismic Coefficient (Ah)
- Fundamental Time Period
- Modal Frequencies
- Modal Mass Participation
- Structural Stiffness
- Comparative Dynamic Behaviour

These parameters formed the basis for evaluating the effectiveness of each bridge pier configuration under earthquake loading.

VII. RESULTS AND DISCUSSION

A. Modal Analysis

Modal analysis was performed to determine the dynamic characteristics of the bridge models before carrying out Response Spectrum Analysis. The natural frequencies, mode shapes, and corresponding time periods were obtained for all twelve analytical models developed in MIDAS Civil.

The results indicated that the dynamic characteristics of the bridge were significantly influenced by the bridge pier configuration. Differences in structural stiffness among the Portal, Hammerhead, and Wall-Type piers resulted in variations in the fundamental time period and modal frequencies. The Wall-Type Pier exhibited comparatively lower time periods due to its higher lateral stiffness, whereas the Portal Pier demonstrated relatively higher time periods because of its comparatively flexible structural configuration. The Hammerhead Pier exhibited intermediate dynamic behaviour.

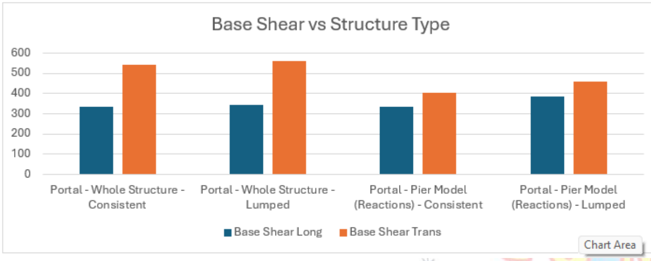
The comparison between consistent mass and lumped mass modelling indicated only marginal differences in the first few vibration modes. However, consistent mass modelling produced slightly more refined modal properties due to the distributed representation of structural inertia.

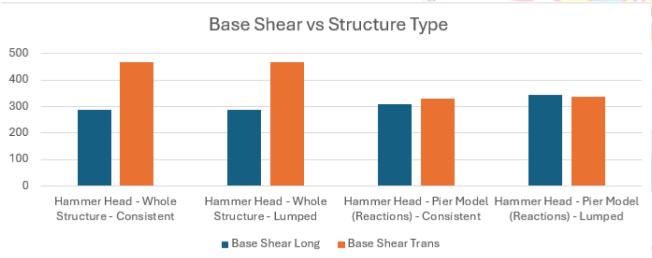
B. Base Shear Analysis

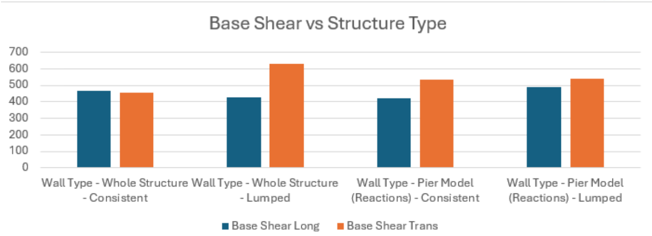
Base shear represents the total horizontal seismic force transferred from the bridge superstructure to the foundation through the supporting piers. It is one of the most important parameters in evaluating seismic bridge performance.

The analytical results showed that the complete bridge models generally developed higher base shear values than the corresponding simplified pier models. This difference occurs because the complete bridge model accounts for the interaction between the bridge deck, bearings, and supporting piers, thereby representing the actual structural system more accurately.

Among the three bridge pier configurations, variations in base shear were observed because of differences in structural stiffness and geometry. The Wall-Type Pier generally resisted higher lateral forces due to its greater stiffness, whereas the Portal Pier distributed seismic forces more flexibly. The Hammerhead Pier demonstrated intermediate behaviour between the two configurations.







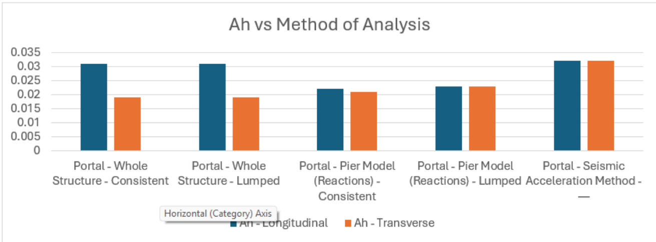
The comparison between consistent mass and lumped mass approaches indicated that although both methods produced similar trends, the consistent mass model yielded slightly different base shear values because of improved representation of distributed inertia effects.

