

Comparative Study of Conventional and Tubular Bridge Pier

Vinod.B.Ingle¹, Dr. A.W.Kharche², Dr.A.A.Malokar³, S.S.Pawar⁴

¹ Student of Department of Civil Engineering, Padm. Dr. V.B. Kolte College of Engineering, Malkapur, Dist- Buldana, 443101 Maharashtra, India.

² Professor in department of Civil Engineering, and Principal of Padm. Dr. V.B. Kolte College of Engineering, Malkapur, Dist- Buldana, 443101 Maharashtra, India.

^{3,4} Assistant professor in department of Civil Engineering, Padm. Dr. V.B. Kolte College of Engineering, Malkapur, Dist- Buldana, 443101 Maharashtra, India.

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ABSTRACT

Bridges play a crucial role in overcoming geographical obstacles, man-made structures, or easing traffic movement. The construction of these large structures requires sturdy vertical supports, known as piers. These piers are designed intricately and use significant amounts of concrete to withstand axial and transverse loads. This research aims to introduce an innovative form of pier made from reinforced concrete. The design combines principles from both hollow and solid pier structures, incorporating a central core and an outer ring wall connected by concrete elements throughout the vertical length and a concentric ring type section connected radially through concrete elements throughout the height. The pier will be designed by following codal provisions and standard practices implemented in the designing of traditional piers. The study involves a comprehensive examination of the pier's performance in different conditions, compared to traditional pier designs. Additionally, the research aims to identify the variance in concrete quantity, potentially resulting in cost savings for the proposed pier design.

Keywords:- Bridges, Bridge construction, Reinforced concrete piers, Structural engineering, Innovative pier design, Axial loads, Transverse loads

1. INTRODUCTION

The Piers are the structures that provide vertical supports for bridge spans at intermediate points and perform two main functions: transferring superstructure vertical loads to the foundations and resisting horizontal forces acting on the bridge. Piers are traditionally designed to carry vertical loads but designers now need to take into account the high lateral loads caused by seismic events. The ductility aspect of the design of bridge is therefore crucial as it will distribute the seismic energy and prevent brittle shear failure. Piers are predominately constructed with reinforced concrete. Steel, to a lesser degree, is also used for piers. Steel tubes filled with concrete, known as composite columns, have been used in some recent projects in China and other countries. Concrete piers are more durable, stronger, cost-efficient, versatile, and weather resistant than steel piers. They can be used in a wide variety of applications, making them a great option for different types of structures and soil conditions. On the other hand, steel piers are mainly used for specific types of structures and they have a higher risk of rust and corrosion over time. With the development in analysis techniques designing non-conventional pier type is becoming common globally. The traditional column type pier is being replaced with innovative and aesthetically pleasing bridge pier designs resources.

1.2. Forces Acting on Bridge Pier

Bridges are subject to forces from many sources such as vehicular traffic, wind, seismic, ice flow, and temperature etc. Vehicular traffic is referred to as live load and is considered static. The bridge must be able to hold up its own weight, which is referred to as dead load. Dead loads also include permanent attachments such as signs and luminaires and utilities. Additional types of loads include water, wind, and extreme-event (earthquake shift) loads and frictional forces. Each of these loads translates into a type of member force. In bridge design, there are five member forces that are considered: axial tension, axial compression, shear, flexure and torsion. The forces are transmitted through the components of the bridge—girder, pier cap, pier, and foundation—via a combination of direct axial load paths, lateral shear force transmission, and bending moment distribution. The geometry, material properties, and design of each element play a crucial role in ensuring effective load transfer and structural stability. The load paths are established based on principles of equilibrium, compatibility, and the mechanical behaviour of materials.

1.3. Classification of bridge pier

Bridge piers can be categorized according to various criteria. Every pier type is unique in its own with aspect to load transfer mechanism, type of material used or simply the structure of the pier. Based on different set of aspect the bridge piers can be classified as follow.

1.4 Based on structure

Piers are categorized into two major types based on its structure which include solid piers and open piers. These types are further classified into several types: Solid piers are solid and impermeable structure, and usually constructed from bricks, stone masonry, concrete or reinforced concrete. Solid piers can be made from stone masonry or reinforced concrete

1.5 Based on material of construction

Depending upon the material used for construction the piers can be classified as Stone masonry piers, Mass concrete piers, Timber piers, Composite piers. Stone masonry and timber piers are seldom used in transportation projects. They are replaced with mass concrete piers and piers made of composite section. Timber piers and stone masonry piers alone are used for aesthetic purposes or can be found in old bridge structures which are not subjected to modern loading. Today almost all bridge piers are designed using concrete as it offers resistance to weather action for a longer span of time.

