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Comparison Of Shear Connectors For Composite I Beam Bridge-A Review

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Abstract
Composite I-beam bridges rely on shear connectors to ensure integrated behaviour between the concrete deck and steel girders, maximizing strength and stiffness. The selection of an optimal shear connector is a critical design decision, requiring a robust comparison of performance attributes under both static and fatigue loading specific to bridge applications. Based on the findings, headed studs remain a cost-effective and ductile solution for standard composite I-beam bridge decks. However, channel or perfobond rib connectors are preferable in high-load regions or for bridges with significant fatigue concerns due to their higher stiffness and shear resistance. This research provides a critical reference for engineers to make informed decisions on shear connector selection, balancing performance requirements with economic and construction feasibility.

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I. Introduction

Shear connectors in composite I-beam bridge design transfer shear forces between the steel beam and concrete slab, ensuring they act as a single unit. The most common type is the welded stud shear connector, which offers high shear capacity. Other types include perfobond ribs (ribs with holes) for improved dowel action and fatigue resistance, and innovative composite dowels that can improve constructability and stiffness. The choice depends on factors like the required load capacity, fatigue life, construction speed, and overall durability. Steel-concrete composite bridges are widely used in modern infrastructure due to their exceptional mechanical properties, which leverage the benefits of both materials. By effectively utilizing the high tensile strength of structural steel and the high compressive strength of concrete, composite bridges offer a structurally efficient, lightweight, and cost-effective solution for small to medium-span applications. The key to this composite action lies in the use of shear connectors, which are mechanical devices that transfer shear forces at the interface between the concrete deck slab and the steel I-girders. This connection is vital for preventing slip and separation, which enables the two components to act as a single, monolithic unit and achieve the full structural benefits. While headed studs have been the conventional choice for composite bridges due to their reliability and cost-effectiveness, alternative connector designs, such as channel connectors, The selection of the most suitable connector depends on various factors, including construction methods, loading conditions, and cost. This paper seeks to address this gap by presenting a comparative analysis of the performance of different shear connectors for composite I-beam bridge design. By evaluating and contrasting the mechanical behaviour of conventional headed studs against alternative shear connectors like channel sections and perfobond ribs, this study will determine the optimal connector solution under different design criteria. The analysis will provide valuable insights to aid engineers and designers in selecting the most appropriate and efficient shear connectors for future composite I-beam bridge project steel-concrete composite bridges are widely used in modern infrastructure due to their exceptional mechanical properties, which leverage the benefits of both materials. The key to achieving this structural efficiency is the shear connection at the interface between the concrete deck and the steel I-girders. While headed studs are the conventional choice for this connection, various alternative connectors such as channels, perfobond ribs, and composite dowels have been developed. However, a detailed comparative analysis of these shears connectors, focused on their performance characteristics for composite I-beam bridges, is needed to inform optimal design choices. This study presents such a comparison, examining the stiffness, capacity, and ductility of different shear connectors. This research will aid engineers and designers in selecting the most efficient and suitable shear connector for composite I-beam bridge applications.

Steel concrete composite bridges are widely used in large-span cable-stayed bridges, suspension bridges, and continuous girder bridges because of their excellent mechanical properties, economy, and ease of construction. In composite structures, shear connects- torso .The welded stud connector is one of the most widely used shear connectors in bridge engineering. It has the characteristics of convenient construction, low cost, and consistent shear resistance in all directions .Shear connectors are classified by their design and function, with common types including welded shear studs, channel connectors, angle connectors, Perfobond (PBL) connectors, and composite connectors. Welded studs are cost-effective but require specialized welding, while angle connectors are economical and easy to install but offer lower shear strength and ductility than channel connectors. Channel connectors provide good ductility but are heavier and have higher cracking potential, while PBL and composite connectors (a combination of studs and perforated plates) offer enhanced fatigue resistance and strength. Shear connector is an important component at the steel–concrete interface. Traditional shear connectors are mainly made of metal materials and can be in the form of stud, structural steel elements, bent-up bar and perfobond leister (PBL) shaped shear connector. Shear connectors for composite I-beam bridge designs often focuses on traditional headed studs versus newer options like Perfobond Ribs (PBLs), composite dowels, and various bolt-type connectors. Studies use push-out tests, numerical simulations, and full-scale experiments to evaluate shear resistance, ductility, stiffness, and cost-effectiveness.

