Experimental Investigation of the Structural Performance of Inclined Headed Shear Stud in Steel-Concrete Composite Construction

By

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Dedication

By the name of Allah, I want to dedicate this project to my amazing family for infinitely supportive during the study. It was a long journey indeed to achieve this degree. Only for this M.Engg degree, job transfer occurred from a big urea fertilizer project namely GPUFP, Polash, Narsingdhi to CUFL, Anwara, Chattogram . I had only two options, job without study or transfer if study, but suddenly the transfer was done unexpectedly. During the project job time, it was so tough to continue the class physically on every week at a distance of approximately 700km (up-down). That time my all the family members support me to complete this degree without hesitation, specially to my superior wife Marium Akter Smrity and my younger brother Md. Jahangir Hossain support me mentally every time on each tough situation.

Declaration by the Supervisor

This is to certify that Md. Seragul Islam has carried out this research work under my supervision, and that he has fulfilled the relevant Academic Ordinance of the Chittagong University of Engineering and Technology, so that he is qualified to submit the following Thesis in the application for the degree of MASTER of ENGINEERING in Earthquake Engineering. Furthermore, the Thesis complies with the PLAGIARISM and ACADEMIC INTEGRITY regulation of CUET.

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Abstract

In the building industry, steel-concrete composite constructions are becoming more important and popular for sustainable construction. A shear connector is used in steel-concrete composite structures to produce the full composite action between the two materials concrete and steel. The transverse shear that develops at the steel-concrete interface is transferred by the shear connector. The most popular kind of shear connector is headed shear stud, which is typically welded perpendicular to the steel beam's flange surface at a zero angle to the normal of the beam flanges as per current design standards including BS5400, Eurocode 4, CSA S6-14, BNBC-2020, AASHTO LRFD etc. In this study the structural performance of inclined headed shear stud in steel-concrete composite construction has been attempted to be investigated experimentally. 08(eight) test specimen were made at different inclination (0,15,30,45) degree using headed shear stud for investigating of their structural performance. The ultimate shear resistance of the 15, 30, and 45-degree inclined headed shear stud specimen is found to be reduced by 23.38%, 37.57%, and 50.45%, respectively, for inclinations along the direction of loading, in comparison to the perpendicularly oriented headed shear stud. The 15-degree, 30-degree and 45-degree inclined headed shear studs showed ductile behaviour with maximum slip values of 17.58 mm, 19.95mm and 16.29 mm; respectively will above the limiting value of 6 mm as suggested by BS5400 for ductile behaviour. Considering the shear resistance capacity, perpendicularly oriented shear stud is found better around 95.31 KN as compared to inclined oriented shear connector. Considering the ductility, inclined headed shear stud showed be their performance with the maximum slip of 19.95mm for 30º inclination.

বিমূর্ত

ইমারাত শিল্পে, টেকসই নির্মাণে ষ্টীল-কনক্রিট কম্পোজিট কাঠামো দিন দিন গুরুত্বপূর্ণ এবং জনপ্রিয় হয়ে উঠছে। কম্পোজিট কাঠামোতে কনক্রিট এবং ষ্টীলের মধ্যে সম্পূর্ণ কম্পোজিট ক্রিয়া তৈরি করার জন্য শিয়ার কানেক্টর ব্যবহার করা হয় । শিয়ার কানেক্টর কনক্রিট এবং ষ্টীলের সংযোগস্থলে উৎপন্ন হওয়া শিয়ার ফোর্সকে স্থানান্তর করে থাকে । শিয়ার কানেক্টরের সবচেয়ে জনপ্রিয় ধরন হ'ল হেডেড শিয়ার স্টাড, যা সাধারণত স্টীল বিমের ফ্ল্যাঞ্জ পৃষ্ঠের সাথে স্বাভাবিকভাবে শূন্য কোণে উলম্বভাবে ওয়েল্ডিং করে বর্তমান ডিজাইন স্ট্যান্ডার্ড যেমন বিএস৫৪০০,ইউরোকোড ৪, সিএসএ এস৪-১৪, বিএনবিসি-২০২০ এবং এস্টো এলআরএফডি অনুযায়ী লাগানো হয়। এই গবেষণায়, ইস্পাত-কংক্রিট যৌগিক নির্মাণে কৌণিকভাবে স্থাপনকৃত হেডেড শিয়ার স্টাডের কাঠামোগত কার্যকারিতা পরীক্ষামূলকভাবে তদন্ত করার চেষ্টা করা হয়েছে। ০৮ (আট)টি পরীক্ষামূলক নমুনায় হেডেড শিয়ার স্টাড ব্যবহার করে (০,১৫,৩০,৪৫) ডিগ্রিতে তৈরি করে তাদের কাঠামোগত কার্যকারিতা পরীক্ষা করা হয়েছে । এটি দেখা গিয়েছে যে, উলম্বভাবে অবস্থানরত শিয়ার স্টাডের শিয়ার প্রতিরোধ ক্ষমতার সাপেক্ষে ১৫, ৩০ এবং ৪৫-ডিগ্রিতে অবস্থানরত হেডেড শিয়ার স্টাডের শিয়ার প্রতিরোধ ক্ষমতা যথাক্রমে ২৩.৩৮%,৩৭.৫৭%,এবং ৫০.৪৫% হ্রাস পেয়েছে । ১৫-ডিগ্রী, ৩০-ডিগ্রী, ৪৫-ডিগ্রী হেডেড শিয়ার স্টাডের সর্বাধিক স্লিপ মান এসেছে যথাক্রমে ১৭.৫৮ মিমি, ১৯.৯৫ মিমি এবং ১৬.২৫ মিমি, যা নমনীয় আচরণের ক্ষেত্রে বিএস৫৪০০ দ্বারা প্রস্তাবিত সর্বনিম্ন মানদণ্ড ৬মিমি অপেক্ষা বেশী। শিয়ার রেজিস্ট্যান্স ক্যাপাসিটি বিবেচনা করলে, উলম্বভাবে অবস্থানরত শিয়ার স্টাড কৌণিকভাবে অবস্থানরত শিয়ার স্টাডের তুলনায় ভালো যেখানে সর্বোচ্চ চূড়ান্ত শিয়ার রেজিস্ট্যান্স পাওয়া যায় ৯৫.৩১ কিলোনিউটন। নমনীয়তা বিবেচনা করলে, ৩০-ডিগ্রী বাঁকে অবস্থারত হেডেড শিয়ার স্টাড সর্বাধিক ১৯.৯৫ মিমি স্লিপ সহ তাদের কর্মক্ষমতা দেখিয়েছে।

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Nomenclature

Symbol	Meaning	Unit	Section
Q_n	Nominal Shear Strength	KN	2.7.1
A_{Sc}	Shear connector sectional area	mm^2	2.7.1
Ec	Concrete modulus of Elasticity	MPa	2.7.1
F_u	Minimal tension capacity of connector	MPa	2.7.1
R_g	Group Effect Factor	--	2.7.1
R_p	Position Effect Factor	--	2.7.1
w_c	Unit Weight of Concrete	Kg/m^3	2.7.1
t_f	Flanges Depth	mm	2.7.1
t_w	Web Depth	mm	2.7.1
L_c	Length of connector	mm	2.7.1
f'_c	Compressive Strength of Concrete	MPa	2.7.2
q_r	Ultimate shear resistance connector	N	2.7.3
Q_{sc}	Shear connection resistance factor	--	2.7.3
h	Stud's Hight	mm	2.7.3
d	Connector diameter	mm	2.7.3
P_{rd}	Shear Resistance	KN	2.7.4
Yv	Partial Safety Factor for Shear Resistance	--	2.7.4
n	Total number of anchors in the group	--	2.7.4
A_{ss}	Stud Shank Cross Sectional Area	mm^2	2.7.5
d_{ss}	Shear Stud Diameter	mm^2	2.7.5
h_{ss}	Shear Connector Height Above the Flange Surface	mm	2.7.5
f_{sud}	Design tensile Strength of Stud	MPa	2.7.5
f_{suk}	Characteristics tensile strength of stud	MPa	2.7.5
P_n	Nominal Shear Strength of One headed Stud	KN	2.7.10
A_{Sc}	Headed Shear Stud's Area	mm^2	2.7.10
Ecm	Concrete modulus of Elasticity	MPa	2.7.10
F_u	Specified Nominal tensile capacity of connector	MPa	2.7.10
b	Angle length	mm	2.7.11

h	Width of the Angle's Upper Leg	mm	2.7.11
f_{ck}	Cylinder’s Compressive Robustness	MPa	2.7.11
Yv	Concrete’s Partially secure aspect, taken as 1.25.	--	2.7.11

Acronyms and Abbreviations

BNBC	Bangladesh National Building Code
AASHTO	American Association of State Highway and Transportation Officials
CSA	Canadian Standard Association
AISC	American Institute of Steel Construction
EC4	Eurocode-4
ANSYS	Analysis System Software
RCC	Reinforced Cement Concrete
FEM	Finite Element Method
HSS	Headed Shear Stud
ASCE	American Society of Civil Engineers
JSCE	Japan Society of Civil Engineers
ACI	American Concrete Institute
CEN	Commission for European Normalization
LRFD	Load and Resistance Factor Design
BS	British Standard
UTM	Universal Testing Machine
CUET	Chittagong University of Engineering and Technology

Chapter 1: INTRODUCTION

1.1 BACKGROUND

Composite materials are being popular day by day due to its high strength, aesthetics, partial re-useable & environmental sustainability. In civil engineering construction field, the most common form of composite material is steel-Concrete composite construction. It's become the most prevailing and broadly used construction system in current time. Concrete as a material is much weak in tension but perform well in compression. Conversely, structural steel has a very high tensile strength, even with minimal usage. High compressive strength of concrete and high tensile strength of steel together create composite structures. Structures like multi-story structures and bridges are frequently made of steel and concrete that are physically connected together with the right bonding to produce a very rigid, effective, and efficient unit. The interaction and connection between the steel and concrete contact primarily determine the durability or performance of the composite part. Generally, I-shaped steel beams or girders are normally attached with deck slab of composite construction by mechanical shear connector positioned at normal, or perpendicular, to the flange surface. There are unique kinds of connectors like, angle shear stud, channel shear stud, V-shaped shear stud, Pipe shear stud, headed shear stud, deformed rebar cut L-shaped shear connector etc. that are usually utilized in concrete-steel hybrid construction. The main operation of these shear stud is to allow the joint behavior of beam with slab, to withstand elongated shear forces throughout the steel-concrete contact point to prevent concrete from getting divided from the steel beam.

A significance contract of research has been done to better understand how steel-concrete composite beams behave. (Viest, 1960) [1] and (Johnson, 1970) [2] published reviews of studies conducted on composite beams through 1920 to 1958 and 1960 to 1970, correspondingly. In the United States, an overview of composite construction was provided by (Moore, 1987) [3]. A lot of text, including (Ritchie and Chien, 1984) [4], (Kulak GL, Green DL, 1990) [5], have provided extensive documentation on ductility characteristics of hybrid beams. Advantages as well disadvantages that of different types shear studs like headed shear connector and perfobond shear connectors were discussed by (Sariati et.al, 2016) [6]. Recently, some new guidelines for beam design of composite frame were added on Canadian standard [7]. Some of these modifications take into account the necessity to include specifications akin to those found in European standards, while others represent the findings of current research conducted in North America. Simply supported beams with compressed concrete are the primary focusing guidelines of the Canadian standard for the design of composite beams. Push-out experiment results for full-size sample/specimen with channel shear stud were published via Viest IM, 1951 [8]. Their principal objective was comprehending the characteristics of channel shear connections as well assess whether or not channels might be used as shear connectors. They evaluated 4 full-size beams and 43 push-out specimens as part of their research strategy. The majority of the examples had channel connectors that were 102 mm high. Three examples featured 3-inch Hight channel connections, whereas 2 samples had 5-inch channel. As evidenced by the test outcomes, a channel connector's functionality varies depend on the depth of flange and web as well the length of channel. No discernible impact was seen on the channel shear connector's behavior by the channel connector's position, or whether the stress was applied on the channel's front or rear. Experiment findings on tiny push-out samples with channel shear connections were published by (Hosain, M. U., & Pashan, A., 2006) [9]. His experiments' findings demonstrated that the channel shear connections' load carrying capacity was significantly higher and they provided a respectable level of flexibility when compared to the headed stud type flexible connectors. A better option would be a channel connector oriented vertically, with one flange resting on top of the other flange embedded in the concrete. This would eliminate the necessity of hasp by offering an enhanced pliability of shear connection and ability to resist getting up. According to Hawkins as well Mitchell (1984) [10], shear connections that connect the steel section and slab of concrete are thought to be able to deliver the necessary combined activity in bending. Furthermore, shear connections utilized to spread considerable sideways inertia load across the main sideway force-bearing components of the construction. The addition of shear studs between the deck and beam results in bond stresses that are significantly higher than chemical bond stresses, which causes the reaction to become ductile. In contrast, the response becomes brittle in the absence of these mechanical devices (Daniels, B. J., and Michel Crisinel, 1993) [11]. Fig. 1.1 shows Slip behavior in contrast to shear resistance according to (Daniels, B. J., and Michel Crisinel, 1993) [11] for shear stud.

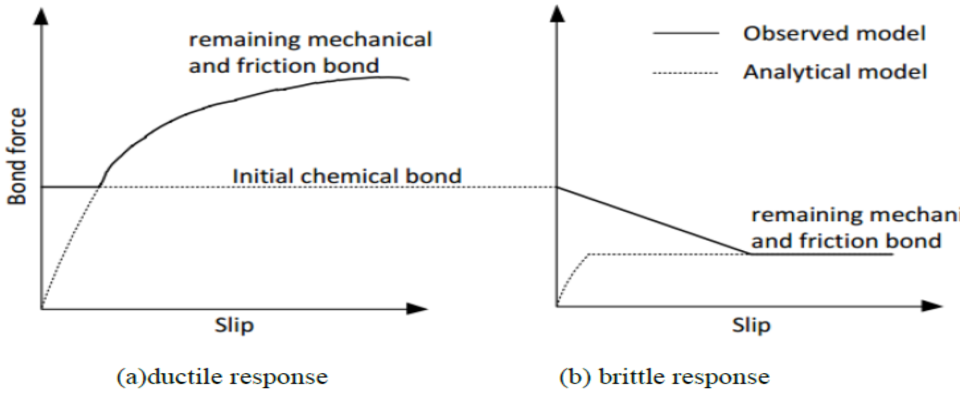


Fig. 1.1. Slip behaviour in contrast to shear resistance (Daniels, B. J., and Michel Crisinel, 1993) [11].

Several studies have investigated how stud connectors behave when it comes to load transfer in solid slab applications. Lungershausen (1988) [12] has developed one of the most illustrated prototypes to elucidate the stud's load transmission in stiff slate programs whereas 4 different elements are the total ability of connector as shown in Fig. 1.2.

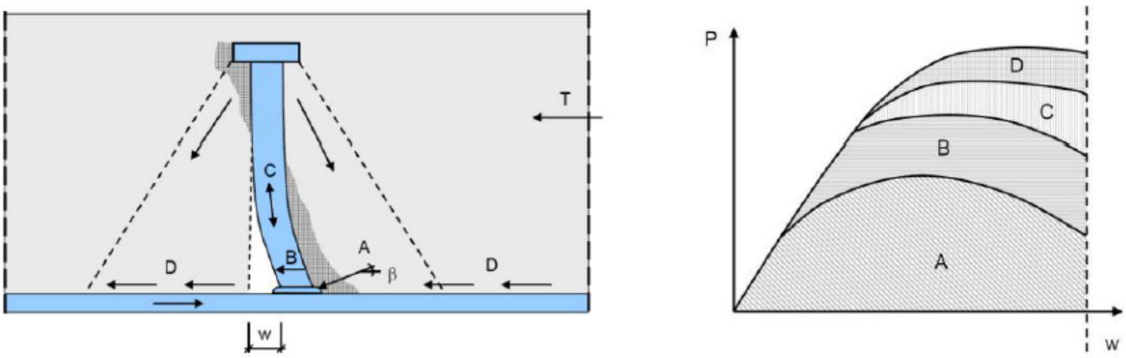


Fig. 1.2 Headed stud weight transmission mechanism in slab [12].

First, most of the longitudinal shear stress is transmitted nearby concrete (A) near the connector foot, wherein the majority of it responds within the welding collars. Shear pressures eventually redistribute to higher points up the stud's shank due to the localized crushing of the concrete at the stud's bottom caused by the multiaxial large carrying stresses in the concrete (B). The stud's shank experiences bending and tensile pressures since its top is inserted into concrete as a result it cannot flex, but the base of connector is grown within the concrete below the stud head so as to counteract these tensile stresses. After apply the load to the specimens, stud experiences shear forces, vertical force, and momentary bending and its shank becomes stretched and flat at the root part. This simultaneous failure of shear and tension occurs just over the weld collar, ultimately resulting this to failure of shear connector (Xue, W., Ding, M., 2008) [13]. When the concrete slab slides among the metal girder and the floor material, the stud spins and the concrete surrounding its end begins to distort. Simultaneously, the concrete surrounding the other edge on the stud restricts the stud's movement. As a result, as the force applied to the specimen expands, it also increases the force which the metal girder passes to the connector. According to Bangladesh National Building Code -2020, Section 13.2.1.7, The minimum shear capacity of single shear stud inserted into the stiff concrete is

$$Q_n = 0.5A_{sc}\sqrt{f'_c\, E_C} \leq A_{sc}F_u \tag{1.1}$$

Where, A_{sc}= Shear stud sectional area, mm^2

F_u = Shear stud nominal tensile strength, MPa

1.2 PROBLEM STATEMENT

In steel-concrete composite construction, metal girder is connected mechanically with the slab through using shear stud. Generally, connector is placed perpendicularly to the flange surface of a steel girder. In this study, experimental investigations of the structural performance such as load-slip characteristics, failure mechanism, optimum inclination as well as flexibility characteristics of inclined headed shear stud will be investigated here at different slopes of inclination like 0º,15º,30º,45º. To evaluate these parameters, Universal testing machine is used for each experiment.

