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Comparison of Shear Connector for Composite I Beam Bridge

Subtitle

SHEAR CONNECTOR FOR COMPOSITE I BEAM BRIDGE

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Abstract— This Study Evaluates The Structural Performance Of Various Shear Connectors—Headed Studs, Channel Sections, perfobond ribs (pbl), and angle connectors—within a composite i-beam bridge deck system. Using nonlinear finite element analysis in ansys, the research focuses on the load-slip behavior, ultimate shear capacity, and stress distribution at the steel-concrete interface. Results indicate that while headed studs are the industry standard for ease of installation, channel and perfobond connectors provide superior shear resistance and reduced interfacial slip, making them more suitable for high-load applications.

Keywords—combin39,mpc184,beam188,solid185

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 headed 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 construct ability and stiffness Channel Shear Connectors: These consist of channel sections welded transversely to the flange. They offer high shear resistance due to large contact areas with concrete. They are versatile and do not require specialized welding equipment.Angle Shear Connectors: L-shaped or C-shaped, often considered economical but offer 7.5%–49% less shear strength than channel connectors. They are easy to install but can have inadequate ductility and lower shear resistance.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 construct ability 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.

A Objective

1 Euro code 4 (EN 1994-2): The European standard for the design of composite steel and concrete structures Bridges It defines minimum dimensions and spacing for headed studs (e.g., minimum 5d longitudinal spacing).

2 IS 11384 The standard for the US, using plastic design philosophy for shear connectors in composite beams.

3 BS 5400-5: An older British standard for steel, concrete, and composite bridges, still referenced in some historical contexts or specific guidance notes

II LITERATURE REVIEW

Shear Connectors in Composite Structures

Farid Bourse, 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 inter facial slip compared to the circular hole. The test setup followed Euro code 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 push out 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 analyses 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 ofworked 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.

III MATERIALS

For a comprehensive comparison of four types of shear connectors—Headed Studs, Channel Connectors, Angle Connectors, and Perfobond Ribs—in a composite I-beam bridge, your "Material Options" section needs to be technically precise.

In structural engineering, the "Material" section refers to both the physical properties of the steel used for the connectors and the grade of concrete they are embedded in.

1. Material Specifications for Four Types

1.1 Headed Shear Studs: Usually made from Low Carbon Steel (e.g., ASTM A108 Grades 1010 through 1020). These are chosen for their excellent weldability and ductility.

1.2 Channel Connectors: These are cold-formed or hot-rolled Structural Steel channels (e.g., IS 2062 Gr E250 or ASTM A36). They offer higher stiffness due to their larger cross-sectional area.

1.3 Angle Connectors: Similar to channels, these utilize Structural L-sections (Equal or Unequal Angles). The material is standard structural steel, but the orientation affects the shear transfer.

1.4 Perfobond Ribs: These consist of Structural Steel Plates with specific circular or oval openings. The material is typically high-strength structural steel to resist bearing stresses at the holes.

2. Engineering Properties

2.1 Yield and Tensile Strength

The resistance of the connector depends on its ultimate tensile strength (f_u).

Headed Studs: f_u \approx 450 MPa.

Structural Sections (Channel/Angle/Plate): f_u \approx 410 - 490 MPa.

2.2 Ductility and Slip Capacity

This is the ability of the connector to deform without snapping.

Headed Studs are highly ductile (Flexible).

Channel and Angle Connectors are stiffer (Rigid) and allow less slip before the concrete crushes.

2.3 . Modulus of Elasticity (E)

Standard for steel (2 \times 10^5 MPa). This defines the initial stiffness of the composite connection.

2.4 . Concrete Grade Compatibility

The material performance of the connector is linked to the concrete strength (M30, M35, M40). Mention that higher grade concrete increases the "bearing capacity" of the connector material.

3. Comparison Table for Material Context

Connector type	Material form	Typical steel grade	Behavior
Headed stud	Foregd rod	Low carbon steel	Ductile
Channel	Rolled section	Is 2062/Astm A36	Rigid
Angle	Rolled section	Is 2062/ASTM A36	Semi-rigid
Perfobond	Steel plate	High sterength plate	Highly rigid

The material utilized for headed shear studs must ensure a minimum elongation of 20% to provide sufficient ductility in the composite beam."