1.6 Based on load transfer mechanism

The process of transfer of exposed load from one structural element to the other is termed as load transfer mechanism. Depending upon this mechanism the piers are categorized into two broad categories. Fixed pier which supports a bearing and are subjected to both the transverse and longitudinal forces and free pier which supports bearing which transfers only axial forces from the bearing to the foundation.

1.7 Based on special requirement

Depending upon requirements various new types of piers have been developed which follow complex load transfer mechanism and help increasing strength to weight ratio and also help to reduce cost of construction. Following are a few piers which are being widely used in bridge making Hammerhead Piers, V shaped Piers, Pylons, Hollow Piers, etc.

2. LOADS ACTING ON BRIDGE

Bridges are always subjected to different types of loads, which can be divided into three big categories: vertical loads, transversal loads, and longitudinal loads. For the first category, representative loads include dead loads, live loads, and impact. The second category is described by loads such as earthquakes, wind, centrifugal force, and lateral shock. Longitudinal loads are often described by loads like friction, wind, thermal, earthquakes, and braking.

2.0 Dead load

Dead loads are the most basic of all the loads any structure would have to resist. These include the self-weight of the structure and the superimposed dead loads, which are loads applied by railings such as crash barriers, medians, and wearing courses. These loads are permanent and are always present till the service life of the bridge. Furthermore, dead loads and superimposed dead loads are generally transferred to the substructure using safety factors as per structural strength and serviceability. Dead Loads are also critical for seismic analysis, which is converted into masses. Besides, time-dependent effects such as creep are also greatly influenced by the dead loads considered.

2.1 Live load

Traffic loads become an essential aspect of bridge design. Traffic loads or moving loads are not stationary and they become important to obtain the critical vehicle position, which may cause the worst loading effect or, in other terms, may govern the design

2.2 Accidental or Collision load

Accident or collision loads are those loads that are directly applied to the pier or substructure. They are considered to either act normal or parallel to the carriageway and should not be combined.

2.4 Wind load

Wind loads are lateral loads that are critical in transverse direction since bridges have less resistance in the transverse direction. Wind forces defined as per code are for bridge spans of up to 150m and pier heights of up to 100m. Beyond this, the bridge may be considered dynamically sensitive, and advanced analysis or wind tunnel testing may be needed. The transverse wind force may be calculated as: $F = P_z * A * G * C_d$ where, P_z is wind pressure, A is the area of the location, G is the gust factor (kept as 2), and C_d is the drag coefficient which depends on the geometrical shape of the structures.

2.5. Water pressure

Water pressure loads are applied to only bridges constructed on the waterfront. The intensity of the water pressure parallel to the water current is calculated as below: $P = k V^2$ Where, V is the velocity of the water current at the location, and k is a constant depending on the pier's shape

2.6 Seismic loads

Bridges are to be designed for seismic loads other than culvert or minor bridges with a span of fewer than 10 m and bridges in zone 2 and 3 with spans less than 15m and a total length of 60m. Furthermore, additional research must be conducted for long-span bridges and bridges having high pier lengths in seismic higher zones. The seismic response is generally calculated using the elastic response spectrum method. For the horizontal seismic force,

$F_{eq} = A_h (\text{Dead load} + 20\% \text{ Live Load})$

Where A_h is the horizontal seismic coefficient and $A_h = \frac{z}{2} * I * \frac{S_a}{G}$

Where z = zone factor, I = importance factor, and S_a/g = Average response acceleration, which depends upon the fundamental period of vibration, T . Horizontal seismic forces for live loads are considered only in the direction perpendicular and vertical to the vehicle movement, and is considered for 20% of the live load without the impact factor. Time period of pier/abutment of the bridge along the horizontal direction is where, D is the dead load + 20% of the live load in kN, and F is the horizontal force in kN required for 1mm horizontal deflection for top of pier/abutment.

2.1.1 Objective of work

- Understanding load transfer mechanism of different types of bridge piers.
- Understanding modeling of bridges and applying loads as per relevant codes.
- Developing innovative tubular pier that combines the mechanism of solid and hollow pier.
- Identifying the advantages of innovative pier over the traditional piers.

2.1.2 Scope of work

- Modeling of bridge in CSI Bridge software and applying loads as per IRC guidelines.
- Creating different innovative sections for bridge piers.
- Analyse the different bridge models to obtain suitable section dimensions.
- Comparing different parameters that affect the performance of innovative pier.
- Comparing the innovative piers with traditional piers to identify its benefits.
- Comparing performance to obtain material conserved by innovative piers.