1.3 THE GOALS AND PURPOSES OF THE RESEARCH

General objectives of this investigation are the innovative studies for the characteristics of inclined shear connector used as a mechanical connecting device between steel & concrete in composite construction. The particular goals are listed below.

- To Examine the load-slip characteristics of inclined headed shear stud under applied load.
- To ascertain the ultimate shear capacity of different inclined headed shear connector subjected to the load applied parallel to longitudinal axis of the steel beam.
- To investigate failure pattern of different inclined headed shear stud due to the applied load.
- To determine the optimum inclination for the best performance of inclined headed shear stud.

1.4 SCOPE OF THE RESEARCH

The focus of the is on how an innovative kind of inclined headed shear connector behaves and how strong in different slopes conditions i.e. in which degree of inclination is the most strong and effective in hybrid beams connection with solid reinforced concrete slabs. General position of placing the shear key is in perpendicular to the surface of flange of girder. Actually, no significant research is executed previously to see the optimum position i.e. degree of inclination of shear key for the best performance while fix-up it with the girder. In this research, it was planned to examine the optimum degree of inclination of headed shear stud. Also, scrap nut was used in place of traditional shear stud for locally availability in the market. The similar shear stud parameters were followed while choosing the scrap nut from the local market. In this study, total of 8(eight) samples were made with 0º,15º,30º,45º angle respectively. For each inclination of shear key, two samples were tested.

1.5 THESIS OUTLINE

There are five chapters in this report. The study's background, problem statement, scope, aims, objectives, review of literature, experimental program, results, discussion, conclusions etc are presented systematically in this report.

Chapter 1 presents the study background, problem statement, scope, aim and objective of the study.

Chapter 2 provides a brief description of the code requirements for various connector types as well as the literature review of the study.

In the chapter 3 the experimental test program, comprehensive test specimen descriptions, test sample manufacturing, material attributes, setup and test procedures are presented.

In the chapter 5 all the test findings, discussions, as well as compare with the codes are listed.
In chapter 5 concludes overview of the findings of the experimental studies and advice for further research.

Chapter 2: LITERATURE REVIEW

2.1 GENERAL BACKGROUND

Composite frameworks are utilized in many different contexts for the long time. The benefits of composite structural building such as quick construction time, compact vertical floor plans, overall lighter weight, and low structural costs, can make services more affordable for communities. Well-known as an integrated structural element of composite buildings, a steel beam-concrete slab with shear connector exhibits excellent structural performance and economic viability. To combat the threat of natural disasters like earthquakes, cyclones, etc., the building industry requires better ideas. In the event of such natural disasters, the structure's mass is essential to its operational effectiveness. The structure's mass can be greatly decreased by using composite material for hybrid construction. The advantages of composite structures include lightweight design, ease to handling, speedy of construction, convenient transportation, higher strength than traditional reinforced concrete beam slab and contact strength. When composite building is taken into account, it is possible to reduce construction costs, build times, and structural deformation. Shear connectors are used to avoid an upright slab disconnection from the metal beam and produce efficient transfer of longitudinal shear loads when two structural elements are linked at an interfacial stratum. Shear connector accessories could reduce the single T-beam mechanism produced by composite action by removing individual element slide brought on by horizontal inertia forces. As a result, a composite element becomes stiffer and stronger. This maximizes the composite construction's maximum load-bearing capability. Interlocks, also known as shear connectors, seem to be a dependable means of achieving contact strength. Due to the concrete's partial hold on the steel, there may be a slide and initial strain at the contact.

Additionally, incorrect interlocking will result a vertical uplift. Sometimes these issues are lessened by shear connections. Transferring transverse shearing is the primary function of shear connections, which depends on their resilience and the concrete slab's ability to withstand longitudinal cracking brought on by an excessive amount of shear pressures. The push-out experiment is performed to assess the shear connections' capability and load slippage behaviour. To better understand the behaviour of steel-concrete composite beams, a lot of study has been done. Studies on beams made of composite between 1920 through 1958 and 1960 till 1970 have been examined by (Viest Ivan M., 1960) [1] and (Johnson R. Paul. 1970) [2], according to the sequence. Nowadays, shear connectors are the primary subject of research for composite structures. Mechanical shear connectors are being develops since the 1930s to substitute Jointed headed shear studs. These consist of the H or I-shaped, channel, bolted, pipe, L-shaped, crest bond, rigid tee, etc., shear connections. Shear connections were mostly utilized in composite beams prior to the development of profiled metal decking. Nevertheless, because of the existing design guidelines for welded headed shear connectors and the thorough deck welding process, shear stud is the major broadly used and well-liked in the construction sector nowadays. Fig. 2.1. display as an instance of a conventional shear stud that is soldered at the upper flange of the metal girder. This shear connections come in lengths ranging from 50 to 250 mm and diameters varying from 13 to 25 mm.

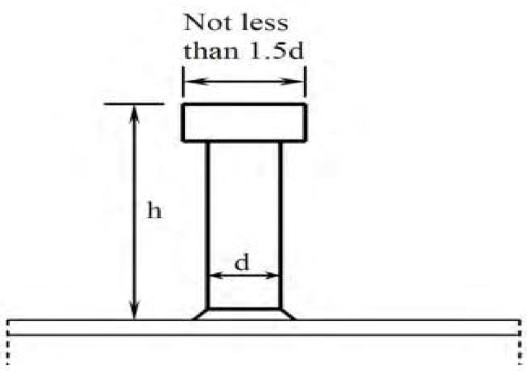
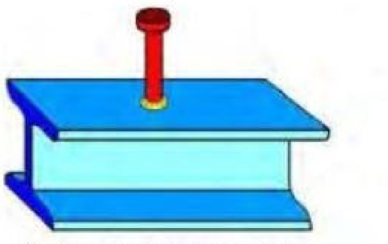
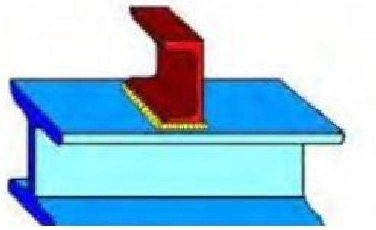


Fig. 2.1. Conventional Headed Shear Stud

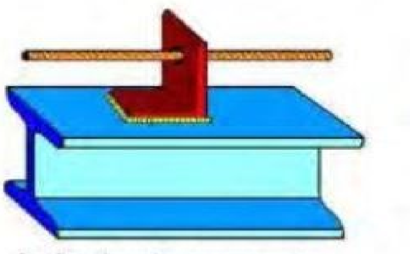
This chapter attempts to give a general overview of several types of shear connections particularly the kind that is typically employed and other options that also feature in compounded constructions, as displayed in Fig. 2.2. A summary and discussion of representative stud connections behaviour were given. Beginning, according to relevant rules of professional regulations, this section assesses the latest methods now employed in the development of concrete shear connections. It offers a summary of the findings that produced the equation which utilized in code of conduct. And lastly, this article summarizes earlier research in order to discuss the latest advancements in shear connections.



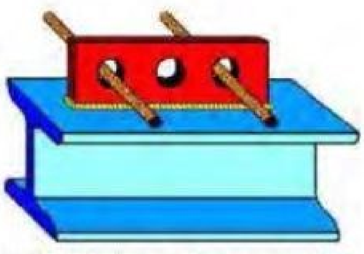
(a) Stud connector



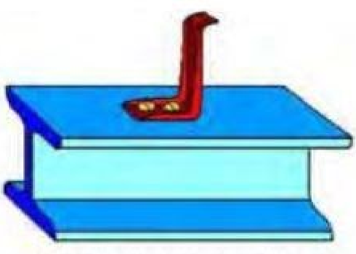
b) Channel



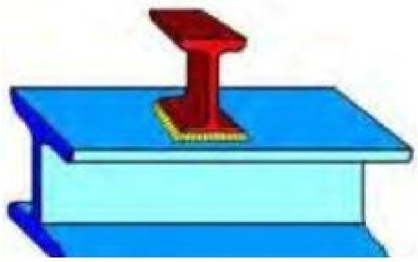
(c) Angle connector



(d) Perfobond



(e) Hilti Connector



(f) I Shaped

Fig. 2.2.(a,b,c,d,e,f). Unique Kinds of Shear Connections (Mazoz, Aida., 2013) [14]

2.2 PRESENT CONDITION OF THE PROBLEM

The investigation looks at the behaviour and failure manner of headed shear connections that have formed into a I shape as shown in Fig. 2.3. to assess its viability and design. However, as inclined headed shear stud at different degree of inclination are the primary topic of this thesis. As of right now, no design code or design guidelines are provided for this connector. Thus, this chapter discusses formula for designing of inclined headed shear connectors that are accessible in several design codes. These design equations may then be utilized to evaluate the shear capacity of headed shear connections. Since, suggested inclined headed shear connection/connector is parallel to headed stud connectors in numerous ways—like, having a multiple width, lengths, strengths, as well as elasticity with respect to the joining and establishing process. This novel kind of shear coupling could be studied using soldered headed stud aggregator.

Fig. 2.3. The Suggested Inclined Headed Shear Stud

2.3 DIFFERENT METHOD OF PUSH OUT TESTING

Push-out experiment frequently employed for examine capacity as well failure mechanism of headed stud connector. Shear stud on both flanges of a steel section embedded in concrete slabs make up an experiment sample. The specimen squeezed vertically until the web of the steel segment breaks. In order to calculate each connector's strength, divide the final load by the total amount of shear connectors (Driscol and Slutter, 1961) [15]. Presumably, the load is dispersed equally throughout the connectors and that it is exclusively transmitted through the connectors from the steel section to the slabs (Viest, 1956) [16]. So as to assess shear strength of helical stud connections, described method was first applied in Switzerland in the 1930s (Davies, 1967) [17]. North American design codes provide a measure of capacity for conventional shear studs. Finding shear resistivity of soldered headed stud connector within compound beams, EC-2004 offers a straightforward process for push-out specimen evaluation together with formulas. Nevertheless, solid concrete slabs with welded shear connectors are intended to use test standards of push-out experiment specified in EC- 4 as displayed in Fig. 2.4. In order to save money and time lieu of a comprehensive composite beam test, this can conduct. Another important component of combined construction is flexibility. Push-out tests may also accustom to assess any shear connector's flexibility; these tests results rely on the ability to quantify movement of steel beam and composite interface.

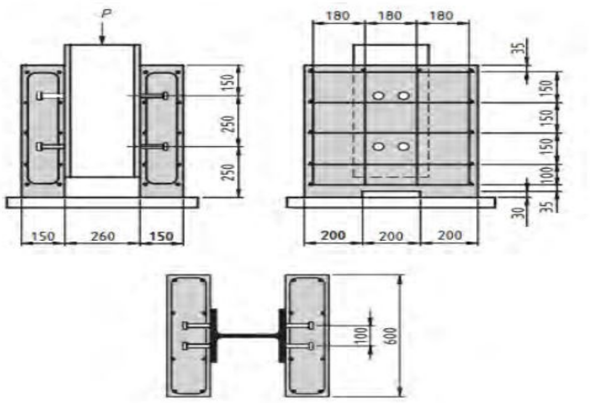


Fig. 2.4. General Eurocode 4 Test Arrangements

The highest amount of movement seen at the distinctive force levels is the slippage capacity, displayed in Fig. 2.5. studs are contemplated flexible if they can tolerate adequate distortion. As per EC-4, if movement/slip reaches 6 mm, the shear connector is deemed ductile. A headed shear connector with a large amount of plastic deformation indicates a very ductile construction. It is said to exhibit fragility and little plastic distortion in the headed stud connections are not able as well pass 6 mm barrier.

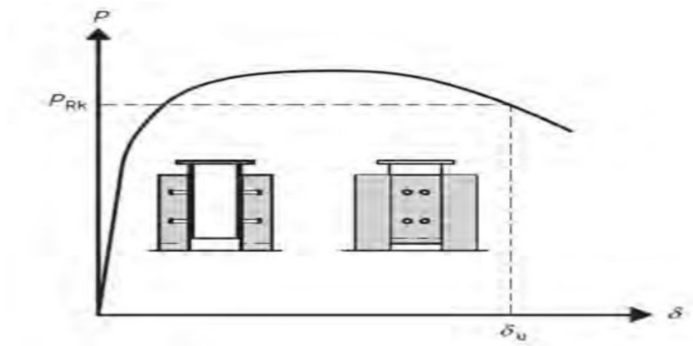


Fig. 2.5. Slip Capacity Computation Using Eurocode 2004

This work examines the durability of angled head shear connector in hybrid construction through experimental means are investigated accordingly BS5400 as displayed in fig. 2.6.

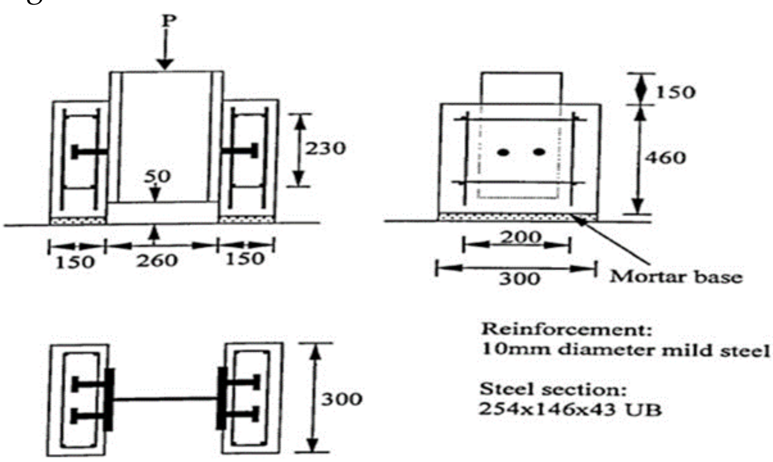


Fig. 2.6. Typical Testing Procedure as Per BS5400

The experimental model will be deemed accurate enough to estimate the shear capacity of shear connections inserted in their respective concrete after adopting the proper material model, mesh sizing, and contact limits criteria. The overall structural performance of headed shear stud including varying slopes will be examined using UTM and varying static loads applied along the steel I-beam's longitudinal axis. Load-slip behaviour, failure pattern & ductility characteristics of different inclined headed shear stud connector will be investigated from the investigated result of UTM machine on the laboratory. An optimization for the slopes of inclination for the best structural performance of inclined headed shear stud key will be proposed considering the overall structural behaviour for the practical uses in the field for sustainable construction with cost efficiency.

2.4 COMPONENT OF COMPOSITE STRUCTURE

Composite structure is the most trending construction nowadays which is made by steel and concrete together. The steel hot rolled H, W or I-shaped beam/girder is the foundation of a steel concrete composite structure. This consists of a steel-jointed, stiff concrete slab that was made in site. Cold formed metal deck, which is supported by a steel I-shaped section, generally employed to cast concrete floor. The concrete floor is maintained linked to the metal beam by the shear connection. To avoid slipping at the point where the concrete slab and steel beam meet, shear connectors transfer horizontal shear forces generated there. In fig. 2.7. various steel-concrete composite structural components are displayed.

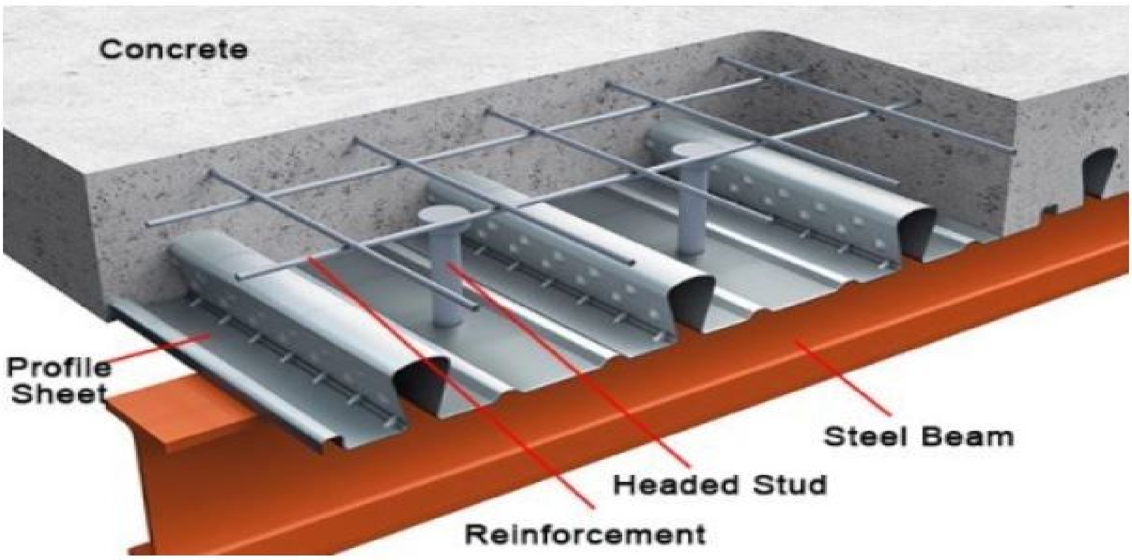


Fig. 2.7. Steel-Concrete Composite Structure's Components

2.5 SHEAR CONNECTOR ADVANTAGES

- Shear studs easily support large loads and provide robust protection against shearing failure in composite structures.
- A very high rate of production is achievable while the structure is being built.
- Simplicity in operation during construction. There is no particular talent required for welding.
- Flexibility in the architectural blueprint.
- Shear connectors can be welded through deck sheets to form a concrete slab.
- Sturdy, enduring, stable, and resistant to earthquakes

2.6 PROFESSIONAL DESIGN CODES: THE STATE OF THE PRACTICE

The capacity of connector is a crucial part in the design of composite structure. Professional standard codes provide the design values and formulae. Currently, the design code only includes the equation and specifications for a small number of shear connector types and headed stud connectors. This part evaluated modern technology for a number of design codes utilizing the accepted and obtained formulas following practical push-out experiments.