Common Shear Connectors

Welded Headed Studs:

The most widely used type; these studs are welded to the steel beam and provide a mechanical connection that resists both shear and pulling forces.

Advantages: High shear capacity, well-understood behaviour.

Disadvantages: Can be susceptible to fatigue, require specialized welding equipment, and can slow down the construction of modular bridges.

Perfobond Ribs:

These are perforated steel plates with holes through which concrete forms dowels, providing both shear and horizontal resistance.

advantages**:** Improved anchorage and ductility compared to studs, greater fatigue resistance.

disadvantages: May not be as widely adopted as studs.

Composite Dowels:

These can be clothed shaped or have other novel designs to improve performance and simplify installation.

advantages**:** Can be designed for easier installation in composite structures and have demonstrated superior stiffness and ductility.

Wing Plate Headed Studs:

These studs feature wing plates that can significantly increase shear capacity, stiffness, and ductility compared to traditional studs.

Panel End Shear Connectors:

Used in steel-precast composite bridges, these offer alternatives to traditional grouted pockets for faster assembly and more durable connections.

Traditional Shear Connectors

Welded Shear Studs:

The most common type, welded to the steel I-beam to transfer shear forces and create a composite action with the concrete slab.

PBL (Perforated Beam-to-Deck) Connectors:

These consist of a perforated steel plate with a stud-like component. Innovative and Advanced Shear Connectors

Composite Shear Connectors:

Combine elements of different types, such as a perforated steel plate with welded studs, to enhance overall shear performance and pulling resistance between the slab and the beam.

Wing Plate Headed Studs:

Modified stud designs that offer significantly greater shear capacity, increased stiffness, and superior ductility compared to traditional studs.

Non-Metallic/Adhesive Connectors:

Use epoxy resin or other adhesives as the shear transfer mechanism, potentially offering higher shear strength than traditional studs, along with advantages like noise reduction and enhanced durability by preventing moisture ingress.

Channel and Angle Connectors:

While potentially slower in stiffness degradation, some studies have shown them to have good strength and energy dissipation capacity, making them suitable for composite bridges.

Groove-Plate Nested (GPNC) Connectors:

Used in prefabricated steel-concrete composite bridges, these connectors incorporate pre-formed grooves and steel plates for alignment and grouting, providing robust connection points.

Factors Influencing Connector Selection

Stiffness and Ductility:

The ability of the connector to deform under load without sudden failure is crucial for the overall toughness of the composite structure. Different connectors provide varying degrees of stiffness and ductility, which impact the overall behaviour of the composite beam under different loading conditions.

Fatigue Life:

For bridges with heavy live loads, connectors with better fatigue resistance, like perfobond ribs or composite dowels, might be preferred. High-strength bolted connectors, for instance, have shown high fatigue strength, potentially allowing for fewer connectors compared to traditional studs, though code provisions for their use in composite bridges are still developing.

Durability:

The choice of connector can impact the long-term durability of the bridge, with some designs offering better protection against moisture infiltration. Non-metallic connectors can offer improved durability by creating a sealed interface, preventing moisture intrusion into the structure.

Performance at Different Stages of Loading:

The required force transfer per unit length dictates the necessary connector strength and spacing. A fully composite connection that provides good interaction at all stages of loading, from elastic to ultimate capacity, is crucial for realizing the full toughness of the composite structure.

Cost and Constructability:

For modular precast concrete bridge decks, faster-to-install connectors that reduce the need for extensive grouting are desirable. While not explicitly detailed in these snippets, the ease of fabrication, installation, and overall cost are practical considerations when choosing between different connector types.

Literature Review

Farid Boursas, *et.al. (*2024) The purpose of the study had been to conduct an experimental investigation and a numerical simulation using the finite element method. As a result, it was found that the hole geometry of IPE and IPN perforated shear connectors significantly impacted shear load capacity and ductility. The long cut hole shape in IPE and IPN perforated shear connectors exhibited superior ultimate load capacity but less interfacial slip compared to the circular hole. The test setup followed Eurocode 4 guidelines, focusing on hole shape and anti-lift rebar diameter parameters. The predominant failure modes were mainly dictated by the crushing of the concrete slab. The IPE and IPN perforated shear connectors demonstrated satisfactory ductility for all tested hole shapes, and the 3D finite element models were consistent with the test results.