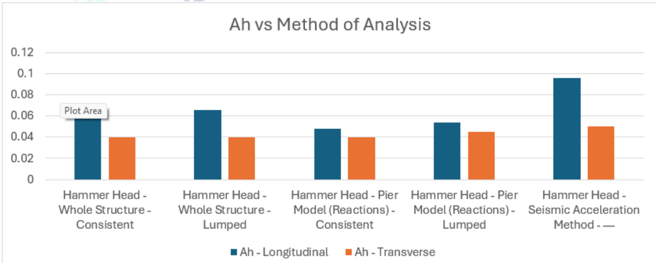
C. Seismic Coefficient (Ah)

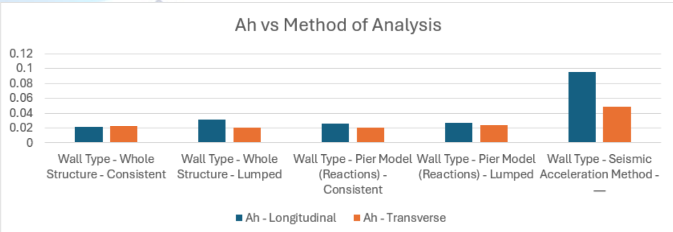
The seismic coefficient (Ah) was determined for each bridge model using the response spectrum procedure. The obtained values were compared with manually calculated seismic coefficients to evaluate the reliability of the numerical models.

The results indicated that the analytical values obtained from MIDAS Civil closely followed the theoretical values prescribed by IRC SP:114. Minor variations were observed because the response spectrum method considers modal participation and dynamic interaction, whereas manual calculations are generally based on simplified assumptions.

The Portal Pier exhibited relatively higher seismic coefficients because of its greater flexibility. Conversely, the Wall-Type Pier produced comparatively lower coefficients in several cases due to its higher stiffness. The Hammerhead Pier again demonstrated intermediate behaviour.







D. Influence of Mass Modelling

One of the objectives of this investigation was to evaluate the influence of mass representation on bridge dynamics.

The comparison revealed that both lumped mass and consistent mass approaches produced similar overall seismic trends. However, the consistent mass model more accurately represented inertia distribution within structural elements, resulting in slightly improved prediction of modal properties and dynamic response.

Although lumped mass modelling considerably reduced computational effort, consistent mass modelling is recommended for detailed seismic evaluation because of its higher analytical accuracy.

E. Comparison Between Complete Bridge Model and Simplified Pier Model

A comparison was performed between the complete bridge models and simplified pier models subjected to equivalent superstructure reactions.

The complete bridge model consistently produced a more realistic representation of seismic behaviour because it incorporated the interaction between the bridge deck, bearings, and substructure. The simplified pier model, while computationally efficient, neglected certain interaction effects and therefore exhibited slight variations in the predicted seismic response.

Nevertheless, the simplified model produced reasonably accurate estimates of the principal response parameters and may therefore be adopted during preliminary design stages where rapid assessment is required.

F. Comparative Performance of Bridge Pier Configurations

Based on the analytical results obtained in the present study, the following observations were made:

- **Portal Pier** demonstrated comparatively greater flexibility and higher fundamental time periods because of its twin-column structural configuration.
- **Hammerhead Pier** exhibited balanced structural behaviour with moderate stiffness and satisfactory seismic performance under the selected loading conditions.
- **Wall-Type Pier** provided higher lateral stiffness and lower fundamental time periods, making it suitable for applications where displacement control is a primary design consideration.

The study demonstrates that no single pier configuration is universally superior. The appropriate selection depends on project-specific requirements, expected seismic demand, structural performance objectives, construction feasibility, and economic considerations.

VIII. CONCLUSION

The present study investigated the seismic performance of three commonly adopted reinforced cement concrete (RCC) bridge pier configurations, namely Portal Pier, Hammerhead Pier, and Wall-Type Pier, using Response Spectrum Analysis in MIDAS Civil. A comprehensive finite element analysis was performed by considering both Complete Bridge Models and Simplified Pier Models with Consistent Mass and Lumped Mass representations.

The analytical results demonstrate that bridge pier geometry significantly influences the dynamic characteristics and seismic response of bridge structures. Differences in structural stiffness among the three pier configurations resulted in noticeable variations in base shear, natural time period, modal characteristics, and seismic coefficient.