2.6.1 CONNECTOR WITH HEADED SHEAR STUD

The headed studs seen in Fig. 2.8. are largely utilized shear connections in industries. In order to stop slabs in composite constructions from moving vertically, they offer steel shanks with an anchorage head that can endure longitudinal shear stresses (Ollgaard et al.) [18]. Typically, installing connector in a pre-makes metal beam requires specialized soldering ingredients. Ideally, the soldering capacity just ideally exceed connector capacity. But when these solders are repeatedly loaded, exhaustion issues typically arise (Lee P.G, 2005) [19], (Deng, W., Xiong, 2019) [20], (Liu Y., Zhang Q., Bao Y., 2019) [21]). Since Viest introduced the headed stud shear connector seven decades ago, stud connectors have been the subject of numerous investigations [22].

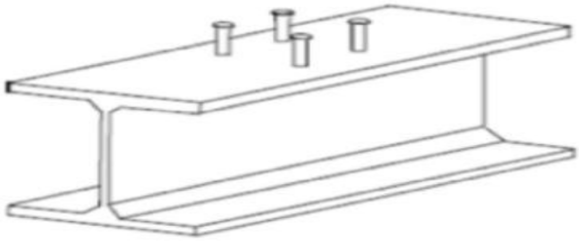


Fig. 2.8. Connector with Headed Shear Stud

In order to show correctly preferred how stud connectors, transfer load in solid slab applications, Langershausen [23] created a model. Four distinct components make up the connector's capacity as displayed in Fig. 2.9. The longitudinal shear tension from the bottom of the stud (A) first reacts with the weld collar when a considerable portion of it reaches the nearby concrete. The concrete crushes near foot of the stud for multiaxial extended bearing tension. Next, shear loads are reorganized upper leg (B) of connector. The connector's bottom can slide in any direction and the connectors shank (C) is subject to bending and tensile loads since the connectors top is immersed in undisturbed solid/concrete and unyielding. At the steel-concrete contact, additional frictional forces (D) are created because tensile stresses are balanced by compression load in concrete below of connector. When the stud shank merges shear-tension failure above the weld collar, the shear connection breaks.

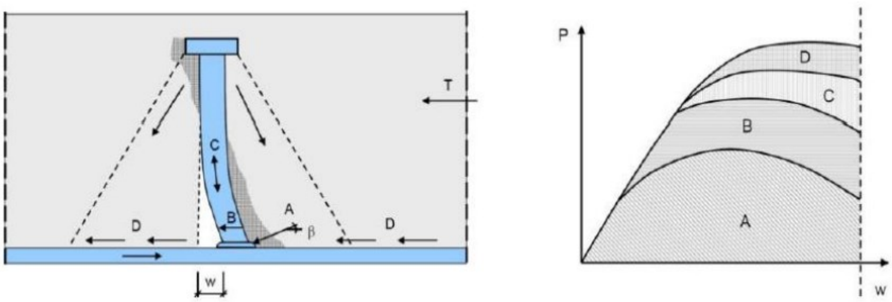
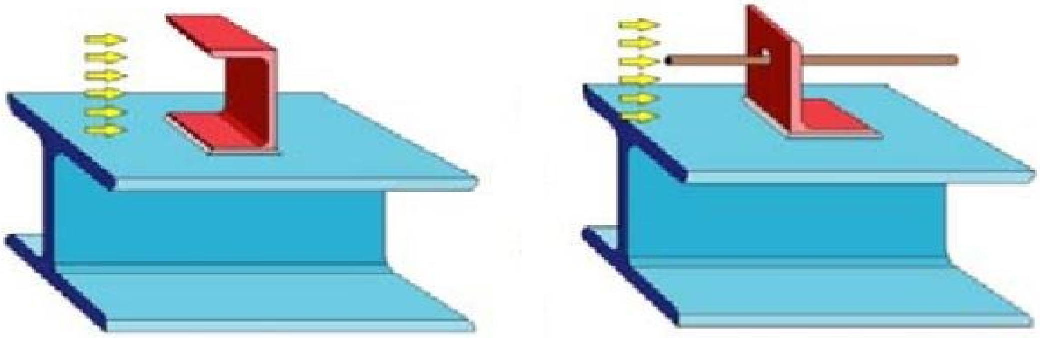


Fig. 2.9. Header stud shear connector load transfer in hard slab according to (Lungershausen, H., 1988) [23]

2.6.2 SHEAR CONNECTORS WITH C-SHAPED ANGLE AND CHANNEL

Fig. 2.10. illustrates the main causes for potential evolution of c-style shear connections that is inadequate strength of headed studs and the difficulties associated with supplying transverse rebar in PBL holes. The established constructability benefits of channel connectors were attributed to their improved reinforcing environment and double the shear capacity of headed connector (Shariati, M., 2011) [6]. There are two types of C-shaped connectors: angle and channel profile. Rajaram published the findings of experiments on push-out static forces on composite structures incorporating shear connector made with angles [24]. This experiment, attitude of conventional and angle connections was compared with the innovative form of channel connection proposed by (Deng et al.) [20]. The test findings showed that the channel connection had a maximum



(a) channel connector (b) angle connector.

Fig. 2.10. Two Type C-Shape Shear Connector

bearing capacity that was about 47.5% higher and an appropriate energy dissipation capability that was approximately 92.1% greater than the T-PBL & angle connector, respectively. New Zealand Heavy Engineering Research Association (HERA), Hicks et al. [25] evaluated the bridge shear connections from the Gisborne region, New Zealand and Hawke's Bay districts, North island, Christchurch and the West Coast locations in 1940. Bridges with welded channels accounted for 72% and 63% of total bridge in Gisborne, Hawke's Bay, Canterbury, and West Coast regions shown in Fig. 2.11. while V-angles were utilized in 18% and 30% of those sections. That being said, shear studs and other connectors are installed on only 3% & 7% of bridge. The Composite Bridge over waterway in

Waipoua's is being utilized as a working model to further develop new design concepts. As part of this research, For the resistivity of welded channel shear connectors, a new design formula has been developed. Moreover, an established method for assessing the flexibility of the soldered channel connection was also formed. Study presents novel approach to assessing beam bending capacity that integrates the recently suggested design formula for channel shear connectors. A new review process that incorporates the new design method has been devised, based on an adaptation of the Bridge manual. The historical bridge that is still standing in New Zealand serves as an example of capability, which increases with decreasing shear connection degree.

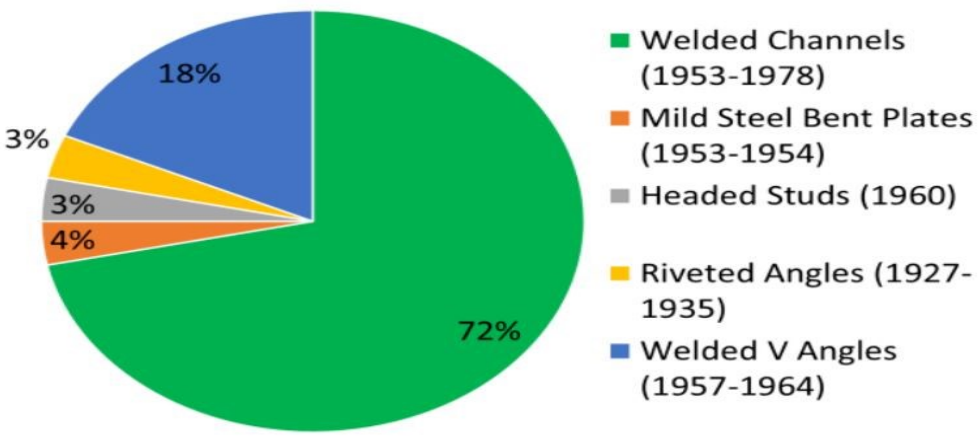
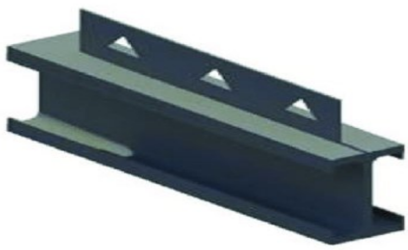


Fig. 2.11. Comparative Statement of Various Kinds of Shear Connection used in Composite Bridge. Hicks et al. [25]

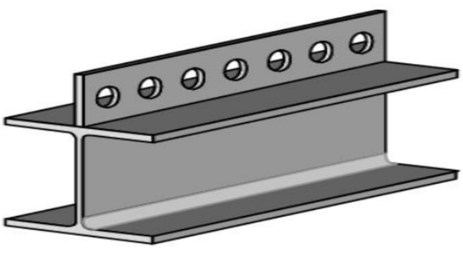
2.6.3 PERFOBOND SHEAR CONNECTIONS WITH RIBS

Perfobond-ribbed (PBL) shear connectors are designed for composite buildings because they are more easily installed and have a better fatigue strength than standard headed studs (Leonhardt F., Andrä W.,) [26], (Oguej., and Hos.,) [27-29]. This connector leiste studs need to utilize steel plates that are rectangular and have circles in them. larger in diameter than the transverse reinforcement, as well as perforating rebars. Steel girder upper flanges are usually welded to PBL plates. Vellasco et al. [30] constructed T-rib perfobond shear connections to transfer forces from rebars to corner, edge, and hogging moment zones of column flanges for composite portal frames as shown in Fig. 2.12a. The T-rib perfobond shear connections web plate, which has one or two rows of two holes as shown in Fig. 2.12b or four holes are displayed in Fig. 2.12c, was built by (Vianna J.C.,) [31]. PBL shear connector that works well with mixed girder arrangements made up of steel and prestressed reinforced cement concrete (RCC) was introduced by Ahn et al. [32]. so as to account for the impact of concrete-dowels, transversal reinforcements within ribs holes, and concrete end bearing effects, shear capacity formulas were developed for both individual and double PBL ribs. (Vianna.,) [33] investigated T-rib connectors under various conditions, like premium concrete, steel-reinforced connections gap, and slab's depth to assess failure mechanism, slippage capacity, and shear resistivity. Design of connections was emphasized by Costa-Neves et al. [34], who also introduced double T-perfobond Fig. 2.12d. The outcomes of their push-out test demonstrated which rib holes with and without transverse reinforcement in connector flange layout can result in resistance improvements of approximately 150%–300%. Rodrigues and Lam [35] measured the ductility, collapse mode, and shear resistance capacity at room temperature and at different elevated temperatures. experimentally explored the functionality of T-blocks, T shear connections, and TPBL in a fire.

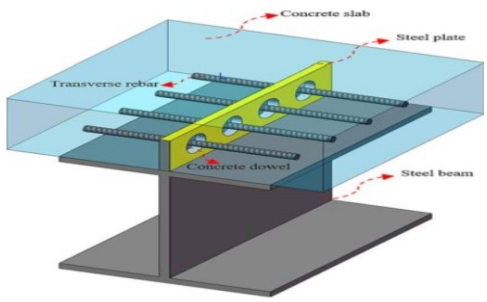


(a) Traingular T-Rib (Vellascoet al. [30]

(b) Two Hole T-rib (Vianna J.C.,) [31]



(c) Perfobond T Rib



(d) Four Hole T-Rib

Fig. 2.12(a,b,c,d). Various Types of Rib Connections

The "Y"-shaped PBL shear connector was formulated by (Kim S.H., Choi K.T.,) [36] as displayed in Fig. 2.13. Ongoing analysis and experimentation research in a static stress (Kim S.H., Choi J.,) [37–39] and periodic loading (Kim S.H., Kim K.S.,) [40–42] has proven the connector's superiority in fatigue and shear resistance.

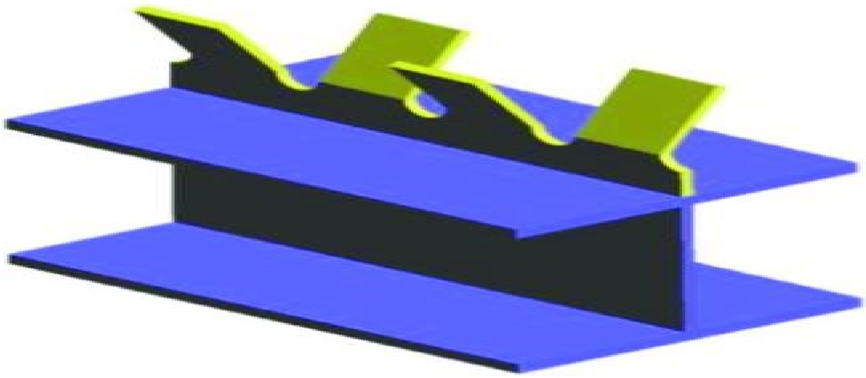
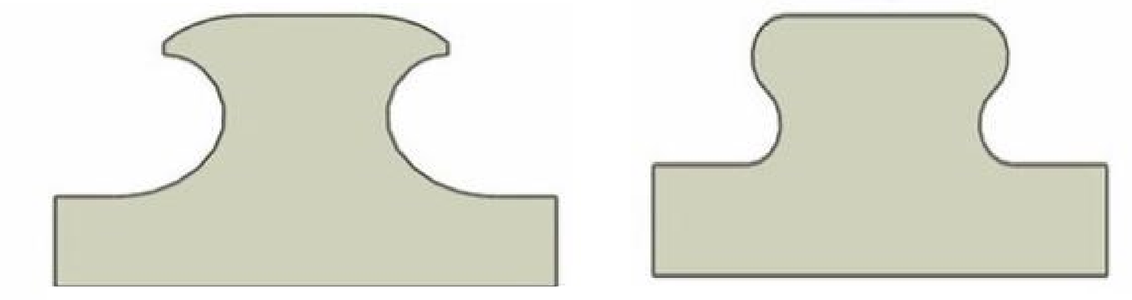


Fig. 2.13. Y form PBL Connector [36]

2.6.4 SHEAR CONNECTOR MADE OF COMPOSITE DOWELS.

Fig. 2.14. shows clothoidal and puzzle combined chock for usage of shear connectors in composite beams were contextually described by Kopp et al. [43]. Based on the data, technical guidelines have been created for manufacturing, construction, ultimate limit states, and structural design principles. According to Seidlet al. [44], the PZ and CL composite dowels' symmetrical shape allows shear stress to be distributed uniformly and in both directions in composite structures. These dowels include radius connectors that are both highly fatigue resistant and robust enough to withstand fatigue cracks. For PZ type continuous shear connections in the building of prefabricated composite beams, Hechleret al. [45] presented a fatigue design strategy in their publication. Modified CL-shaped composite dowels were subjected to a beam test and FE analysis were carried out in addition to Dudziski et al.'s [46] investigation of fatigue cracks and fatigue durability. Shear resistance is employed in comprehensive push-out experiments using periodic loadings, Lorencet al. [47] were able to uncover the load-carrying capacity behavior of PZ (PZ 300/100) shear connections. During testing,

contributing factors such the steel grade, dowel size, and web thickness were examined.



(a) Clothoidal (b) puzzle

Fig. 2.14. Shear connectors made of (a) clothoidal and (b) puzzle-shaped composite dowels (Kopp et al.) [43]

2.6.5 COMBINING OF VARIOUS SHEAR CONNECTOR

Researchers have been Capable of enhance the shear characteristics of composites constructions by combining headed stud and PBL. So as to assess ductility, load-slip behavior, fracture process, and shear capacity utilizing ten test specimens for push-out [20] designed as well evaluated a mix of shear connections with heads comparing individual perfobond rib, displayed in fig. 2.15. Testing shear performance, Gu et al. [48] built a pre-embedded tube, shear pockets, and sleeves for a combination-type perfobond rib shear connection in concrete. Bottom concrete carrying capacity as a result of the shear connector's increased shear resistance. The entire collapse sequence beneath shear force is created, as the mechanical model demonstrated. Shear abandonment, characterized by transverse fractures, was found to be the main mode of failure for combined PBL connections based on test results and the sample.