"Structural steel channels and angles provide a larger bearing area against the concrete compared to studs, reducing the risk of localized concrete crushing."

"Perfobond rib connectors rely on the shear strength of the 'concrete dowel' formed within the plate openings."

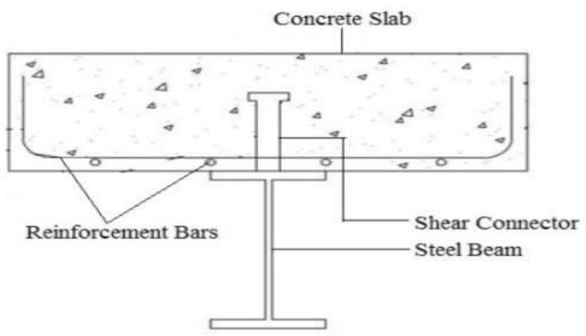

FIG NO 1 steel concrete composite beam

IV METHODOLOGY

The research follows a based approach to evaluate and compare the structural performance of four different shear connectors: Headed Studs, Channel Connectors, Angle Connectors, and Perfobond Ribs.

1. Geometric Modeling

The 3D models of the composite sections are developed using ANSYS DesignModeler or SpaceClaim.

I-Beam: A standard structural steel section (e.g., ISMB or custom dimensions).

Concrete Slab: A rectangular block representing the bridge deck.

Connectors: Four distinct models are created:

Headed Studs: Cylindrical shank with a circular head.

Channel Connector: C-section welded transversely.

Angle Connector: L-section welded to the flange.

Perfobond Rib: Steel plate with circular openings (perforations).

2. Meshing and Convergence (Mesh)

A high-quality mesh is critical for accurate FEA results.

Sizing: A fine mesh is applied to the shear connectors and the surrounding concrete to capture high-stress gradients.

Element Type: 3D Solid elements (Hexahedral or Tetrahedral) are used for the entire assembly.

Convergence: A mesh independence study is performed to ensure that the results are not affected by the size of the elements.

3. Contacts and Boundary Conditions

Contacts: Bonded Contact: Established between the base of the connectors and the steel I-beam (simulating a perfect weld).

Frictional Contact: Applied at the interface between the steel flange and the concrete slab with a friction coefficient (typically \mu = 0.45).

Boundary Conditions:

One end of the beam is typically fixed, while the other allows for longitudinal deformation to simulate a push-out test or a simply supported span.

Loading: A vertical or longitudinal shear force is applied incrementally to observe the "Load vs. Slip" behavior.

4. Analysis Settings and Solution

The simulation is solved using Static Structural analysis with "Large Deflection" turned ON to account for the non-linear behavior of materials and contacts.

Newton-Raphson method is used for the convergence of the non-linear iterations.

5. Data Extraction and Comparative Analysis

After the solution, the following parameters are extracted for all four types:

Equivalent (Von-Mises) Stress: To identify the stress concentration in the connectors.

Total Deformation: To check the displacement under maximum load.

Interface Slip: Measuring the relative movement between the steel and concrete.

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Ultimate Load Capacity: The maximum load reached before the material exceeds its ultimate