3. INNOVATIVE BRIDGE PIER

3.2. General

This chapter deals with the concept of innovative bridge pier. Information regarding the section characteristics and properties has been explained here.

3.3. Description of the Innovative Bridge Pier

Solid cross sections have long been preferred for their easy construction and support against compressive forces. They feature a continuous material distribution that provides high compressive strength and stability, making them reliable for bearing axial loads. However, their heavy weight often requires more material, leading to increased costs. On the contrary, hollow cross sections offer significant advantages due to their efficient material distribution. By spreading material further from the center, they create a larger moment of inertia, enhancing resistance to bending and torsional forces without adding extra material. This results in a lighter structure, while still providing excellent support against both axial and lateral loads. Solid and hollow bridge piers each pose distinct challenges and considerations in the design and construction phases. Solid piers, though robust and straightforward to construct, require significant material, resulting in higher costs and environmental impacts due to increased concrete and steel consumption. Their substantial weight places greater demands on foundations, leading to more intensive and costly foundational work. Moreover, solid piers may exhibit lower efficiency in seismic performance due to their greater mass, which can generate larger inertia forces during earthquakes, potentially leading to heightened stress and damage. Their inherent rigidity makes them less flexible and ductile, crucial characteristics for withstanding seismic activity without failure. Additionally, thermal expansion and contraction in solid piers can induce significant internal stresses, leading to potential cracks. In contrast, hollow bridge piers offer several advantages, including a superior strength-to-weight ratio and efficient material distribution, resulting in reduced overall weight without compromising structural integrity. Hollow sections are particularly advantageous in seismic-prone regions due to their optimized geometry, enhancing bending and torsional resistance. However, they introduce complexities during construction due to precise formwork requirements, reinforcement placement, and concrete pouring techniques.

Durability concerns may arise from potential corrosion and water ingress, with internal voids posing challenges

for inspection and maintenance. Hollow piers may also be susceptible to buckling under axial loads, necessitating careful design to reduce this risk. Their behaviour under seismic loads requires thorough evaluation due to the complex stress distributions resulting from their hollow geometry. Additionally, reduced cross-sectional areas impact shear strength, requiring additional reinforcement. Accessing internal voids for inspection and maintenance is challenging, and their thermal expansion and contraction behaviour can lead to stress concentrations and potential cracking. The innovative bridge pier design aims to capitalize on the strengths of both solid and hollow configurations by introducing two new cross sections for comprehensive study and analysis. The first cross section, referred as the Solid Tube cross section, shown in Fig.3-1 features a solid central core that provides stability and structural integrity. Surrounding this core is an outer ring-type wall that adds further support and distributes loads efficiently. The solid core ensures excellent compressive strength, while the outer ring enhances the pier's resistance to lateral forces and bending moments. Both elements are interconnected with wall-type members, optimizing the load-bearing capacity of the entire cross section.

3.4.Characteristics of the Innovative Bridge Pier

Moment of inertia is one of the critical factors in determining the performance of a bridge pier because it directly influences the structure's stiffness and resistance to bending and buckling under applied loads. Higher moments of inertia lead to greater stiffness, reducing deflections and increasing the pier's overall stability and load-bearing capacity. The material in these sections is strategically arranged to achieve a higher moment of inertia compared to a solid bridge pier, while using the same quantity of material. This optimized distribution enhances the structural stiffness and load-bearing capacity.

This increased moment of inertia enhances the flexural rigidity of the structure, making it more resistant to bending and deformation under loads. This means that the pier can better withstand lateral forces, such as those from wind and seismic activity. Reinforcement is more efficiently utilized when positioned along the periphery of the section. These innovative bridge pier designs maximize the covered area, allowing for an optimal arrangement of reinforcement steel, which enhances the structural integrity and load-bearing capacity of the piers.

3.5.Closure

This chapter explores the innovative design concept of bridge piers, detailing their characteristics and properties. It provides comprehensive information about the structural elements involved. The subsequent chapter will focus on the project methodology, covering an overview of the structures, their evaluation criteria, and outlining the analysis methods aimed at achieving specific research.

4. METHODOLOGY

• General

How the analysis is to be carried out and what outcomes are expected out of the analysis are discussed here.

• Project Methodology

The project model was developed using CSI Bridge software, utilizing the built-in section designer option to create the innovative bridge pier sections. Once the model was complete, it was analysed in three distinct parts, each providing significant outcomes.