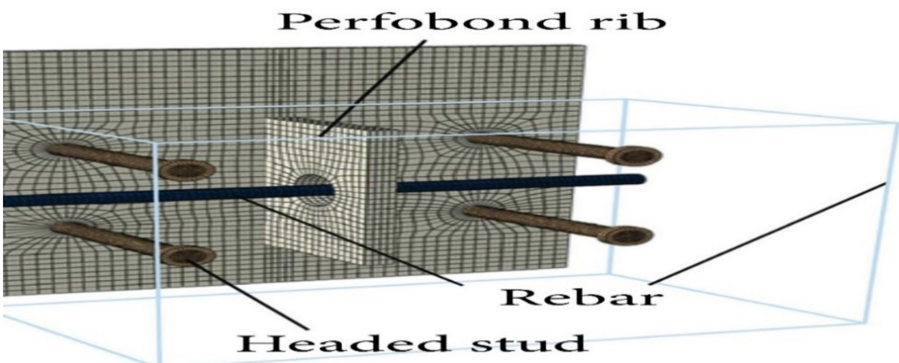


Fig. 2.15. Combination of One Perfobond Rib and Headed Shear Connectors Deng and associates [20]

2.7 SHEAR CONNECTORS DESIGN CODES

The shear connector's design strength is a crucial component in the building of a composite product. Professional standard codes supply the design values and formulae. Only headed stud connections and a few other kinds of shear connectors are currently covered by the equation and the design code's rules. The available codes of practice for various shear connectors are covered in the section that follows.

2.7.1 Bangladesh National Building Code (BNBC)-2020 [49]

The least shear strength of a single headed stud inserted in a stiff floor in composite construction can be represented as follows, according the Bangladesh National Building Code (BNBC)-2020;

$$Qn = 0.5\, A_{sc}\sqrt{(f'cEc)} < RgRpAscFu \qquad (2.1)$$

Where, A_{sc} = Shear connector sectional area, mm^2

E_c = Concrete modulus of Elasticity, MPa

= $0.043 w_c^{1.5}\sqrt{f'_c}$, w_c = *Unit weight of concrete (1500≤w_c≤2500 kg/m^3)*

Fu = Minimal tension capacity of connector, MPa

Rg= group effect factor

Rp= position effect factor

Whenever attached channels shear connections in solid concrete during composite construction, Minimum capability of single soldered connections can be calculated using following formula.

$$Q_n = 0.3(t_f + 0.5t_w)L_C\sqrt{f'_c E_C} \qquad (2.2)$$

Where, t_f = flanges depth, mm

t_w = web depth, mm

L_c = Length of connector mm

2.7.2 AISC 360-16 (2016) [Welded Connector] [50]

The AISC (360-16) guidelines contained options regarding hybrid erection as late of 1936. The guidelines of the AISC in 1961 was the first to indicate capability of shear connections in stiff slabs as a function of stud diameter as well concrete strength. Regarding profiled metal decking in composite construction, a new regulation was adopted in 1978. The Ollgaard [18] suggested formula that was used by AISC 360-16 to find out the shear resistivity of welded shear connection. To accomplish this, forty-eight push-out samples using sixteen mm and nineteen mm connector attached in both regular as well thin concrete had to be tested. The durability, area, and modulus of elasticity all affect the shear connector. so as to ascertain the upper bound of the experiment information, Eq. 2.3 utilize compute the connector's tensile strength. By considering the group factors and the location of the shear connector, AISC 360-16 additionally computed the nominal shear capacity (Qn);

$$Q_n = 0.5Asc\sqrt{(f'_c E_C)} < RgRpAscF \tag{2.3}$$

Where;

Rg= factor of group effect

Rp= factor of position effect

Asc= the area of a connector's cross section, mm^2

Fu= Nominal strength of stud, MPa

f'c= The concrete cylinder strength, MPa

Ec= modulus of elasticity, MPa

2.7.3 CSA S6-14 (2009) [51]

According to CSA-S6-14-2009, Shear capacity of an end-welded connections in a rigid floor that is headed or hooked and has a h/d ratio of at least 4.0 is;

$$qr = 0.5\ \varphi scAsc\sqrt{(f'cEc)} \leq \varphi_{sc} A_{sc}\ F_u \tag{2.4}$$

Here,

q_r = Ultimate shear resistance connector, KN.

φ_{sc} = Shear connection resistance factor [0.8 is used]

A_{sc}= Connector sectional area, mm^2

$f'c$= compressive strength of concrete, MPa

Ec= Modulus of elasticity, MPa

Fu = Nominal capacity of shear connector, MPa

h = Stud's Hight, mm

d = Connector diameter, mm

The stud's calculated flexural ability is represented by the limiting value of φscAscFu in Eq. 2. 4. In order to prevent the stud from eventually bending and failing under tension, this is done to make sure that its tensile capacity is not exceeded.

2.7.4 EUROCODE 2004 [52]

The Eurocode guidelines for combined/hybrid structures were first published in the 1990s, and Eurocode 4 was then released. In BS EN 1994-1-1:2004, two equations (Eqs. 2.5 & 2.6) for shear capacity of soldered headed shear connections within the sturdy slabs are provided by Eurocode 4 clause 6.6.3.1. The smallest value obtained from these two equations need for design resistance (PRd). Connector breakdown and concrete breakdown are the two primary failure modes that are addressed by these two equations.

$$P_{Rd} = \frac{(0.29\alpha d^2\sqrt{f_{ck}E_c)}}{\gamma_v} \tag{2.5}$$

$$P_{Rd} = \frac{0.8 f_u \pi d^2}{4\gamma_v} \tag{2.6}$$

Where,

$$\alpha = 0.2\left(\frac{h_{sc}}{d}+1\right) \leq 1.0, \qquad for\ 3 \leq \frac{h_{sc}}{d} \leq 4$$

$$\alpha = 1.0, \qquad for\ \frac{h_{sc}}{d} > 4$$

$d = is\ the\ shear\ connector\ shank\ diameter, mm\ (16\ mm \leq d \leq 25\ mm)$

$h_{sc} = is\ the\ overall\ nominal\ height\ of\ shear\ connector, mm$

$f_u = is\ the\ shear\ connector\ ultimate\ tensile\ strength, N/mm^2$

$f_{ck} = is\ the\ characteristic\ compressive\ strength\ of\ concrete\ cylinder, N/mm^2$

$E_c = Modulus\ of\ elasticily\ of\ concrete, N/mm^2$

$\gamma_v = is\ the\ partial\ safety\ factor\ for\ shear\ resistance\ (\gamma_v = 1.25)$

2.7.5 JSCE (2005) [53]

JSCE specify the minimum value for the shear resistance of the welded headed studs both connector and concrete failure which found in Equations 2.7 and 2.8. The proportion of heights to width in this instance is restricted to hss/dss ≥ 4.

$$V_{sud} = (31A_{ss}\sqrt{(\frac{h_{ss}}{d_{ss}}) * f'_{cd}} + 1000)/\gamma_b \tag{2.7}$$

$$V_{sud} = A_{ss}f_{sud}/\gamma_b \tag{2.8}$$

Where, $A_{ss} = stud\ shank\ cross\ sectional\ area, mm^2$

$d_{ss} = shear\ stud\ connector\ diameter, mm$

$h_{ss} = shear\ connector\ height\ above\ the\ flange, mm$

$f_{sud} = design\ tensile\ strength\ of\ stud, N/mm^2$ $(=\frac{f'_{suk}}{1})$

$f_{suk} = characteristic\ tensile\ strength\ of\ stud, N/mm^2$

$f'_{cd} = design\ compressive\ strength\ of\ concrete, N/mm^2\ (= \frac{f'_{ck}}{1.3})$

$f'_{ck} = characteristic\ compressive\ strength\ of\ concrete, N/mm^2$

$\gamma_v = is\ the\ partial\ safety\ factor\ for\ shear\ resistance\ (\gamma_v = 1.3)$

2.7.6 ACI 318-08 (2008) [54]

ACI 318-08 states that full-depth prefabricated connection anchorage isn't described in details. A collapsed cone of concrete is specified as ± 1.5hef for both regular tension and the shear in anchors themselves on each side of the anchor. where hef is the anchor's practical insertion depth. The explanations cover the following factors: eccentric loads, edge effects, single anchors, groups of anchors, and cracking. The minimum capacity of an anchorage, Vsa, for a post-mounted anchorage or cast-in headed bolt and a cast-in head stud anchor is determined by the steel potency of anchor's shear, which may be calculated in Equations 2.9 and 2.10, respectively.

$$V_{sa} = nA_{se}f_{uta} \tag{2.9}$$

$$V_{sa} = n\ 0.6\ A_{se}f_{uta} \tag{2.10}$$

Where,

n = The amount of group anchors

A_{se}= the single anchor's effective cross-sectional area in shear, in^2

f_{uta} should not exceed 1.9fya minus 125 ksi, whichever is smaller. where futa is the anchor steel's stated tensile strength and fya is its stipulated yield strength. It is suggested that the tensile strength be used in place of the yield strength for calculating nominal shear capacity due to the majority of anchor ingredients do not have a precise threshold of break point. The statement also clarifies that the fixity of the weld gives welded stud anchors their increased shear strength.

2.7.7 Channel Connector as per AISC 360-16 (2016) [55]

The following formula is provided by the most recent American Standard (AISC 360-16) to ascertain the durability of a channel shear connector set into a slab of solid concrete:

$$Q_n = 0.3(t_f + 0.5t_w)L_c\sqrt{(f'_c E_C)} \tag{2.11}$$

Where,

$Q_n = Nominal\ strength\ of\ one\ channel\ shear\ connector, N$

$t_f = Flange\ thickness\ of\ channel\ shear\ connector, mm$

$t_w = Web\ thickness\ of\ channel\ shear\ connector, mm$

$L_c = Length\ of\ channel\ shear\ connector, mm$

$f'_c = Specified\ compressive\ strength\ of\ concrete, MPa$

$E_c = Modulus\ of\ elasticity\ of\ concrete, MPa$

The equation established by Slutter and Driscoll [44] is somewhat altered in this version. To the intent of determining the shear capacity of channel connections with varying concrete weights.

2.7.8 CAN/CSA S16-09: [50]

Using Eq. 2.12, one may estimate the minimum Capability of a channel shear stud put off stiff concrete floor, in accordance with the recent Canadian Standard is:

$$Q_{rs} = 36.5\varphi_{sc}(t_f + 0.5t_w)L_c\sqrt{f'_c} \qquad (2.12)$$

Where, $\varphi_{sc} = Resistance\ factor\ for\ channel\ shear\ connectors$

$t_f = Flange\ thickness\ of\ channel\ shear\ connector, mm$

$t_w = Web\ thickness\ of\ channel\ shear\ connector, mm$

$L_c = Length\ of\ channel\ shear\ connector, mm$

$f'_c = Specified\ compressive\ strength\ of\ concrete, MPa$

Lehigh University tests on 41 push-out specimens provided the basis for this equation as well [50].

2.7.9 EC-2004 (CEN 2001), Channel Shear Connector [56]

The European code has a formula for design of rigid channel shear connector. This connector's usual orientation is depicted in Fig. 2.16. We call this type of connector a Barrier connection. Owing to the channel's design, a steel knot is included to stop lifting.

This type of connector has a particular design resistance (PRd):

$$P_{Rd} = \eta A_{f1} F_{ck}/\gamma_c \tag{2.13}$$

Here,

A_{f1} = The front surface area appears in the illustration 2.16.

A_{f2} = The front surface region is increased at a 1:5 slope with relation to the adjacent connector's back surface.

For $\eta = \sqrt{(Af2/Af1)}$, a maximum of 2.5 in the case of concrete with ordinary density or 2 in the case of thin aggregate-based concrete.

γ_c = Partially safe parameter for concrete.

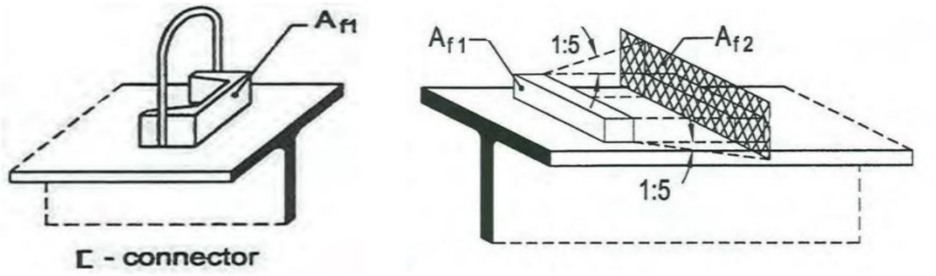


Fig. 2.16: Inflexible Channel Shear Coupling and the Parameters of Rigid Shear Connectors

2.7.10 AASHTO LRFD [57]

The minimum shear strength of single shear stud in composite construction represented as follows, according to the AASHTO LRFD:

$$P_n = 0.5Asc\sqrt{(f'_{ck}\,\mathrm{Ecm})} \leq Ascfu \tag{2.14}$$

Where, A_{sc} = headed shear stud's area, mm^2

f'_{ck} = Concrete compressive strength, MPa

Ecm = Modulus of Elasticity, MPa

Fu = Specified minimal tensile capacity of a stud connector, MPa

2.7.11 Eurocode 4 (CEN 2001), Angle Shear Connector [58]

As per EC-04-CEN 2001, L-shaped angle shear connector's strength (PRd) within a sturdy slab the illustration 2.17. displays as follows:

$$P_{Rd} = 10bh^{3/4}{f_{ck}}^{2/3}/\gamma_v \tag{2.15}$$

where, b = Angle length, mm, h = width of the angle's upper leg, mm

fck = Cylinder's compressive robustness, MPa

y_v = Concrete's a partially secure aspect, taken as 1.25.

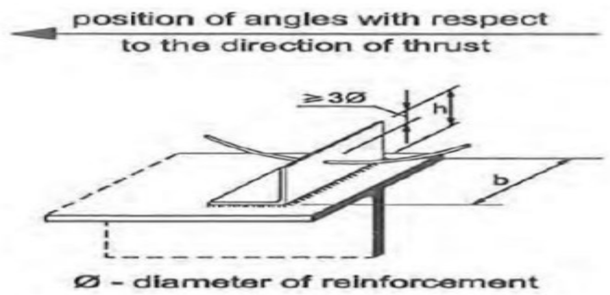


Fig. 2.17. Common Angle Shear Connector with an L-shaped form

2.8 BENEFITS OF HEADED STUD SHEAR CONNECTOR OVER OTHER SHEAR CONNECTOR

Shear connectors with heads are better than other types because:

- They are useful for use in steel deck slabs and have quick welding and strong concrete anchoring.
- They don't get in the way of the slab support.
- They allow the concrete around the connectors to compact to a more suitable degree.
- In any direction, it provides the same shear strength.
- Simplicity in producing huge quantities.
- Has a standard dimensional head that serves as a barrier against slab lifting.

2.9 METHODOLOGY OF PUSH OUT TEST

A common method for analysing shear connection capacity and failure mechanisms is the use in push-out examinations. A steel section with shear connectors inserted into concrete slabs on both flanges is a classic push-out illustration. In this case, the steel section's web is loaded vertically. It is believed that only the connectors transmit the load from the steel section, and so the weight is dispersed equally among the slabs Viest [15]. On the other hand, as Fig. 2.18. illustrates, Eurocode 4 provides information on the push-out evaluation that is applicable to welded shear connections in sturdy concrete floors. In lieu of the composite beam test, this test is used to cut down on the expense and duration involved with a complete evaluation. The testing specimen details for calculation of slip capacity using BS5400 is shown in Figure 2.18. and 2.19. A shear connector's ductility can be ascertained by push-out testing. This is determined by the slippage ability between junction of the metal girder and the hybrid concrete floor. Shear connectors are deemed ductile if their capacity for deformation is sufficiently high. According to Eurocode 4, if the slide exceeds 6 mm, that stud is Sayed ductile. The headed shear stud's good ductile behaviour characterized by significant deformation caused by plasticity. However, brittle headed shear connector behaviour with little plastic deformation is identified in a shear connector that does not cross the 6 mm threshold.

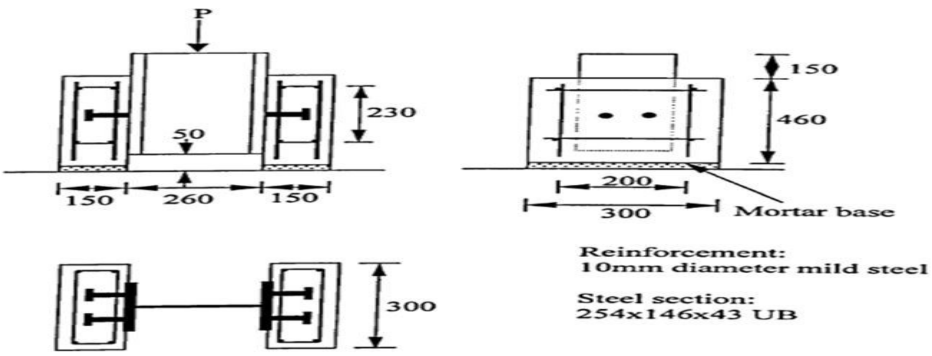


Fig. 2.18.: Push Out Test as Per BS5400 used in Experimental Work

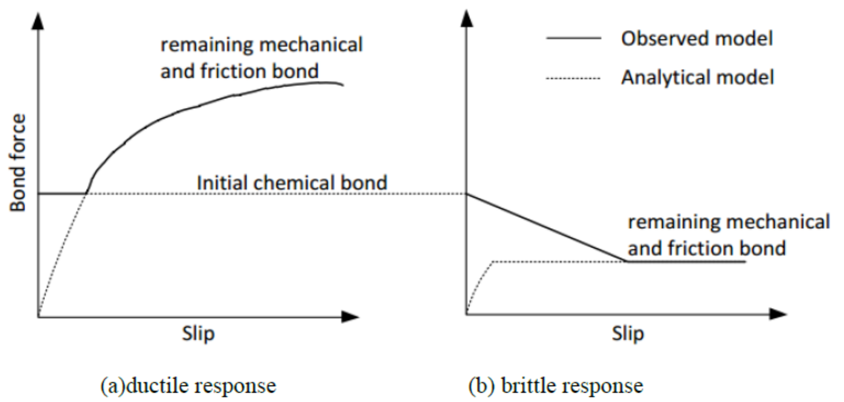


Fig. 2.19. Slip behaviour in contrast to shear resistance (Daniels, B. J., and Michel Crisinel, 1993) [11]

2.10 PREVIOUS STUDIES ON STUD SHEAR CONNECTOR

Push out experiment is the most widely used and recognized technique for figuring out a shear connector's static strength and load slip behaviour. Many push-out tests were carried out by multiple researchers. This article will provide a thorough conversation of the complete-scale and push-out beam testing conducted by earlier investigator.