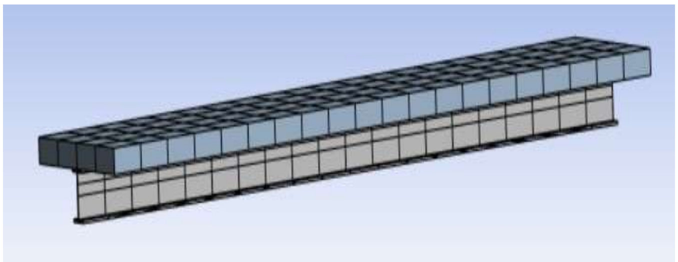

Fig No 2 Composite I Beam Bridge

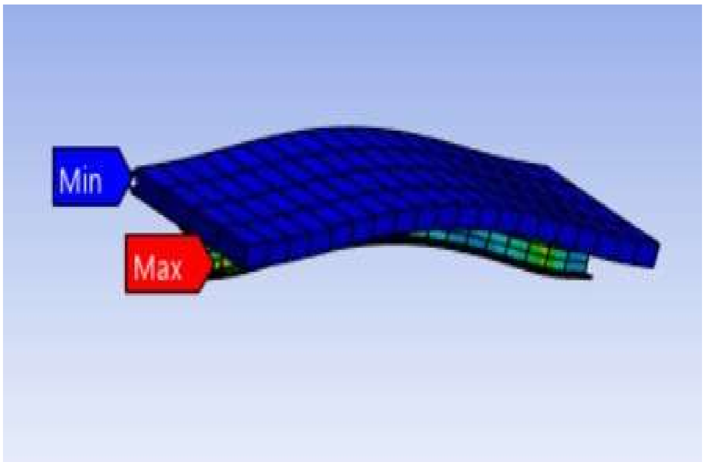

Fig No 3 Equivlent Stress

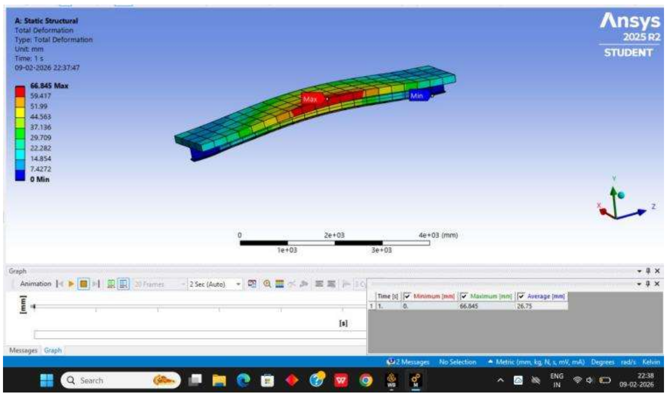

Fig No 4 Deformation

CONNECTORS: FOUR SHEAR CONNECTORS HAVE BEEN CREATED IN ANSYS SPACECLAIM AS PER THE STANDARDS OF EUROCODE 4. THE SIZE OF THE CONCRETE BLOCK HAS BEEN KEPT AS 150 \TIMES 150 \TIMES 150MM

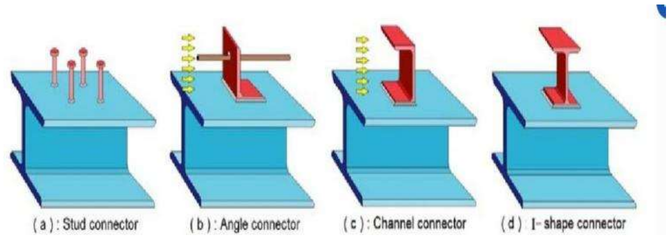

Fig No 5 Shear Connector

Pre-Processing

This stage is about setting up the "digital twin" of your experiment.

Material Definition: In ANSYS Engineering Data, you define the non-linear properties. For concrete, you use the Concrete Damaged Plasticity (CDP) model, and for steel (connectors and I-beam), you use Bilinear Isotropic Hardening.

3.D. Modeling: Using DesignModeler or SpaceClaim, you create the geometry. You must model the I-beam flange, the four types of connectors (Stud, Channel, Angle, Perfobond), and the surrounding concrete slab.

Processing

This is where you define how the parts interact and how the bridge is supported.

Meshing: This is the most critical technical step. apply a Fine Mesh on the connectors and a Coarse Mesh on the outer concrete slab to save computing time.

Bonded: Between the connector and the steel beam (simulating a weld).

Frictional: Between the steel flange and the concrete slab (usually a friction coefficient of 0.45).

Boundary Conditions: You fix the base of the concrete or beam and apply a Displacement-Controlled Load to simulate the push-out test.

Post-Processing

Once the solver finishes, you extract the data to make your comparison.

Load-Slip Curves: You plot the Force applied versus the relative displacement (slip) between the beam and slab. This tells you which connector is the "stiffest."

