

Behavior of Shear Connectors in Composite Structures

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Abstract: This study investigates the effect of concrete slab thickness on the behavior of headed shear studs in composite structures. Experimental tests were conducted using single stud connectors embedded in concrete slabs of 150 mm and 200 mm thickness. The results indicate that the shear resistance of the study is primarily governed by its deformation and failure, rather than concrete crushing. Load-slip behavior analysis revealed a nearly linear, flexible response up to the ultimate load, with failure occurring at the base of the stud shank before the concrete reached its maximum stress capacity. The ultimate load capacity for the 150 mm thick slab was slightly higher than that of the 200 mm thick slab, suggesting that increasing the concrete cover beyond 50 mm has minimal impact on stud performance. The findings suggest that a 50 mm clear cover is an optimal and economical choice, as increasing slab thickness does not significantly enhance stud behavior but substantially raises material costs.

Keywords: Shear stud, headed stud, composite structures, concrete slab thickness, load-slip behavior, stud failure, stud shank deformation, slab cover, composite connections, cost efficiency.

1. INTRODUCTION

Composite construction, which integrates steel and concrete, has become a more efficient and standardized method of building, gaining widespread acceptance, particularly in developing countries. This construction approach is replacing traditional reinforced concrete due to its numerous benefits. While still emerging in India, this method is gaining ground. Despite India being the third-largest steel producer globally, its per capita consumption remains significantly lower, at 50 kg, compared to the global average of 170 kg. Notable examples of composite construction in India include the Sardar Vallabhbhai Patel Flyover in Mumbai, the Vidyasagar Setu cable-stayed bridge over the Hooghly River, the Dhola Sadhiya Bridge across the Brahmaputra, and the canopy at Kolkata Airport.

One of the key advantages of steel-concrete composite construction is its simplicity, lightness, and ease of implementation, making it a superior alternative to reinforced concrete. This method combines the strengths of both materials to create more efficient structures, facilitating the construction of high-rise buildings, large industrial complexes, and long-span bridges.

In composite construction, concrete slabs are connected longitudinally to steel beams using shear connectors. These connectors prevent slip between the components and ensure that the concrete slab remains securely attached to the steel beam, enhancing the overall efficiency and cost-effectiveness of the structure. Shear connectors, which are welded to the steel beam's top flange, resist separation forces and are crucial in developing composite action. The design and properties of these connectors are key factors influencing the performance of composite slabs.

Shear connectors come in various types, such as adhesive and mechanical, with mechanical connectors being the most commonly used. Many of these connectors are patented by manufacturers and are outlined in various building codes. The Indian standard IS:11384-1985 (Reaffirmed 2003) specifies five types of connectors: 1) Headed studs, 2) Bar connectors, 3) Channel connectors, 4) Tee connectors, and 5) Helical connectors. Additionally, IRC:22-2015, “Standard Specifications and Code of Practice for Road Bridges,” outlines specifications for shear and channel connectors. Among these, headed stud shear connectors are the most widely used, comprising almost 90% of total connectors. They are easy to install, require minimal labor, and are cost-effective when used in large quantities. Furthermore, these connectors exhibit superior shear capacity and ductility compared to other types, making them a significant area of focus in research. Most of the design tests and guidelines for composite construction are based on the performance of these connectors.

The concept of composite construction dates back to ancient times when early humans combined bamboo straws with mud and lime to build huts. Over time, this evolved into steel-concrete composite construction. In the early 20th century, engineers in the US began incorporating lightweight ‘I’ sections into concrete to improve structural strength. Pioneers like Josef Melan and Julius Kahn patented early composite actions, leading to the integration of steel and concrete into unified structural systems using connectors. Initially, connectors were made from materials such as steel bars, hoops, and plates, but these evolved into more advanced mechanical shear connectors, which became dominant.

2. REVIEW OF LITERATURE

Joseph Melan (Late 19th Century): Joseph Melan, an Austrian engineer, pioneered the use of steel reinforcements embedded within concrete to enhance structural strength. His work laid the foundation for modern composite construction methods.

Julius Kahn (1903): Julius Kahn patented the concept of composite materials by inserting metallic reinforcements into concrete. His innovations played a crucial role in the development of reinforced concrete structures.