Slutter and Fisher's, 1966 [59]

One of the primary sources for the study of headed shear stud is the test conducted at Leigh University [51]. To ascertain fatigue life, Response to load slip, and stagnant capacity of studs, they evaluated forty-four push-out specimens. Research by [51] yielded the AASHTO LRFD and the Canadian Highway Bridge Design Code. According to findings, researcher recommended that weariness existence is determined by the anxiety limit and maximum load has little bearing on fatigue design.

Menzies And Mainstone,1967[60]

Menzies And Mainstone conducted push out test on shear stud specimen. In their research, push-out sample were used to undergo tiredness as well as stagnation testing on channel, shear stud and bar connector. In order to account for both unidirectional and reverse loading scenarios, shear stud connectors were put through employing nineteen-millimetre diameter and hundred-millimetre-tall studs, there were eleven static tests and twenty-three fatigue tests. According to their findings, stud shear connectors were more susceptible to strength variations than bar and channel shear connectors.

Hallam Investigation [61]

Using 17 push-out specimens with shear connector that were nineteen millimetre in dia and 76-millimetre-tall, the behaviour of headed stud connections under repetitive stress was investigated. There were four fatigue tests and one static test with amplitudes that were preprogramed, and thirteen fatigue tests with stress ranges that varied but amplitudes remained constant. The most crucial factor for predicting static strength, Shear connection lifespan and load slippage behavior, according their research, is the concrete's compressive strength [53].

Oehler & Foley,1985 Evaluation [62]

The capacity of connections was investigated by 129 push-out experiment. The results indicated that, application of cyclic loads caused stud shear connections' static strength to diminish. In line with the findings of Mainstone and Menzies (1967) [54], there was a 50% loss in static strength as found from according to two tests, and a 73% reduction in another test.

Amar Prakash et al. [63]

The researchers used adjusted push-out examinations to find the stiffness and shear strength of connector. They considered confinement of reinforced concrete in their investigation. According to experimental data, concrete confinement around the heading shear stud greatly increased the concrete's compressive strength and splitting resistance; as a result, push out specimens should take this into consideration. The study's novelty could be considered while emphasizing the significance of limited concrete strength when creating pushout specimens. The addition of steel fiber concrete near HSS studs inserted in the push-out samples in RC slab may allow for even greater improvements.

Manik Mia Numerical Analysis [64]

A comprehensive parametric research with varying stud sizes and concrete potency was carried out employing a finite element designs to examine the load-slippage characteristic & shear capacity of connector with small & large heads. A numerical analysis reveals that when concrete strength increases, slip falls but shear strength increases. For both small and big shear connectors, the same failure mode was noted. A headed shear stud's shear capacity is usually estimated conservatively using the European designation, EC4. while research has shown that the Canadian code overestimates the constant stud force with heads by up to 22.3%.

Huu Thanh & Seung Eock [65]

Using the suggested finite element studies, researcher worked with thirty-two push-out samples that had varying connector sizes and concrete capacity. EC4 & AASHTO LRFD design principles were contrasted with finite analysis of headed stud shear connection capability and ductility. Findings of investigation describe the headed shear connections' capacity was exaggerated by up to 27% in the AASHTO LRFD standards. For connector dia of twenty-two & twenty-five millimetre but fewer connector depth of twenty-seven millimetre, the design standards outlined in EC4 are generally conservative.

2.11 RESEARCH GAP

- Generally, shear stud is welded perpendicularly to the girder flange surface. During welding, some HSS becomes inclined. What the performance impact due to this inclination is checked in this experiment.
- Before this experiment, Various research conducted on perpendicular headed shear stud. No research held on inclined headed shear stud.
- In this experiment, Different structural performance of inclined headed shear stud is investigated comparing with the perpendicular headed shear stud.

2.12 SUMMARY OF LITERATURE REVIEWS

An overview of past and present research on shear connectors in composite material beams is given here. Majority popular shear connections in hybrid beam, welded headed studs, are likewise covered by the design code's rules. Additionally, it is provided with a summary of other shear connector types that can be substituted for welded inclined headed shear studs. Current design guidelines and these literatures do not provide exact information of inclined headed shear connector's different parameters. This research uses traditional push-out experiment to look at the capacity and collapse activities of different experiment samples using inclined shear connections on composite construction. Details of the different experiment finding, their application & uses history are discussed in this chapter.

Chapter 3: EXPERIMENTAL INVESTIGATION

3.1 GENERAL

In order to look into structural characteristics of inclined connector in steel-concrete combined framework, this experimental was conducted. Different specimen was prepared according to the guidelines of BS5400. Geometric details, material properties, reinforcement details, step by step specimen preparation, testing arrangement, testing procedures etc are included in this chapter. This experimental program has tested through the construction of eight push-out test specimens in four types considering 15-degree, 30-degree & 45- degree angle of inclination of shear stud with the perpendicular one.

3.2 DETAILS OF PUSH OUT TEST SPECIMEN

All the test specimen was categorized into four types depending on the degree of inclination and tested under static loading condition. A hot-rolled standard (I-shaped) compact metal girder of size 254 X 146 X 43 UB is contemplated here as steel element of each push-out samples. Fig. 3.1. displayed details of test arrangement as per BS5400. Steel beam is supported vertically by two identical reinforced concrete slabs, each measuring length 300 mm, width 150 mm & height 450 mm. To form the reinforcement skeleton, 4 nos. 12 mm Ø steel rebar is used as a longitudinal bar and 2 nos. 10 mm Ø rebar is used as stirrups.

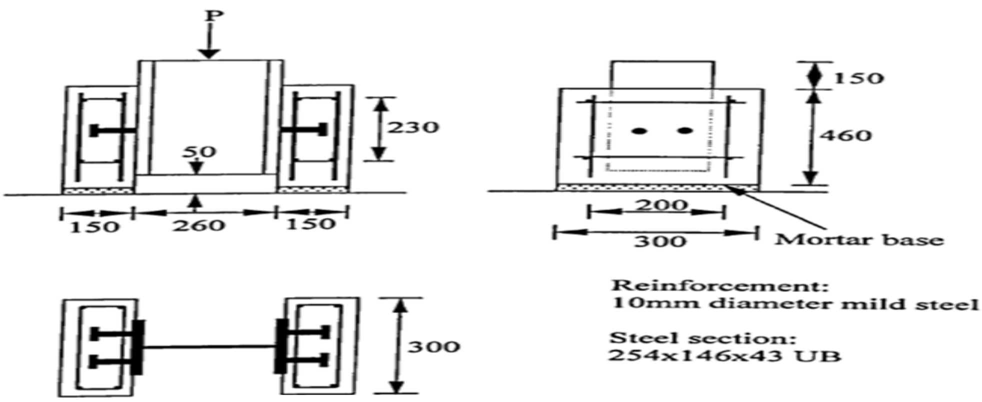


Fig. 3.1. Push Out Test as Per BS5400

The stirrups were spaced 230 mm from center to center, with a 30 mm transparent cover. Typical Headed shear stud type shear connector having 16 mm diameter, length 110 mm, head diameter 26mm & yield strength 43.5 ksi is considered here as mechanical connecting device for the connection between steel & concrete. Connectors are fastened with the girder flange by weld considering perpendicular/0,15,30 & 45-degree angle of inclination. All the stud connected with flange by welding using 5/16 in. (8 mm) dia Electrode E6013 fillet rod. Every test specimen's slab was cast vertically at a single stage. Downward axial compression was applying to the top of girder as displayed in 3,1. When the beam/girder section is subjected to an axial force, connectors cause a shear load to be applied along the point where the concrete slab and steel segment meet. In order to accommodate slippage at the steel-concrete interface under static loading, a 25 mm recess was installed the slab bottom. Installed Headed shear connector was kept symmetric from the middle of girder flange as displayed in fig. 3.2.

Fig. 3.2. Installed headed shear connector [51]

Parametric details of headed connector used in experimental program are given in table 3.1. Cross sectional details of steel I beam section are displayed in fig. 3.3 and the I section beam's geometrical attributes displayed in table 3.2.

Table 3.1. Measurements of Shear Stud for Push-out Experiment

Diameter mm	Shank Hight mm	Head Height mm	Overall Hight mm	Head Diameter mm
16	100	10	110	26

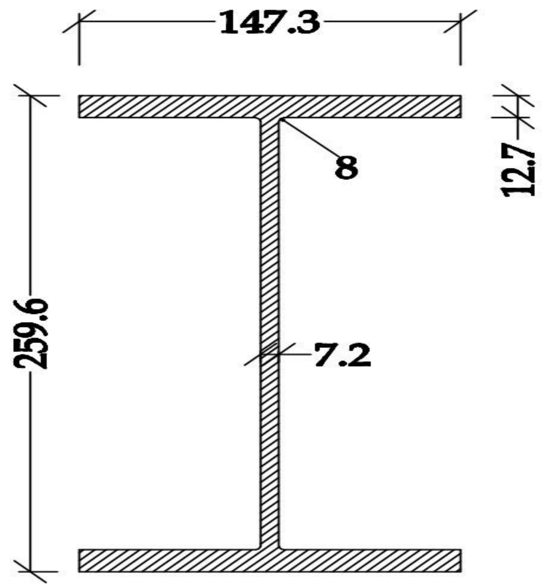


Fig. 3.3. 254 X 146 X 43 UB Steel Girder

Table 3.2. 254 X 146 X 43 UB Steel Section Details

Parameter	Value	Unit
Depth	259.6	mm
Width	147.3	mm
Web Thickness	7.2	mm
Flange Thickness	12.7	mm
Root Fillet Radius	8.0	mm

3.3 MATERIAL PROPERTIES

Concrete, structural Steel, headed shear stud, coarse aggregates, fine aggregates, Binding materials & MS deformed reinforcing steel were used for the preparation of push out test samples. The different properties of these materials are discussed in this section.

3.3.1 Binding Materials

Portland Composite Cement (PCC) served as the cement in each mixture. 28 days Average compressive strength was 43 MPa. Fig. 3.4. displayed the bag of cement while fig. 3.5. shows the cube specimen for compressive strength test. Fig. 3.6. shows the testing of cement also. Table 3.3. shows details of cement testing data for cement used in the experimental program.

Fig. 3.4. Binding Materials (Cement)

Fig. 3.5. 2”x2”x2” Cube for Compressive Strength Test of Cement

Fig. 3.6. Compressive Strength Test of Cement

Table 3.3. Data Table of Cement Test

Type of Strength	Sample No	Strength Mpa(psi)	Average Strength Mpa(psi)	Remarks
Compressive (ASTM C109-16a)	1	42.0 (6090)	43.00(6235)	28 days strength
	2	43 (6235)		
	3	25.5 (6380)		

3.3.2 Aggregates

Sieve analysis were performed for the fine aggregates used in experimental program. Total sample taken was 500gm from the fine aggregate stack. Fineness modulus of fine aggregates was 1.95 and specific gravity was 2.55. Table 3.4 shows the calculation process of fineness modulus. Regionally reachable coarse sand was used as fine particles. The coarse aggregates used are the brick chips of 20mm nominal size. Fig. 3.7. and 3.8. shows fine and coarse aggregate respectively.

Table 3.4. Fineness Modulus

Sieve Size(mm)	Material Retained(gm)	% of Material Retained	Cumulative % Retained	% Finer	FM
4.75	0	0	0	100.0	= W/100
2.36	1.5	0.3	0.3	99.7	=195.3/100
1.18	33.5	6.7	7.0	93.00	= 1.95
0.60	66.0	13.2	20.2	79.8	
0.30	250.0	50.0	70.2	29.8	
0.15	137.0	27.4	97.6	2.4	
Pan	-	-	-	-	
Total Cumulative % Retained W=			195.3		

Fig. 3.7. Fine Aggregates

Fig. 3.8. Coarse Aggregates

3.3.3 Concrete

All concrete mixtures now contain aggregates at saturated surface dry conditions. Local sand with a specific gravity of 2.55 and FM of 1.95 was used as the fine aggregate, while well-graded brick chips with a minimum size of 20 mm were used. Portland Composite Cement was the cement utilized in each mixture (PCC). For concrete mix designs, a slump value of 55 mm was attained. Single set (03 Nos.) of typical cylinder made of concrete having height 12inch and diameter 6 inch was arranged and perform test after 28 days of curing. The compressive strength of concrete was found to be 26 MPa. Figure 3.9. shows the instrumentation for compressive strength test and figure 3.10. shows the failure pattern of the concrete cylinder after test.

Fig. 3.9. Concrete Cylinder Set up

Fig. 3.10. Failure Pattern of Concrete Cylinder

3.3.4 Structural Steel Beam

To ascertain the yield & ultimate strength of structural metal beam, standard coupon test sample were prepared. The yield & ultimate strength of structural metal beam obtained to be 366 Mpa & 468 Mpa respectively as shown in table 3.5. Details of standard coupon experiment as displayed in fig. 3.11.

Fig. 3.11. Coupon Test of Metal Beam

Table 3.5. Tensile Strength of I shape Steel Beam Plate

Nominal Length (mm)	Nominal Thickness (mm)	Nominal Area (mm²)	Yield Strength (Mpa)	Avg. Yield Strength (Mpa)	Ultimate Strength (Mpa)	Avg. Ultimate Strength (Mpa)
12.5	7.0	87.5	366.0	366.0	491.43	468.71
12.5	7.0	87.5	366.0		445.71	

3.3.5 Headed Shear Stud

To determine the tensile strength (yield & ultimate) of headed shear stud standard testing procedure was conducted on UTM. The yield & crucial tensile capacity of stud was found to be 300Mpa & 427Mpa respectively as shown in table 3.6. Details of Tensile test of headed shear stud displayed in fig. 3.12.

Fig. 3.12. Tensile Potency Test of Stud Connector

Table 3.6. Data Table of Tensile Potency Stud

Nominal Dia(mm)	Actual Dia(mm)	Average actual dia(mm)	Yield Strength (Mpa)	Avg. Yield Strength (Mpa)	Ultimate Strength (Mpa)	Avg. Ultimate Strength (Mpa)
16.0	16.0	16.0	300.0	300.00	427.00	427.00

3.3.6 Reinforcement

To determine the tensile strength (yield & ultimate) of used MS deformed reinforcing bar, standard testing procedure was conducted in universal testing machine (UTM). The yield & ultimate tensile strength of reinforcement was found to be 548 Mpa & 642 Mpa respectively as shown in table 3.7. Details of Tensile test of reinforcement is shown in Fig. 3.13.

Fig. 3.13. Tensile Potency Test of 12mm dia Rod

Table 3.7. MS deformed bar Tensile Potency Test Data Calculation

Nominal Dia	Actual Dia(mm)	Average actual dia(mm)	Yield Strength (Mpa)	Avg. Yield Strength (Mpa)	Ultimate Strength (Mpa)	Avg. Ultimate Strength (Mpa)	US/YS
12mm	11.99	12.00	549.11	548.18	628.82	642.49	1.14
	12.00		548.18		645.46		1.17
	12.01		556.11		653.21		1.17

3.4 Typical Fitting, Fixing Details of Headed Stud

In this series, eight push-out test samples were made with two connectors with the same diameter of 20 mm were used in each side of the flange. In this test program, each push-out specimen was identified by a degree of inclination i.e 15º,30º and 45º respectively. 20mm dia 100mm length headed shear stud are placed 38mm center to center keeping 56mm from the side of steel girder flange. Location of stud from the bottom of flange are kept 192.5mm center. Four type sample were made with same dia Stud are weld with the girder at an angle of 0º, 15º,30º and 45º respectively.