4.2.1Analysis I

This analysis focused on identifying how various parameters affect the performance of bridge piers. The following parameters were found to have significant impact: The thickness of hollow sections significantly affects their performance. A very high thickness negates the purpose of material conservation, while a very thin section increases the risk of buckling. The hollowness ratio, defined as the ratio of the inner diameter to the outer diameter, is varied to optimize performance. The sections' performance is then analysed to determine the most effective balance between material conservation and structural stability. The geometric parameters of the solid tube cross section play a crucial role in determining its overall performance. These parameters include the diameter of the inner solid core, the thickness of the connecting wall member, the thickness of the outer ring, and the arrangement of reinforcement steel. By varying these parameters and designing different sections, a range of cross sections is created for analysis. The inner solid core diameter is adjusted to assess its impact on structural stability and load-bearing capacity. The thickness of the connecting wall member influences the rigidity and strength of the connection between the core and the outer ring. The outer ring's thickness affects the overall moment of inertia, which is crucial for resisting bending moments. Additionally, the placement and quantity of reinforcement steel can significantly impact the structural integrity and resistance to loads.

5. CONCLUSION

- A hollowness ratio of 0.5 to 0.6 is better suited for hollow bridge pier sections.
- The number of radially connecting wall members and the central core diameter have no significant effects

on reducing lateral deflection in solid tube-type piers.

- The thickness of the outer wall is a major factor in capacity and displacement control in solid tube-type piers.
- Similarly, in hollow tube-type sections, the thickness of both the outer and inner walls contributes to their capacity and displacement control.

6. REFERENCES

- [1] IRC:6-2017 Standard Specifications and Code of Practice for road bridges Section: II Loads And Load Combinations (Seventh Revision) Indian Roads Congress 2017
- [2] Samy Muhammad Reza, M. Shahria Alam, Solomon Tesfamariam, "Lateral load resistance of bridge piers under flexure and shear using factorial analysis", *Engineering Structures*, Volume 59, 2014, Pages 821-835, ISSN 0141-0296, <https://doi.org/10.1016/j.engstruct.2013.12.009>.
- [3] Lee, JH., Choi, JH., Hwang, DK. et al. "Seismic performance of circular hollow RC bridge columns". *KSCE Journal of Civil Eng* 19, 1456–1467 (2015). <https://doi.org/10.1007/s12205-014-1173-z>
- [4] Delgado, R., Delgado, P., Vila Pouca, N. et al. "Shear effects on hollow section piers under seismic actions: experimental and numerical analysis". *Bull Earthquake Eng* 7, 377–389 (2009) <https://doi.org/10.1007/s10518-008-9098-x>
- [5] . Y.K. Yeh, Y. L. Mo and C. Y. Yang, "Seismic Performance of Rectangular Hollow Bridge Columns". *Journal of Structural Engineering*, Vol. 128, No. 1, January 1, 2002. ©ASCE, ISSN 0733-9445/2002/1- 60–68. [https://doi.org/10.1061/\(ASCE\)0733-9445\(2002\)128:1\(60\)](https://doi.org/10.1061/(ASCE)0733-9445(2002)128:1(60))
- [6] Kim, Jung Han, Ick-Hyun Kim, and Jin Ho Lee. "Experimental Study on the Behavior of Existing Reinforced Concrete Multi-Column Piers under Earthquake Loading" *Applied Sciences* 11, No. 6: 2652, 2021. <https://doi.org/10.3390/app11062652>
- [8] Raghavendra Yadav, Baochun Chen, Huihui Yuan, Zhibin Lian, "Analytical Behavior of CFST Bridge Piers under Cyclic Loading", *Procedia Engineering*, Volume 173, 2017, Pages 1731-1738, ISSN 1877-7058, <https://doi.org/10.1016/j.proeng.2016.12.208>
- [9] Zhong-Xian Li, Chunyu Du, Dong Liu, Xiao Liang, Bo Zhao, "Comparative study on seismic performance of concrete-filled double skin tubular piers and hollow concrete piers: Experimental and analytical", *Structures*, Volume 49, 2023, Pages 1078-1092, ISSN 2352-0124, <https://doi.org/10.1016/j.istruc.2022.11.116>
- [10]. Zhehan Cai, Weidong Zhuo, Zhijian Wang, Bruno Brisegh
- [11][1] Lazaroff, C. (2000) Hidden Ground Water Pollution Problem Runs Deep. *Environment News Service*, Worldwatch Institute, Washington, DC. MoWR (2003) Problems Facing the Water/Irrigation Sector: Water Quality Issues. Ministry of Water Resources, Government of India, New Delhi (article available at MoWR website <http://wrmin.nic.in/problems/default11.htm>).