The Portal Pier exhibited comparatively greater flexibility and longer natural periods due to its twin-column configuration. The Hammerhead Pier provided balanced structural behaviour with moderate stiffness and satisfactory seismic response under the adopted loading conditions. The Wall-Type Pier exhibited comparatively higher lateral stiffness and lower natural time periods, making it effective in controlling structural deformation during seismic excitation.

The comparison between Complete Bridge Models and Simplified Pier Models indicated that complete bridge modelling provides a more realistic representation of bridge behaviour by considering the interaction between the superstructure, bearings, and supporting piers. However, the simplified reaction-based models produced reasonably accurate estimates of the principal seismic response parameters while considerably reducing computational effort. Therefore, simplified models may be adopted for preliminary design studies, whereas complete bridge models are recommended for detailed seismic assessment and final design verification.

The influence of mass modelling techniques was also evaluated. Although both Consistent Mass and Lumped Mass approaches produced similar global response trends, the Consistent Mass approach provided a more accurate representation of structural inertia and modal characteristics. Consequently, it is recommended for detailed dynamic analysis of bridge structures.

Overall, the study confirms that the selection of an appropriate bridge pier configuration should not be based solely on structural stiffness or base shear. Instead, engineers should consider dynamic performance, construction feasibility, serviceability requirements, and project-specific seismic demand during the design process.

The findings of this investigation provide useful guidance for practicing bridge engineers and researchers involved in the seismic analysis and design of RCC bridge substructures.

IX. LIMITATIONS OF STUDY

The present investigation is subject to the following limitations:

1. The study considers only linear elastic Response Spectrum Analysis, whereas nonlinear structural behaviour during severe earthquakes has not been investigated.
2. Soil–structure interaction effects have not been included, and the pier foundations were assumed to be fixed.
3. The analytical investigation is limited to three bridge pier configurations having identical bridge geometry.
4. Material nonlinearity, cracking, and post-yield behaviour of reinforced concrete members have not been considered.
5. Only one seismic zone and one soil condition were considered in the present study.

Despite these limitations, the adopted methodology provides a reliable basis for comparing the seismic behaviour of different bridge pier configurations.

X. FUTURE SCOPE

The present work may be extended in several directions to improve the understanding of bridge seismic performance.

Future studies may include nonlinear time-history analysis using recorded earthquake ground motions to evaluate the inelastic behaviour of bridge piers under severe seismic excitation. Soil–structure interaction may also be incorporated to investigate the influence of foundation flexibility on bridge response.

The performance of additional bridge pier configurations, different span lengths, varying pier heights, and alternative bearing systems may also be investigated. Furthermore, seismic isolation devices, energy dissipation systems, and retrofitting techniques such as fibre-reinforced polymer (FRP) wrapping and steel jacketing may be evaluated to improve seismic resilience.

The integration of optimization techniques and machine learning algorithms for identifying economical and structurally efficient bridge pier configurations also presents a promising direction for future research.

XI. ACKNOLEDGEMENT

We would like to express our deep sense of gratitude to the professors Mr. Mohammed Parvez Affani B.E. (Civil), M.Tech. (Structural Engineering), Global Institute of Engineering and Technology (A), JNTUH who are very cooperative and their guidance was invaluable & inspiring in doing this research paper.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

REFERENCES

[1] M. J. N. Priestley, F. Seible, and G. M. Calvi, Seismic Design and Retrofit of Bridges. New York, NY, USA: John Wiley & Sons, 1996.

[2] A. K. Chopra, Dynamics of Structures: Theory and Applications to Earthquake Engineering, 5th ed. London, U.K.: Pearson, 2017.

[3] Indian Roads Congress, IRC SP:114–2018: Guidelines for Seismic Design of Road Bridges, New Delhi, India, 2018.

[4] Indian Roads Congress, IRC:112–2020: Code of Practice for Concrete Road Bridges, New Delhi, India, 2020.

[5] Bureau of Indian Standards, IS 1893 (Part 1):2016 – Criteria for Earthquake Resistant Design of Structures, New Delhi, India, 2016.

[6] MIDAS Information Technology Co., Ltd., MIDAS Civil User Manual, Version Used for Analysis.

[7] E. L. Wilson, Three-Dimensional Static and Dynamic Analysis of Structures. Berkeley, CA, USA: Computers and Structures Inc.

[8] American Association of State Highway and Transportation Officials, AASHTO LRFD Bridge Design Specifications, Washington, DC, USA.