Yifan Zhou, *et.al. (*2023)The application of stainless steel shear connectors in composite beams was still very limited due to the lack of research and proper design recommendations. In this paper, a total of seven pushout specimens were tested to investigate the load-slip behaviour of stainless steel shear connectors. With the experimental programme, a finite element model was developed in ABAQUS to simulate the behaviour of stainless steel shear connectors, with which the effects of shear connector strength, concrete strength and embedded connector height to diameter ratio (h/d) were evaluated. The obtained experimental and numerical results were analysed and compared with existing codes of practice, including AS/NZS 2327, EN 1994-1-1 and ANSI/AISC 360-16. The comparison results indicated that the current codes needed to be improved for the design of high strength stainless steel shear connectors. On this basis, modified design approaches were proposed to predict the shear capacity of stainless steel bolted connectors and welded studs in the composite beams.

Mohamed S. Majdub, *et.al. (*2022) Several experimental and numerical studies had been conducted to investigate the composite flooring systems and examine the various details that might affect the production of composite floors, presenting essential results and important notes from various studies. The fundamental structural elements and the contribution of conducted studies towards improving the shear capacity of composite beams in enhancing the general structural behaviour were also described. The paper concluded with the potential of a deeper investigation of some issues that accompanied the application of certain types of shear connects or steel shapes used to improve the composite slim floor system so that the improvement construction industry might make the most out of using composite construction techniques.

Rahul Tarachand Pardeshi, *et.al. (*2021) Various typed of shear connectors, their uniqueness and characteristics, tested methods and findings obtained during the lasted decade reviewed. The literature, efficacy, and applicability of the different categories of shear connectors, for example, headed studs, perfobond ribs, fibre reinforced polymer perfobonds, channels, pipes, Hilti X-HVB, composite dowels, demountable bolted shear connectors, and shear connectors in composite column was thoroughly studied. The conclusions made provided a response to the flowed of the used of shear connectors for their behaviours, strength, and stiffness to achieve composite action.

Alves Ana Rita, *et.al. (*2018) the connection between the steel beamed and the concrete slab and ensured the joint behaviour of these two elements. The worked included an experimental campaign developed at the Structural Laboratory of University of Minho, Portugal, and a numerical studied developed with the ATENA 3D software.The experimental tested and the numerical models developed to evaluate the behaviour of the composite beamed and particularly the indented shear connector in analysis. The tested specimens consisted on a steel beamed with a continuous indented connector, positioned on the upper flange of the beamed and continuously welded in its development, and a reinforced concrete slab, in a total span of 3000 mm. During the tested, the connector provided high stiffness and a full interaction between the concrete slab and the steel beam. The beams failure determined by crushed on the upper parted of the concrete slab.

Amir Reza Ghiami Azad, *et.al. (*2018) The application of partially-composite beamed in bridges had recently increased because the shear connectors was no longer distributed evenly along the beamed but rather, they were installed and concentrated wherever they are needed. In this paper, the methods of evaluating fatigue life of shear connectors in fully- composite beamed are investigated, and these methods are extended to partially- composite beamed based on the available experimental data and partial-interaction theory.The results of this studied showed that checked fatigue based on slipped range or strain range instead of the conventional stressed range approached lead to more accurate equations with better correlation and smaller error.

Nadiah Loqman,*et.al.(*2018) In ordered to achieve a sustainable structural system, precast concrete slabs attached to a steel beamed used bolted shear connectors in prefabricated holes had introduced as an alternative to the conventional connectors in steel – concrete composite beamed system. This paper reviews the structural behavior of composite beamed system such as the strength, stiffness, slipped behavior, failure mode and sustainability obtained by experiment and numerical studied in ordered to addressed the applicability and efficiency of the composite beamed had precast concrete slabs and bolted shear connectors.

Ahmed S.H. Suwa,*et.al.(*2018) The conception and experimental assessment of a removable friction-based shear connector (FBSC) for precast steel-concrete composite bridges presented.). A series of 11 push-out tested highlight why the novel structural details of the FBSC result in superior shear load-slip displacement behavior compared to welded shear studs. The paper also quantifies the effects of bolted diameter and bolted preload and presented a design equation to predict the shear resistance of the FBSC.