3.5 PREPARATION OF SPECIMEN

3.5.1 Specimen Installation Procedure

In order to prepare the push-out experiment sample, a hot-rolled of six meter length steel I (I-shaped) compact steel beam section (146 by 254 mm) with thickness of web and flange are 7mm and 12mm respectively were selected to cut eight pieces of 450mm length from each girder from the machine shop as seen in figure 3.14(a). Then the top and side of flange section were grinded properly for removing the external dust from the girder side and stored on the site of machine shop for fabricating as a specimen. Then the 16mm dia & 110mm length with head dia 26mm headed shear stud as seen in Figure 3.14(b). was filled at the top most side to fix with an as angle on the side of flange. For maintain the proper angle between flange and the headed shear stud, special technic was used i.e. make three cork sheets at different angle to fix the headed shear stud with the flange of girder as seen in figure 3.15(a,b). Shear connectors were used that were purchased from the market i.e. from the town of Chittagong. Actually, in this study bolt was used shear stud instead of traditional shear stud purchase. The same parameter of traditional shear stud was kept constant as well. As seen in Figure 3.16(a), a certified welder welded this shear stud in machine shop, subsequently welded the headed shear stud connector is to connect with the steel section's flanges in accordance with AWS (American Welding Society) specifications. The distance between the centers of headed connectors maintained a distance of 38mm where the outside clear distance was kept at 56mm.

(b) 450mm Length I Shaped Steel Girder

(a) 110mm Length headed Shear Stud

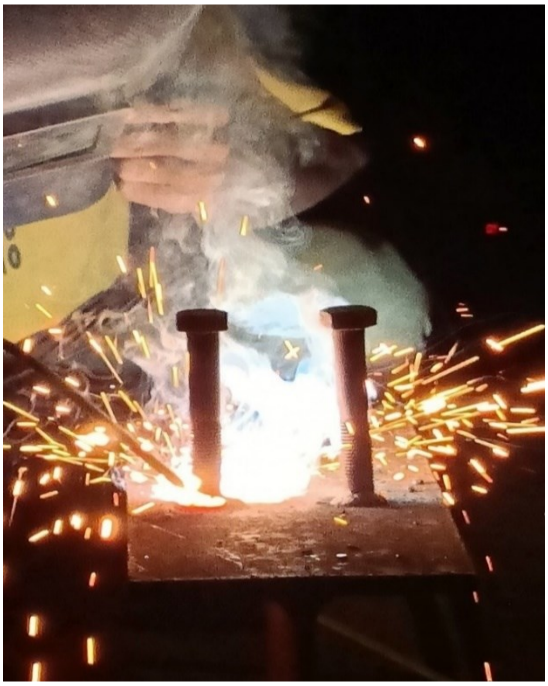
Fig. 3.14.(a,b) Main Components of Specimen [Girder & Headed Stud]

(a) Formwork of inclination

(b) Using formwork during welding Rod

Fig. 3.15.(a, b) Installation System of Headed Shear Stud with Girder

In order to prevent the headed shear stud connector from failing/slipping/shearing as a result of a weld failure during testing, proper welding was applied around stud collar, as seen in Figure 3.16(a,b).



(a) During Welding of Stud with Flange

(b) After Welding of Stud with Flange

Fig. 3.16.(a,b) Welding Process of Headed Shear Stud With Steel Girder

After completion of four type eight nos specimen, the welded specimen was shorted in the welding shop as shown in figure 3.17.

Fig. 3.17. Stacked Finished Piece of Girder after Completion of Welding

After completion of shear stud welding at different inclination with the 450mm length steel beam for insertion in between the formwork for casting of push-out specimen are as seen in fig. 3.18.(a,b,c,d).

(a) 0 Degree Inclination

(b) 15 Degree Inclination

(c) 30 Degree Inclination

(d) 45 Degree Inclination

Fig. 3.18(a,b,c,d). Assembly of Push Out Specimen at Different Degree of Inclination

Following the welding procedure, the steel specimens were put in the formwork for the concrete slab casting process. Assembling of plywood formwork techniques are shown in Fig. 3.19. A 75 mm recess was ensured in the construction of the plywood shapes between the beneath of the concrete slabs and the lowermost portion metal beam to let the slippage under strain. For maintaining proper formwork size, plywood was used instead of traditional wooden plank

(a) Topographic View of formwork (b) Side view of formwork

Fig. 3.19. Assembling of Plywood Formwork

The typical slab reinforcement for each push-out specimen is displayed in Figure 3.20. Here 12mm dia rod was used for as slab main reinforcement where two ties of dia 10 mm rebar were used at the top and bottom layers. 25mm concrete cover was considered while cutting the rod for fabrication. Every slab used for the push-out samples was cast vertically using the technique described by (Mazoz, A., Benanane, A., 2013) [14]. In order to minimize the possibility of variations in concrete strength across slabs, both slabs were poured from the identical lot. In this test program, concrete strengths 26 MPa were employed followed the same water cement ratio & the aggregate and filler material compositions being adjusted as per combination design approach.

Fig. 3.20. Details of Slab Reinforcements

A mechanical concrete mixture machine has been used to mix the materials according to the specified mix design. One batch of concrete mix was cast for two push-out specimens. Test cylinders measuring 6 inches by 12 inches were cast for testing the concrete's compressive strength. Slump values of concrete mix was checked. Prior to dumping the concrete, the beam flanges were oiled to break the mixture ties at the joint face. Following that, the formworks were ready for the casting of concrete. 16mm dia standard tamping rod was used to assist the mechanical compaction in two layers of casting. To remove air gaps at the connectors, every lift was vibrated extensively. Following a 28-day casting period, using jute cloth eight push-out test specimens were cured with fresh water. Test specimens have been wrapped by jute cloth to prevent surface water from evaporating from the concrete face. Following the completion of the curing period and when the concrete surface was dry, the specimen was ready to test. This was carried out to make sure that concrete crack lines could be clearly seen and identified throughout the loading process, making it simpler to label the propagation line. Step by step procedure of construction eight specimen are illustrated through fig. 3.21 to 3.23.

(a). SSD Weight-Based Aggregates

(b). SSD Weight-Based Sand

Fig. 3.21(a,b). SSD Weight-Based Aggregates Measuring by Fera

Fig. 3.22. Push Out Specimen's Formwork Ready for Oiling Before

Fig. 3.23. Oiling on Formwork Before Casting

3.5.2 Procedure for Casting of Specimen

Coarse and fine aggregates are measured by using fera and put it to mixture machine, after that one bag cement is putted into this batch for mixing properly. Then the mixed concrete is put into the specimen formwork. 16mm dia tamping rod is used for compaction of concrete. Step by step work involved for preparation of eight push out specimen is displayed in fig. 3.24 to 3.30.

Fig. 3.24. Concrete Mixing Using Mechanical Concrete Mixture Machine

Fig. 3.25. Pouring of Concrete to the Mould of Specimen

Fig. 3.26. Tamping During Pouring of Concrete to the Specimen

Fig. 3.27. Randomly Collecting Cylinder Test Sample During

Fig. 3.28. Measuring of Slump During Slump Test While Concreting

Fig. 3.29. 28 Days Water Curing Using Jute Jacketing

(a) Total 4 out of 8 Finished Specimens Ready for Test

(b) Total 8 out of 8 Finished Specimens Ready for Test

Fig. 3.30(a, b). Eight Piece Finished Push Out Specimen as Per BS5400

3.6 SETUP FOR TEST AND INSTRUMENTATION

3.6.1 Configuration and Methodology of Tests

Every specimen was tested engaging 1000 kN capacity (UTM). The push-out examination sample was positioned above the UTM's level stage/platform. After that, an adjustable pneumatic crosshead passed through a stiff piece of steel with a 25 mm thickness to apply the load a top of the girder. Metallic beam plate was covered with a rubber pad to ensure even contact and appropriate load distribution. Using a computer running data acquisition software, the data were collected data. Fig. 3.31 displays a schematic illustration of test setup using UTM. At the level of the shear connectors were two 50 mm dial gauges for measuring slip. A bracket next to the connector made it easier to secure each dial gauge to the beam; one bracket was fastened to the web, and the other to the flange. A dial gauge measuring five millimetres was also placed at the concrete's edge to assess any lifting or split in the slab from the metal while loaded the maximum load. To handle the trial, realistic diagrams of the key information were visible while loaded. Digital cameras are used to quantify the movement of each sample during experiment and take images in consideration of the safety risk.

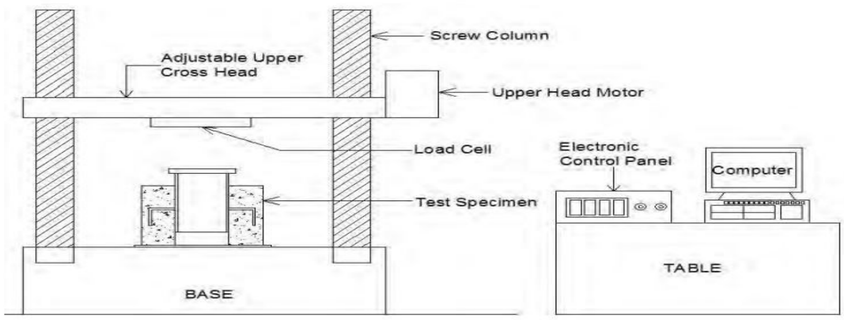


Fig. 3.31. Diagrammatic Representation of the 1000 KN UTM Configuration

3.6.2 Load Application

By using a displacement-controlled technique, the downward axial compression applied statically. When applying force under mechanical test conditions, there are generally two loading techniques that can be used: displacement and load control. In these circumstances, displacements might vary without a change in the load input, making it impossible to properly maintain test conditions using the load control approach. This occurs most prominently at smaller loads where its load-slip graph has a short inclination and, in certain cases, nearly nil. On the other hand, when displacement increases, the breaking at the opposite extreme outcomes indicates significant raise of load. The technique of displacement-control offers a way to test these extreme circumstances. Thus, the displacement-controlled approach was used. The push-out test specimen's load-slip curve had a linear section employing a load step of 5 KN, and a nonlinear branch employing a load step of 1-2 KN was used to accurately measure the post-peak behaviour following the ultimate load. Till each specimen failed, which happened in roughly 5 to 10 minutes approximately, the stress was introduced gradually in multiple phases. Unfortunately, due of the shear connector's abrupt failure, it was not possible to capture the values for majority of specimens with shearing headed shear connectors after the ultimate stress. Until the specimen collapsed or a substantial discharge of load over the maximum load was seen, the process of loading the samples with failures related to concrete was maintained. A normal specimen testing procedure using the UTM machine in the lab is depicted in Fig. 3.32.

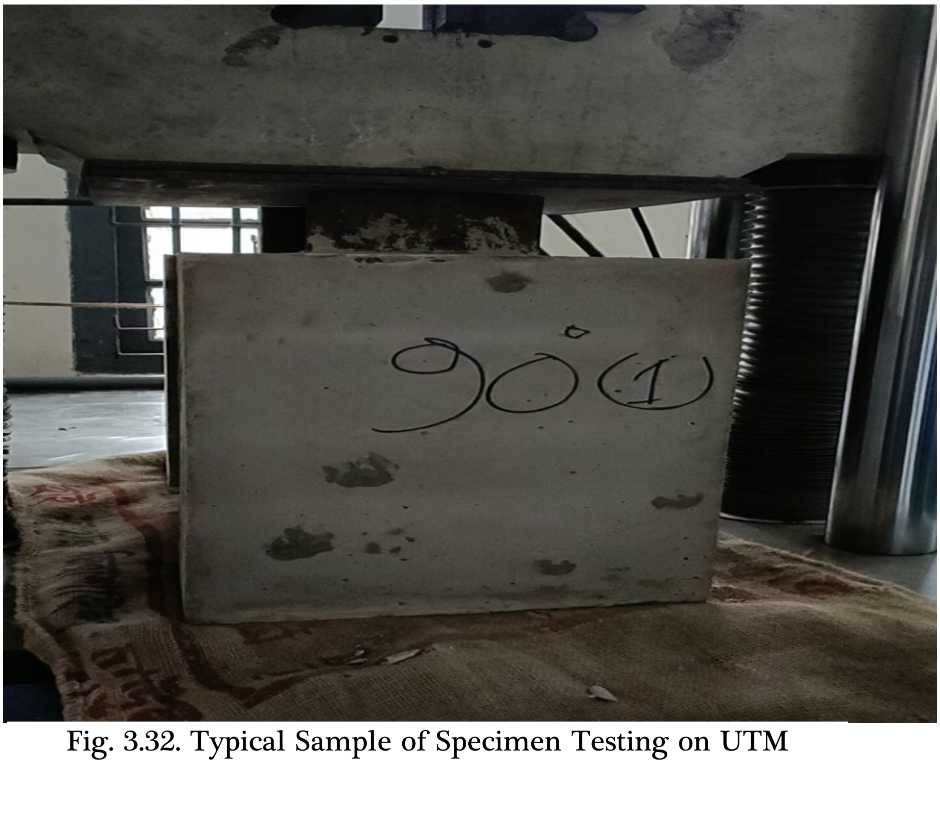


Fig. 3.32. Typical Sample of Specimen Testing on UTM

3.6.3 Data Recording

The amount of shift at the point where the metal girder and concrete slab meet during pressure was calculated using a digital monitoring system that was installed on the UTM machine computer. Data collection system obtained the load step readings by using the "Generic Compression Force vs. Deflection" test technique and the resistivity load is automatically saved by the skyline/HORIZON technology. The spreadsheet created from the saved data was used to analyse the test data in further detail.

3.7 SYNOPSIS

To assess the capacities for shear strength & performance of headed stud connections, an exploratory study was carried out. underneath static central compression, total eight test samples erected via headed stud connections in rigid concrete slabs were examined. This chapter has covered their precise setup, testing process, specimen planning and evaluation. For all the samples relative concrete strengths of 26 MPa was used. Moreover, the experiment sample's stud size was modified regarding latitude, altitude as well breadth to look at how geometric aspects affected the composite specimens' ultimate bearing capacity and breakdown characteristics. so as to ascertain the automated attributes of the headed shear stud and the steel beam section, different tensile strength test was also performed. The characteristics of the concrete were ascertained by performing slump tests and standard cylinder tests on the specimens of concrete. The findings and analysis of the push-out experiment findings are provided and studied in next chapter.

Chapter 4: RESULTS AND DISCUSSION

4.1 GENERAL

This chapter describes results of experimental test to investigate the characteristics of inclined shear stud in steel-concrete composite construction. It presents the results of experimental test of 08 nos. push out test specimen/sample prepared as per BS5400. The behaviour of load slip, maximum capacity to support a shear load, maximum slip during failure, failure mode & elastic energy absorption of perpendicular (0 degree inclined), 1`5-degree,30-degree & 45-degree inclined headed shear stud are described in the subsequent articles.

4.2 TEST RESULTS OF PERPENDICULAR HEADED SHEAR STUD

4.2.1 Load-Slip Behaviour

Fig. 4.1. demonstrates the load-slip curve for perpendicular (0 degree inclined) headed shear stud (HSS). Two push out test specimens were prepared & tested having perpendicular headed shear stud. Here specimen 1 is named as HSS_90(1) and specimen 2 is named as HSS_90(2). HSS_90(Avg.) indicates the average load and slip value of specimen 1 and specimen 2. Both the push out tests specimens have a similar trend in results. Slide values grow up to maximum shear force as the load increases, and then the load drops. When the maximum shear force is applied, the load capability swiftly falls. It is seen from the load slip curve is that the average ultimate shear capacity carried per connector is 95.31 KN and maximum slip of the steel beam is 12.83 mm. First crack load is found to be 80 KN which is identified from the curve of load slip where the initial change of slope is observed. Shear load carried per shear stud is reduced to 68.18 KN at the point of failure. One crucial mechanical requirement in steel-concrete composite construction is ductility of the structure element, which is always preferred and

is intrinsically related to the slip value. Usually, a ductile part shows noticeable distortion or slippage before it stops warning users. Any connector is deemed pliable if the slip characteristics is at minimum 6 mm, as per Eurocode 4. As the maximum slip value found here is 12.83 which is greater than minimum threshold, so perpendicularly placed headed shear stud may be treated as ductile.

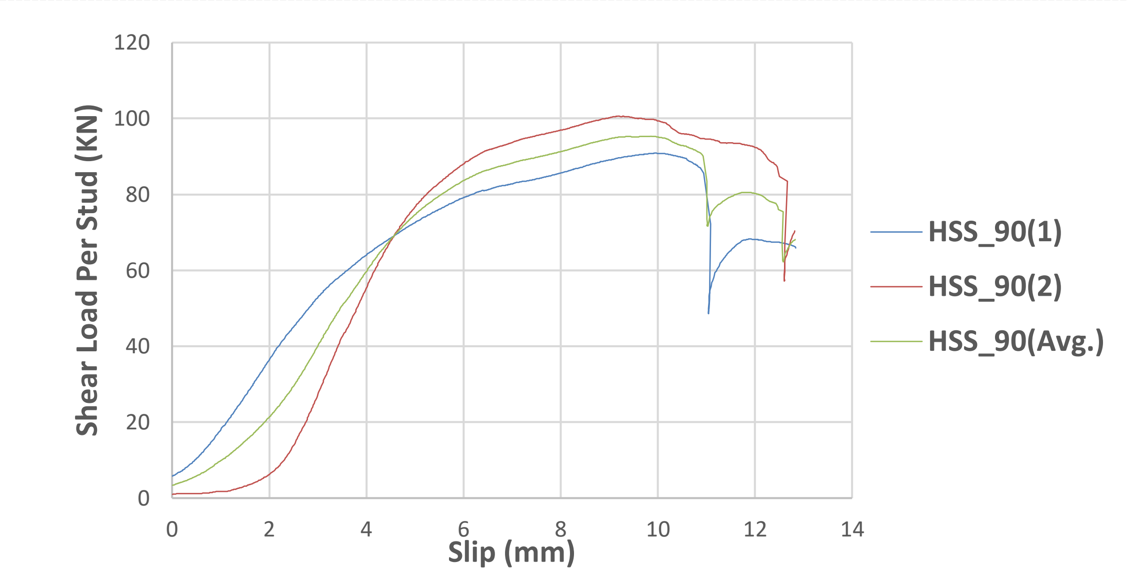


Fig. 4.1. Perpendicular Headed Shear Stud's Load Slip Curve

4.2.2 Failure Pattern

Fig. 4.2. & 4.3. shows the failure pattern of specimen containing perpendicularly placed headed shear stud. It is seen from the figure that both the specimen fails because of shear deformity of the headed stud. Because of diagonal shear strain created intermediate in the metal beam flange and the concrete slab, both the connector and shank fail close to the place of weld. Some hair line crack is developed near the slab's concrete joint area. During failure of headed shear stud no significant damage occurs in concrete slab.