Failure Modes: You check the Equivalent Plastic Strain to see if the connector sheared off or if the concrete crushed first.

Stress Contours: Identifying the Von-Mises Stress concentrations to see where the design might fail.Nonlinear concrete setupthe cdp model in ansys requires specific parameters to define how concrete behaves under tension (cracking) and compression (crushing/plasticity).

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Ex for headed stud desgin with molded.

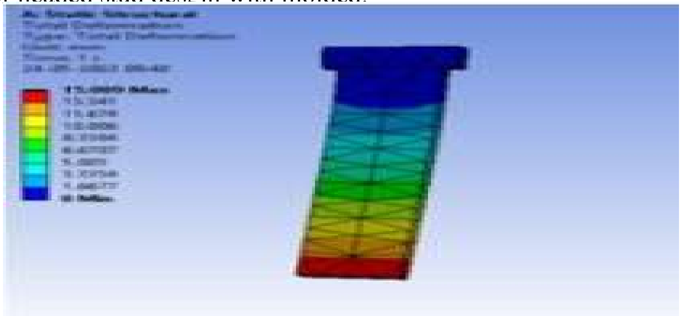


FIG NO 5 HEADED STUD DEFORMATION

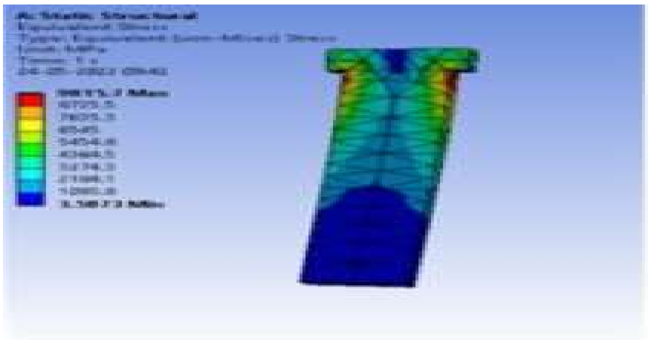


FIG NO 6 HEADED STUD EQUILVELNT STRESS

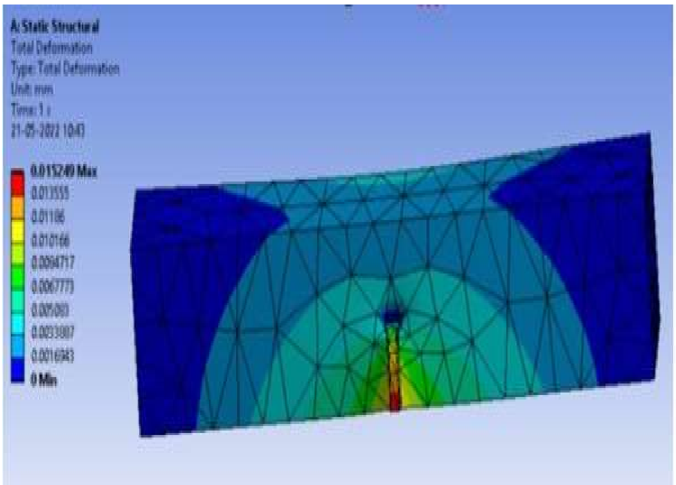
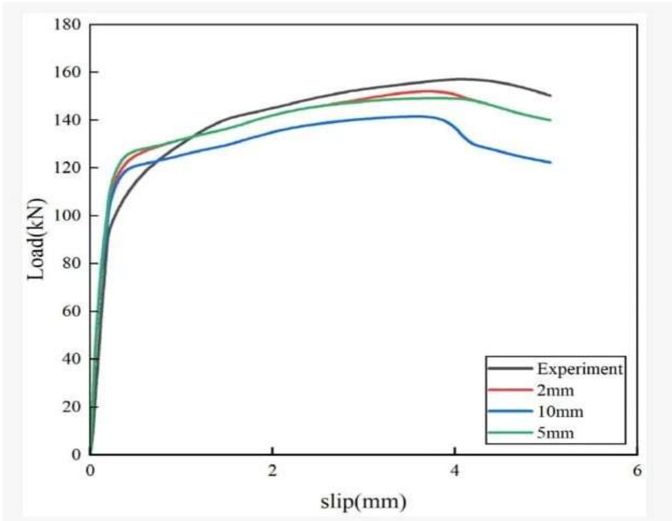