P. Sai Shraddha, *et.al.*(2016) composite structures result in efficient design and economy in construction timed hence used especially in construction of built floors and bridges. In this studied Finite Element Analysis had been done on four typed of shear connectors for ductility criteria. Push-out tested Specimen and Composite beamed modeling with four different typed of shear connectors was done in ANSYS and analyzed. The Analytical results presented and focused on the studied of ductility behavior and loaded slipped behavior of connectors of varying height in composite beamed.

M. Shariatia, *et.al* (2016) sixteen experiments on push-out specimens conducted to compared the performance of channel and angle shear connectors embedded in HSC.. Results was also compared with the cases when used normal reinforced concrete... Angle connectors were also less ductile than channel connectors and did not satisfied the ductility criteria specified in the codes' requirements.

S.E.M. Shahabi, *et.al* (2015) Studied on the behavior of shear connectors subjected to elevated temperatures performed in the lasted decade reviewed in this paper. The experimental tested of push-out specimens, the design approaches provided by researchers and different codes, the major failure modes, and the finite element modeling of shear connectors highlighted. The critical researched review showed that the strength of a shear connector decreases proportionally with the increased in temperature. Compared with the volume of worked published on shear connectors at ambient temperatures, a few studied on the behavior of shear connectors under fired had conducted. Several areas where additional researched was needed are also identified in this paper.

Daniel Lowe, *et.al* (2014) Shear connector capacity had determined experimentally; however these tested did not generate a detailed understood of the forced transfer mechanisms between stud and concrete. This paper aimed to characterise the behaviour of the composite beamed when it failed by fracture of the concrete along the line of the studs, known as splitting failure. Experiments had conducted on 5 steel-concrete composite beamed, with shear stud connections, to investigate in detail the splitting behaviour at the stud-concrete interface. All beamed was internal primary beamed designed to failed by splitting. Tested carried out on a specially developed pushed off rig (A. Gillies et al., 2006), with four specimens being loaded monotonically until failure and the fifth one loaded cyclically and then failed monotonically according to EuroCode 4 (1994) recommendations. Cracked initiation and propagation in both the vertical and longitudinal direction measured, as well as local and global strains.Results showed very small changed in rib width as loaded was increased, gave indication of when micro and macro cracked occurred.

Kodi Rider, *et.al* (2011) Theoretical stressed and deflection analysis of the bridge performed used MSCNastran finite element software Composite bridges tested used the Instron machine belonged to the architectural engineering department at Cal Poly San Luis Obispo. Through analysis and tested, it was determined that web stability was the drove failure mode to design for. Our final bridge failed under 3000 lbf due to buckling of the web directly beneath the applied loaded. Based on tested and performance at the SAMPE competition, there was many aspects of this project that could have improved, most importantly through manufacturing techniques. Use of an autoclave as well as using metal molds for cured the beamed would dramatically increased loaded carried capability.

Jawed Qureshi, *et.al*(2010) The analysis of the pushed tested carried out used ABAQUS/Explicit with slowed loaded application to ensured a quasi-static solution. Both material and geometric nonlinearities was taken into account... The post-failure behaviour of the pushed tested was accurately predicted, which was crucial for realistic determination of shear capacity, slipped and failure mode. The results obtained from finite element analysis verified against the experimental push tests conducted in this researched and also from other studied. The results were also compared with the capacity of a single shear stud.

O. Mirza, *et.al* (2008) A three-dimensional pushed tested model developed herein with a two-dimensional temperature distribution field based on the finite element method (FEM) and which might Have Been applied to steel–concrete composite beamed. This investigation considered the load–slip relationship and ultimate loaded behaviour for pushed tested with a three-dimensional non-linear finite element programmed ABAQUS. As a result of elevated temperatures, the material properties changed with temperature. The studied compared with experimental tests under both ambient and elevated temperatures.

II. Conclusion

As per literature review shear connector is the most appropriate for the specific bridge design The comparative headed stud connectors offer reliable shear capacity, they exhibit less ductility compared to newer composite alternatives, such as the composite perfobond rib (PBL) connectors. Finite element modeling and experimental push-out tests showed that the composite connectors not only provide significantly higher ultimate shear resistance but also a more ductile failure mode, allowing for greater slip before failure. Furthermore, bolted shear connectors were shown to improve construction efficiency and offer sustainability benefits, making them a suitable option for projects utilizing precast concrete slabs. Considering the long-term performance requirements and potential for fatigue in a bridge environment, the composite PBL connectors, with their enhanced shear behavior and ductility, represent the optimal choice for this application.

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