Fig. 4.2. Failure Pattern of HSS_90(1) Specimen

Fig. 4.3. Failure Pattern of HSS_90(2) Specimen

4.23 Strain Energy Absorption at Ultimate Force

The energy that the body stores as a result of applying a load or displacement is known as strain energy. The work performed by the force equals the strain energy. It can be calculated using the load-deformation curve. The maximum peak point applied load area of stress-strain curve represents the strain energy per volume unit. Fig. 4.4. shows the related strain energy absorption curve. Here, per unit volume strain energy at ultimate load is found to be 575 Joule for push-out test specimen having perpendicular headed shear stud.

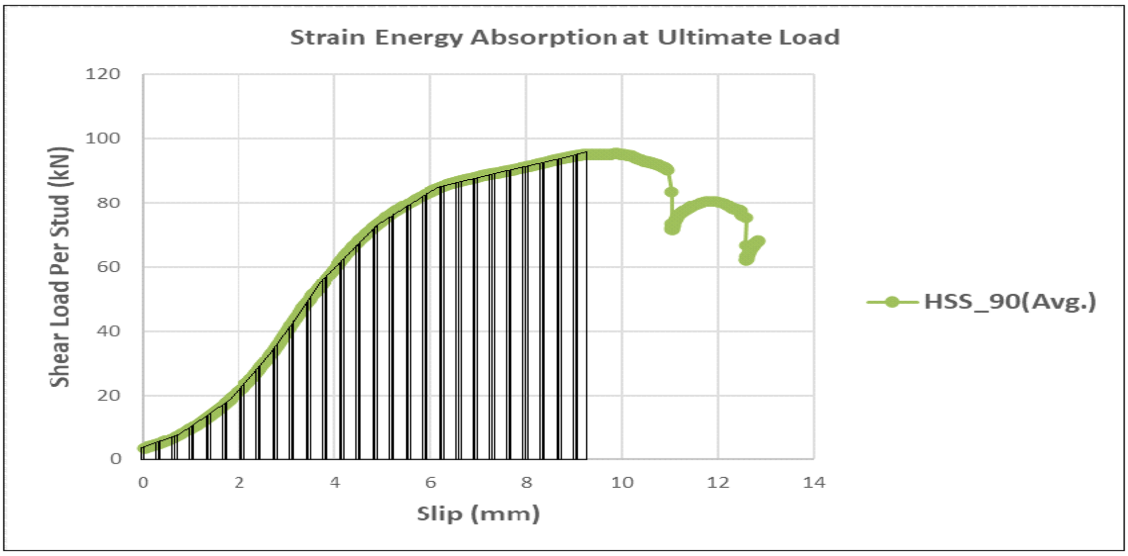


Fig. 4.4. Strain Energy Absorption at Ultimate Load of HSS_90(Avg.)

4.3 TEST RESULTS OF 15 DEGREE INCLINED HEADED SHEAR STUD

4.3.1 Load-Slip Behaviour

Fig. 4.5. displayed load-slip curve for 15-degree inclined headed shear stud (HSS). Two push out test specimens were prepared & tested having 15-degree inclined headed shear stud. Here specimen 1 is named as HSS_15(1) and specimen 2 is named as HSS_15(2). HSS_15(Avg.) indicates the average load and slip value of specimen 1 and specimen 2. Both the push out tests specimens have a similar trend in results. Slide values grow up to maximum shear force as the load increases, and then the load drops. When the maximum shear force is applied,

the load capability swiftly falls. It is seen from the load slip curve is that the average maximum shear load carried per connector is 73.025 KN and maximum slip of the steel beam is 17.58 mm. First crack load is found to be 32.97 KN which is identified from the curve of load slip where the initial change of slope is observed. Shear load carried per shear stud is reduced to 70.52 KN at the point of failure. An essential mechanical criterion in steel-concrete composite construction that is invariably favoured and inextricably connected to the slip values is the structural member's ductility. A ductile member typically exhibits significant distortion or slippage prior to ceasing to alert users. A shear connector is deemed ductile if its slip characteristics are at least 6mm as per Eurocode 4. As the maximum value found here is 17.58 which is greater than minimum threshold, so 15-degree inclined headed shear stud may be treated as ductile.

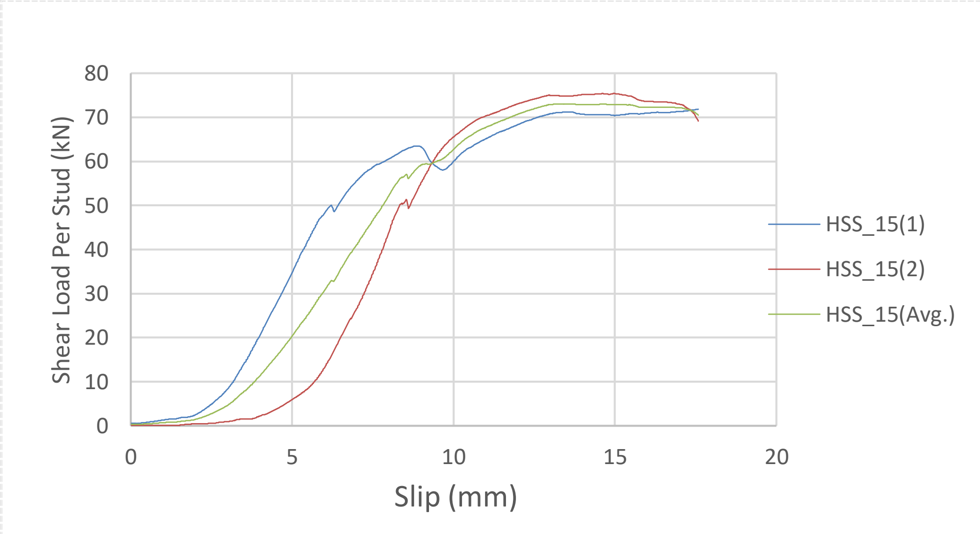


Fig. 4.5. 15-Degree Inclined Headed Shear Stud's Load Slip Curve

4.3.2 Failure Pattern

Fig. 4.6. & 4.7. shows the failure pattern of specimen having 15-degree inclined headed shear stud of specimen 1 & 2. It is seen from the figure that both the specimen fails due to shear deformation of headed shear connector. Because of diagonal shear strain created intermediate in the metal beam flange and the concrete slab, both the connector and shank fail close to the place of weld Some

hair line crack is developed near the slab's concrete joint area. During the failure of headed shear stud no significant damage occurs in concrete slab.

Fig. 4.6. Failure Pattern of HSS_15(1) Specimen

Fig. 4.7. Failure Pattern of HSS_15(2) Specimen

4.3.3 Strain Energy Absorption at Ultimate Load

The energy that the body stores as a result of applying a load or displacement is known as strain energy. The work performed by the force equals the strain energy. It can be calculated using the load-deformation curve. The maximum peak point of applied load area of stress-strain curve represents the strain energy per volume unit. Figure 4.8. shows the related strain energy absorption curve. Here, the strain energy per unit area of ultimate load found to be 459 Joule for push-out test specimen having 15-degree inclined headed shear stud.

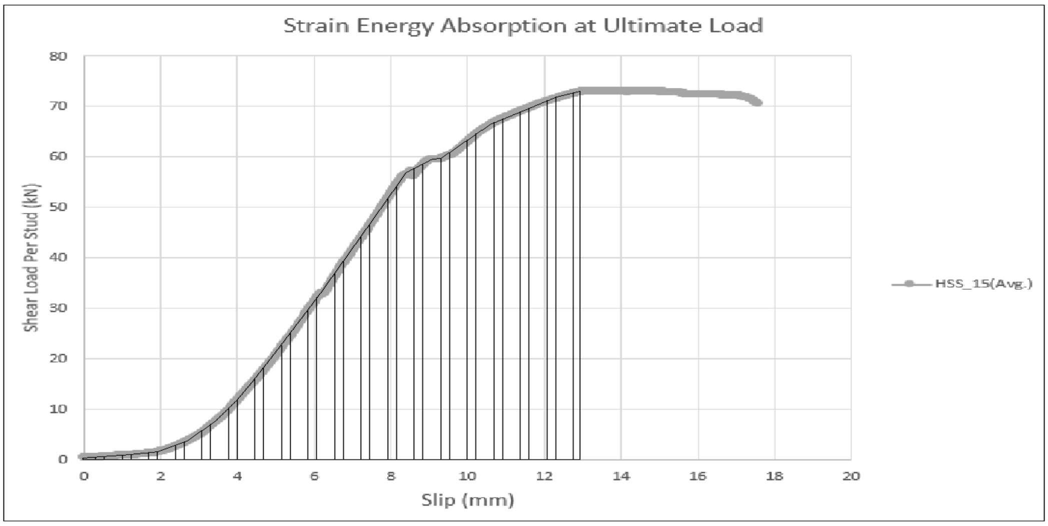


Fig. 4.8. Strain Energy Absorption at Ultimate Load of HSS_15(Avg.)

4.4 TEST RESULTS OF 30 DEGREE INCLINED HEADED SHEAR STUD

4.4.1 Load-Slip Behaviour

Fig. 4.9. displayed the load-slip curve for 15-degree inclined headed shear stud (HSS). Two push out test specimens were prepared & tested having 30-degree inclined headed shear stud. Here specimen 1 is named as HSS_30(1) and specimen 2 is named as HSS_30(2). HSS_30(Avg.) indicates the average load and slip value of specimen 1 and specimen 2. Both the push out tests specimens have a similar trend in results. Slide values grow up to maximum shear force as the load increases, and then the load drops. When the maximum shear force is applied, the load capability swiftly falls. It is seen from the load slip curve that

the average ultimate shear load carried per shear stud is 59.50 KN and maximum slip of the steel beam is 19.95 mm. First crack load is found to be 10.89 KN which is identified from the curve of load slip where the initial change of slope is observed. Shear load carried per shear stud is reduced to 46.31 KN at the point of failure. An essential mechanical criterion in steel-concrete composite construction that is invariably favoured and inextricably connected to the slip values is the structural member's ductility. A ductile part usually shows noticeable slippage or deformation before it stops warning users. A shear connector is deemed ductile if its slip characteristics are at least 6 mm, as per Eurocode 4. As the maximum slip value found here is 19.95 mm which is greater than minimum threshold, so 15-degree inclined headed shear stud may be treated as ductile.

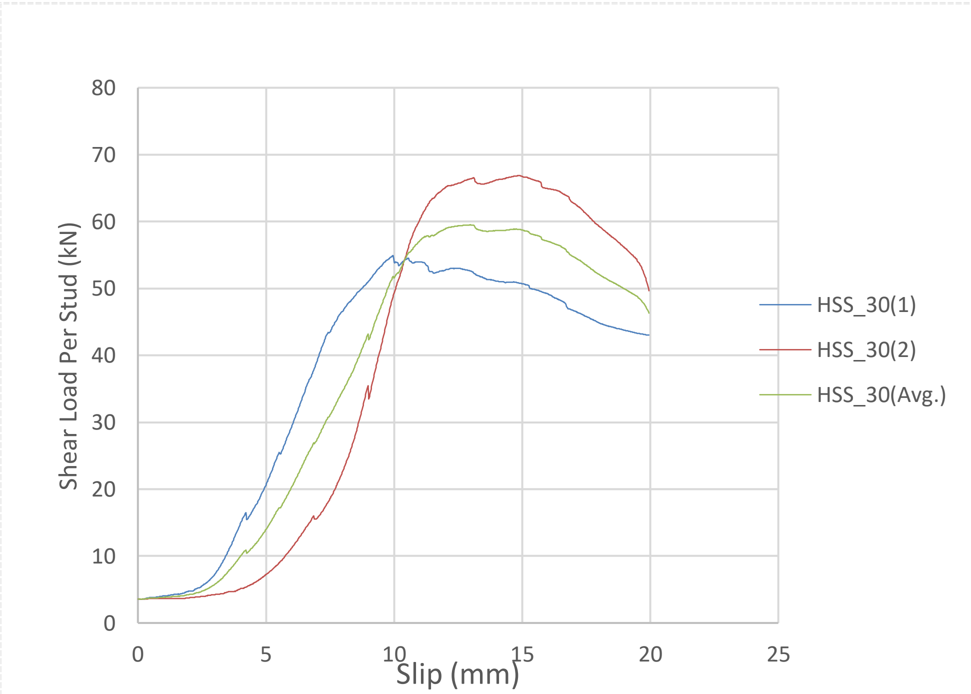


Fig. 4.9. 30-Degree Inclined Headed Shear Stud's Load Slip Curve

4.4.2 Failure Pattern

Fig. 4.10. & 4.11. shows the failure pattern of specimen having 30-degree inclined headed shear stud. It is seen from the figure that both the specimen fails due to

the damage of concrete slab. Concrete slab is damaged near the region of inclined headed shear stud. No failure of headed shear stud is observed.

Fig. 4.10. Failure Pattern of HSS_30(1) Specimen

Fig. 4.11. Failure Pattern of HSS_30(2) Specimen

4.4.3 Strain Energy Absorption at Ultimate Load

The energy that the body stores as a result of applying a load or displacement is known as strain energy. The work performed by the force equals the strain energy. It can be calculated using the load-deformation curve. The maximum peak point applied load area of stress-strain curve represents the strain energy per volume unit. Fig. 4.12. shows the related strain energy absorption curve. Here, per unit volume strain energy at ultimate load is found to be 410 Joule for push-out test specimen having 30-degree inclined headed shear stud.

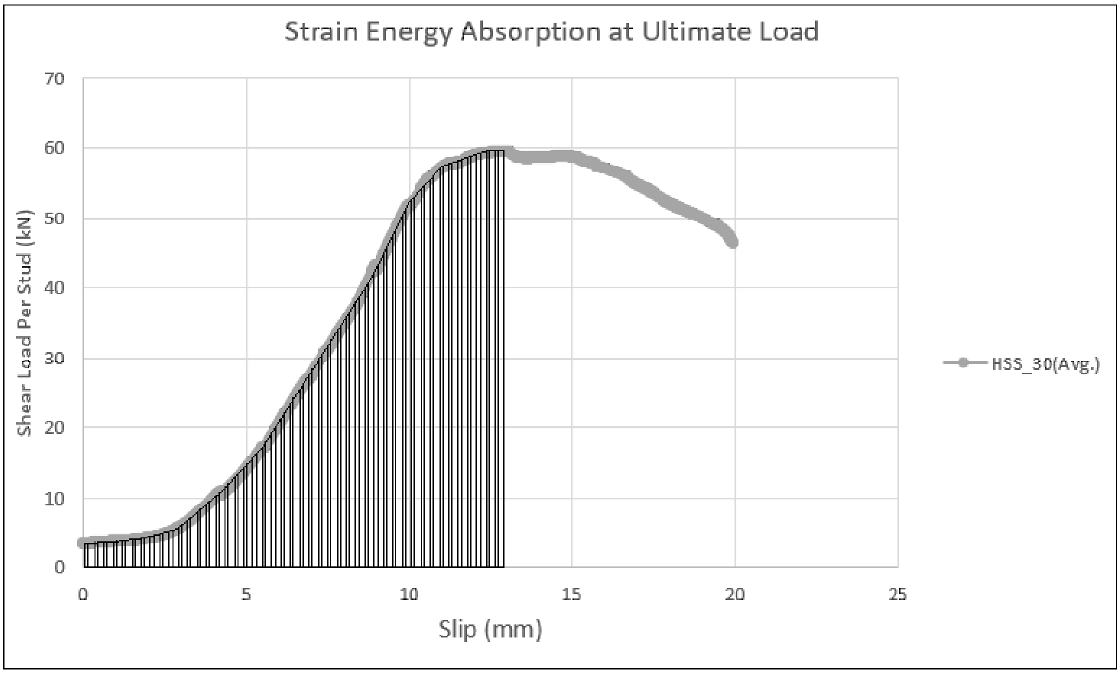


Fig. 4.12. Strain Energy Absorption at Ultimate Load of HSS_30(Avg.)