Scott (1925): Scott derived empirical formulas for determining the ultimate flexural moment capacity of steel beams encased in concrete. His studies contributed to understanding the load-bearing interactions between steel and concrete.

Scott & Caughy (1929): They investigated the impact of different sequences of steel and concrete arrangement on load-carrying capacity, proposing the use of mechanical shear connectors to prevent longitudinal slipping.

Viest (1950s-1960s): Viest was among the first to analyze stud connectors, conducting experiments on shear connectors with different sizes and spacings. His studies laid the groundwork for modern shear connector design in composite beams.

Driscoll & Slutter (1965): They established the relationship between concrete strength and the resistance of shear studs, helping define the inelastic behavior of composite beams and shear connectors.

Amar Prakash et al. (2012): Prakash focused on the confined concrete strength around studs, proving that reinforcement confinement significantly enhances splitting resistance and load-bearing capacity.

3. MATERIALS

Steel Plate

A flat steel plate with dimensions of 1220mm × 254mm × 16mm was used in this study. The 16mm thickness was selected based on Goble's (1968) recommendation that the full static strength of the system can only be achieved if the ratio of the stud diameter to the flange thickness is less than 2.70. In this case, the ratio is 1.1875. The steel flange width chosen is 254mm, which closely aligns with the EC-4 recommendation of 260mm.

Headed Shear Stud

The headed shear studs used in this study had a 19mm shank diameter, a height of 100mm, a head diameter of 30mm, and a head height of 10mm. The 19mm diameter was chosen for its widespread use and ease of installation, which enhances fabrication efficiency. These shear connectors exhibit ductile behavior at the interface between the concrete slab and the steel plate, playing a crucial role in transferring shear forces and preventing vertical separation of the slab from the beam. A coupon test was conducted to determine the yield and ultimate stresses of the shear studs, which were found to be 225.73 N/mm² and 564.33 N/mm², respectively.

4. RESULTS AND DISCUSSION

4.1 Effect of Concrete Slab Thickness on Stud Behavior

A 200 mm thick slab was selected for the tests based on the setup used by Topkaya et al. (2004). This thickness was chosen to align with the current instrumentation and measurement methods.

4.2 Behavior of Stud Connector with 200 mm Concrete Thickness

For the specimen TS1, a single stud was placed in the slab, and the shear load resistance initially came from the deformation of the stud shank. As the load increased, the load was transferred to the concrete through bearing. However, upon further loading, the stud failed by fracturing at the base of the shank, indicating that the stud failed before the concrete reached its maximum stress capacity.

By examining the load-slip relationship of TS1, a nearly linear curve with flexible behavior was observed up to the specimen's ultimate state. The ultimate capacity was reached at a slip of 2.82 mm, with the load gradually increasing to its maximum value of 82 kN at this slip. Therefore, the experimental ultimate load obtained was 82 kN, with the corresponding design value being 67% of the experimental failure load. This design value closely matches the codal value of 57 kN as per IS 11384-1985. Additionally, the calculated compressive resistance provided by the concrete was 86.10 kN, which is higher than the 82 kN ultimate load. Consequently, the stud failed before the concrete, breaking away from the steel plate just above the gun welding point.

4.3 Behavior of Single Stud Connector with 150 mm Concrete Thickness

For the single stud specimen TS2, with a concrete slab thickness of 150 mm, the load-carrying capacity was 83 kN. No cracks were observed in the concrete, and the stud failed by yielding. The maximum slip observed was 2.80 mm. The failure occurred in the stud shank, with no concrete failure, indicating that the stud reached its yield point before the concrete reached its maximum stress. The stud bent and fractured at the bottom of the shank.

5. CONCLUSION

The study evaluated the influence of concrete slab thickness on the behavior of headed shear studs through experimental testing. The results indicate that the primary mode of failure was stud fracture at the base of the shank, with no significant contribution from concrete failure. A comparison between 150 mm and 200 mm thick slabs revealed that slab thickness had minimal impact on stud load capacity, with the 150 mm slab even exhibiting a slightly higher capacity. Load-slip behavior remained consistent across both cases, demonstrating

that increasing the concrete cover does not enhance stud performance. Consequently, a 50 mm clear cover is recommended as the most efficient and economical choice for composite slab applications, balancing performance and material cost.

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