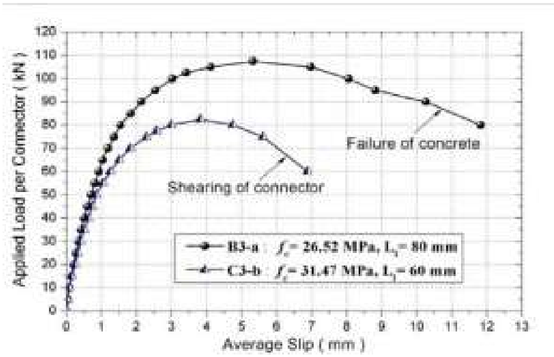
FIG NO 7 COMPOSITE I BEAM BRIDGE HEAHE STUD DEFORMATION DIAGRAM

V RESULTS AND DISCUSSION



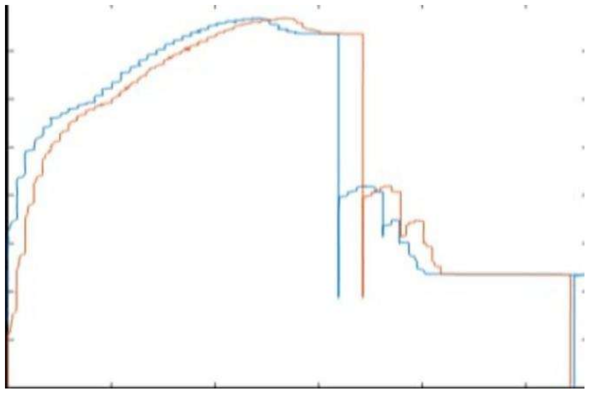
HEADED SHEAR STUD GRAPH

High stress concentration at the base of the stud they proviede excellent multi-directional shear resistance but allow for more “slip”comparded to other shear



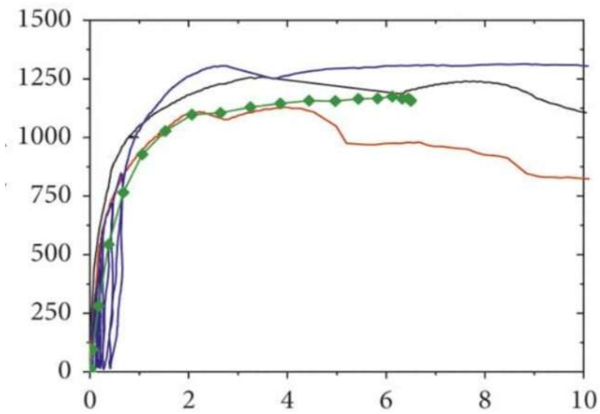
CHANNEL SHEAR CONNECTOR GRAPH

The larger surfacec area facing the shear flow,the initial stifness is much higher than studs.however the concrete in front of the channel web often reaches is crushing limit earlier in the simulation



ANGLE SHEAR CONNECTORS GRAPH

The orientation matters significantly . if the angles is placed toe - forward it behaves differently than heel-forward shows that angle provided a middle ground between the ductility of a stud and the stifness of a channel .



PERFOBOND RIB SHEAR CONNECTOR GRAPH

This is often the superior in high - low seniners by modeling the concrete filing the circular holes of the rib ,ansys demotrates that the shear transfer through the concrete cores.

VI CONCLUSION

Based on the finite element method (FEM) conducted in ansys it is concluded that Channel Connectors provide the highest shear resistance and structural stiffness among the four types. While Headed Studs offer superior ductility and ease of installation, the Channel and Perfobond Rib connectors significantly reduce the interface slip between the steel I-beam and the concrete slab. Therefore, for bridge structures subjected to heavy moving loads, Channel Connectors are recommended as the most efficient option due to their high load-bearing capacity and lower stress concentration at the weld interface."

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