4.5 TEST RESULTS OF 45 DEGREE INCLINED HEADED SHEAR STUD

4.5.1 Load-Slip Behaviour

Fig. 4.13. demonstrates the load-slip curve for 45-degree inclined headed shear stud (HSS). Two push out test specimens were prepared & tested having 45-degree inclined headed shear stud. Here specimen 1 is named as HSS_45(1) and specimen 2 is named as HSS_45(2). HSS_45(Avg.) indicates the average load and slip value of specimen 1 and specimen 2. Both the push out tests specimens have a similar trend in results. Slide values grow up to maximum shear force as the

load increases, and then the load drops. When the maximum shear force is applied, the load capability swiftly falls. It is seen from the load slip curve that the average ultimate shear load carried per shear stud is 47.23 KN and maximum slip of the steel beam found 16.29 mm. First crack load is found to be 44.87 KN which is identified from the curve of load slip where the initial change of slope is observed. Shear load carried per shear stud is reduced to 41.3 KN at the point of failure. An essential mechanical criterion in steel-concrete composite construction that is invariably favoured and inextricably connected to the slip values is the structural member's ductility. A ductile part usually shows noticeable slippage or deformation before it stops warning users. A shear connector is deemed ductile if its slip characteristics are at least 6 mm, as per Eurocode 4. As the maximum slip value found here is 16.29 mm which is greater than minimum threshold, so 45-degree inclined headed shear stud may be treated as ductile.

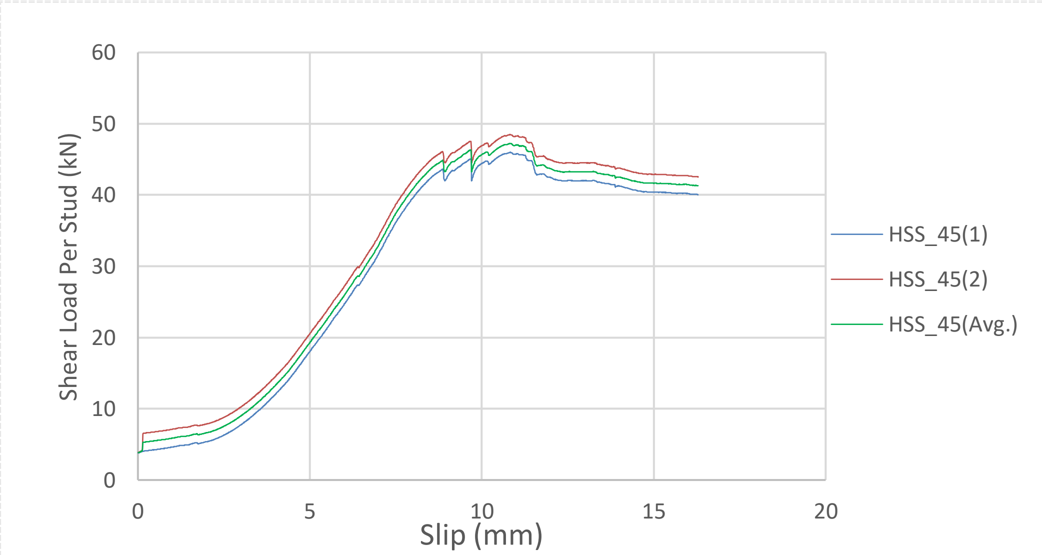


Fig. 4.13. 45-Degree Inclined Headed Shear Stud's Load Slip Curve

4.5.2 Failure Pattern

Fig. 4.14 & 4.15 shows the failure pattern of specimen having 45-degree inclined headed shear stud. It is seen from the figure that both the specimen fails due to the damage of concrete slab. Concrete slab is damaged near the region of inclined headed shear stud. No failure of headed shear stud is observed.

Fig. 4.14. Failure Pattern of HSS_45(1) Specimen

Fig. 4.15. Failure Pattern of HSS_45(2) Specimen

4.5.3 Strain Energy Absorption at Ultimate Load

The energy that the body stores as a result of applying a load or displacement is known as strain energy. The work performed by the force equals the strain energy. It can be calculated using the load-deformation curve. The maximum peak point applied load area of stress-strain curve represents the strain energy per volume unit. Fig. 4.16. shows the related strain energy absorption curve. Here, per unit volume strain energy at ultimate load is found to be 312 Joule for push-out test specimen having 45-degree inclined headed shear stud.

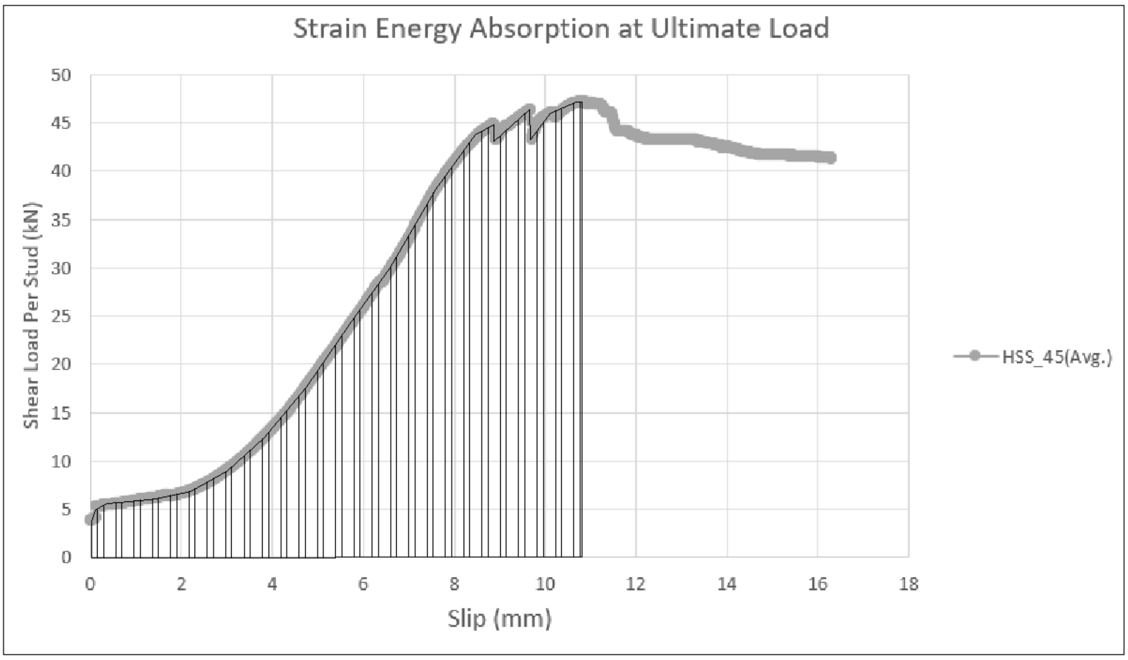


Fig. 4.16. Strain Energy Absorption at Ultimate Load of HSS_45(Avg.)

4.6 COMPARISON OF THE EXPERIMENTAL RESULT WITH THE STANDARD DESIGN CODES

4.6.1 Ultimate Shear Resistance According to CSA S6-14:

According to CSA-S6-14-2009, Shear capacity of an end-welded connections in a rigid floor that is headed or hooked and has a h/d ratio of at least 4.0 is; determined by the equations 4.1 & 4.2.

$$qr = 0.5\ \varphi scAsc\sqrt{(f'cEc)} \le \varphi scAsc\ Fu \qquad (4.1)$$

$$qr = \varphi scAsc\ Fu \qquad (4.2)$$

here,

q_r = Ultimate shear resistance connector, KN.

φ_{sc} = Shear connection resistance factor [0.8 is used]

A_{sc}= Connector sectional area, mm^2

$f'c$= compressive strength of concrete, MPa

Ec= Modulus of elasticity, MPa

Fu = Nominal capacity of shear connector, MPa

Ultimate shear strength:

$q_r = 0.5\ \varphi_{sc} A_{sc} \sqrt{(f'_c E_c)}$

$= 0.5*0.8*\frac{3.1416*16*16}{4}*\sqrt{26*24000}$ N

= 63530 N = 63.53 kN

Again,

$q_r = \varphi_{sc} A_{sc}\ F_u$

$= 0.8*\frac{3.1416*16*16}{4}*427$ N

= 68683 N = 68.68 kN

Hence, the maximum shear strength of a stud according to CSA S6-14 is 63.53 KN.

4.6.2 Ultimate Shear Resistance According to BNBC-2020:

The least shear strength of a single headed stud inserted in a stiff floor in composite construction can be determined by the lowest value of following two equation as per BNBC-2020.

$$Qn = 0.5\ ASC\sqrt{(f'cEc)} \qquad (4.3)$$

$$Qn = RgRpAscFu \tag{4.4}$$

Where, A_{SC} = Shear connector sectional area, mm^2

E_C = Modulus of Elasticity of concrete, MPa

Fu = Specified minimum tensile strength of a stud shear connector

Rg = group effect factor = 1.0

Rp = position effect factor = 0.85

Ultimate shear strength:

Qn = 0.5 $A_{SC}\sqrt{(f'cEc)}$

$= 0.5 * \frac{3.1416*16*16}{4} * \sqrt{26 * 24000}$

= 79412.5 N

= 79.41 KN

Qn = $RgRpAscF$u

= $1.0*0.85*\frac{3.1416*16*16}{4}*427$ N

= 72975 N

= 72.97 kN

Hence, the maximum shear strength of a stud according to BNBC-2020 is 72.97 KN.

4.6.3 Ultimate Shear Resistance According to AASHTO LRFD:

The minimum shear strength of single shear stud in composite construction determined as per AASHTO LRFD can be expressed as the lesser of the following equations 4.5 & 4.6.

$$P = 0.5A_{sc}\sqrt{f_{ck}E_{cm}} \tag{4.3}$$

$$P = A_{sc}f_u \tag{4.4}$$

In these expressions,

$A_{sc} = Area\ of\ the\ headed\ shea\ stud, mm^2$

$f_{ck} = Compressive\ strength\ of\ concrete, N/mm^2$

$E_{cm} = Modulus\ of\ Elascticity\ of\ concrete, N/mm^2$

$f_u = Yield\ Strength\ of\ Headed\ Shear\ Stud, N/mm^2$

Ultimate shear strength:

$P = 0.5A_{sc}\sqrt{f_{ck}E_{cm}}$

$= 0.5 * \frac{3.1416*16*16}{4} * \sqrt{26 * 24000}$ N

$= 63530$ N

$= 63.53$ KN

$P = A_{sc}f_u$

$= \frac{3.1416*16*16}{4} * 427$ N

$= 85853$ N

$= 85.85$ KN

Hence, the maximum shear strength of a stud according to AASHTO LRFD is 63.53 KN. Here, Figure 4.17 & Table 4.1 presents the comparison between ultimate shear strength calculated according to CSA S6-14, BNBC-2020, AASHTO LRFD and from test result. It is seen that the Ultimate shear strength found from experiment is approximately 50 percent greater than the calculated ultimate shear strength according to BNBC-2020 & AASHTO LRFD.

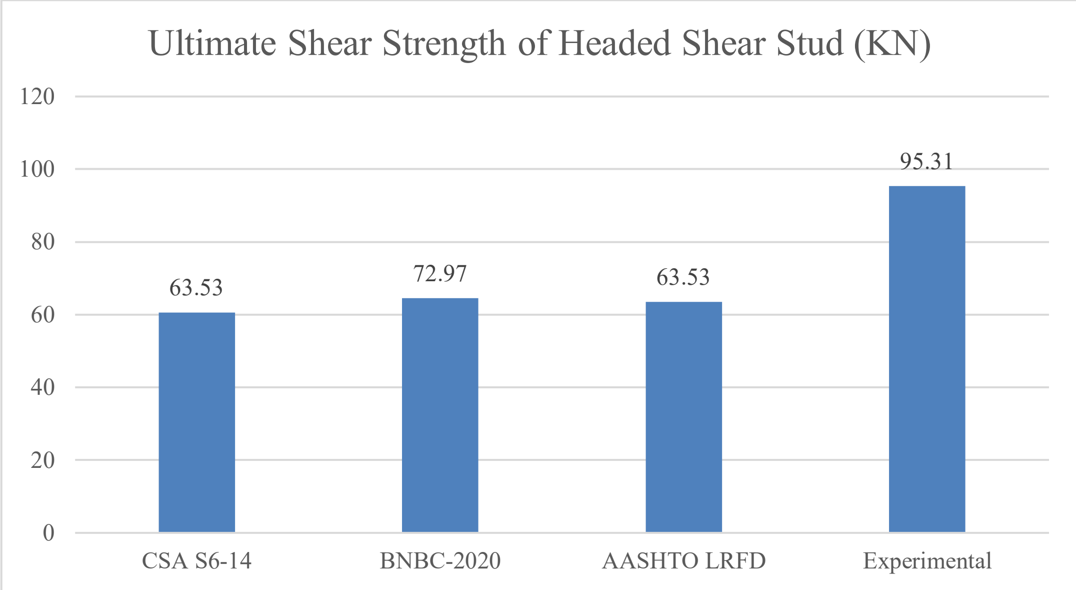


Fig. 4.17. Theoretical and Experimental Result Variation of Maximum Shear Capacity of Connector

Table 4.1 Theoretical and Experimental Result Variation of Maximum Shear Capacity of Connector Obtained from CSA S6-14, BNBC-2020, AASHTO LRFD

Parameter	CSA S6-14	BNBC-2020	AASHTO LRFD	Experimentally Found	$\frac{P_{Exp}}{P_{CSA\ S6-14}}$	$\frac{P_{Exp}}{P_{BNBC-2020}}$	$\frac{P_{Exp}}{P_{AASHTO\ LRFD}}$
Ultimate Shear Strength of a Headed Shear Stud (KN)	63.53	72.92	63.53	95.31	1.50	1.31	1.50

4.7 COMPARISON OF EXPERIMENTAL RESULTS

Fig. 4.18. and Table 4.2. displayed the compare of testing findings of push out test sample for perpendicular, 15-degree, 30-degree & 45-degree inclined headed shear stud. The first crack load is found to be 80 KN, 32.97 KN, 10.89 KN & 44.87 KN for perpendicular, 15-degree, 30-degree & 45-degree inclined headed shear stud respectively. The ultimate crack load is found to be 95.31KN, 73.025 KN, 59.50 KN & 47.23 KN and maximum slip at failure is found as 12.83 mm, 17.58 mm, 19.95 mm & 16.29 mm for perpendicular, 15-degree, 30-degree & 45-degree inclined headed shear stud respectively. When first crack is developed in

concrete slab, the strain energy absorption is found as 575 J, 459 J, 410 J & 312 J for perpendicular, 15-degree, 30-degree & 45-degree inclined headed shear stud respectively.

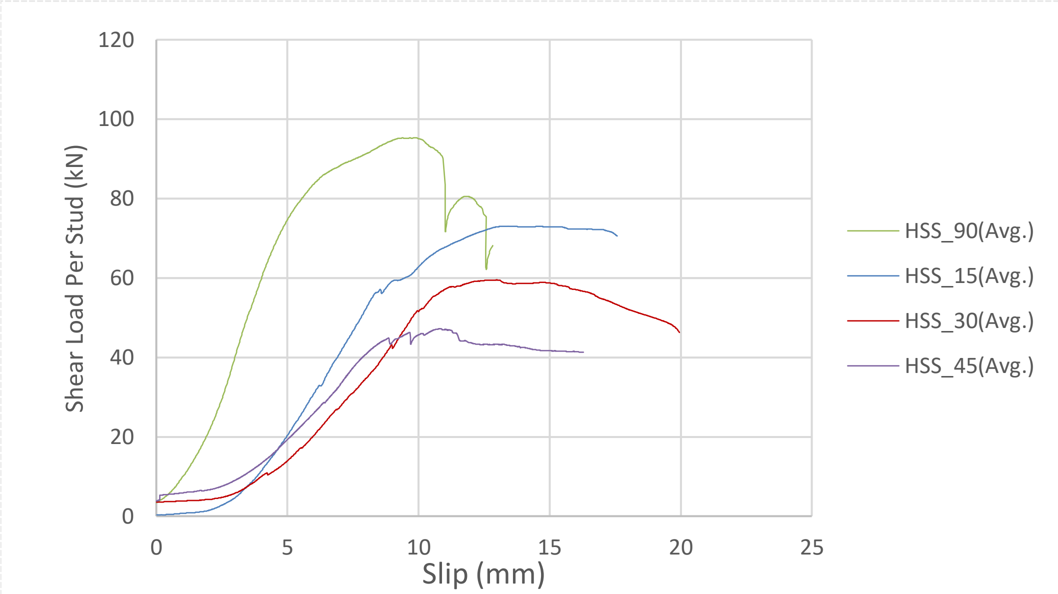


Fig. 4.18. Comparison of Load Slip Curve

Table 4.2. Comparison of Experimental Results

Specimen Type	First Crack Load (KN)	Ultimate Crack Load (KN)	Maximum Slip (mm)	Failure Pattern	Strain Energy at First Crack (J)
HSS_90(Avg.)	80.00	95.31	12.83	Stud Failure	575
HSS_15(Avg.)	32.97	73.00	17.58	Stud Failure	459
HSS_30(Avg.)	10.89	59.50	19.95	Concrete Failure	410
HSS_45(Avg.)	41.3	47.23	16.29	Concrete Failure	312

4.7 COMPARISON OF FAILURE PATTERN

Push out test specimen having perpendicular & 15-degree inclined headed shear stud fails due to the shear failure of headed shear stud and specimen having 30-degree & 45-degree inclined headed shear stud fails because of the failure of concrete slab. The breakdown patterns of different types of shear stud specimens considered in the study is shown below.

(a) 90 Degree Inclined

(b) 15 Degree Inclined

(c) 30 Degree Inclined

(d) 45 Degree Inclined

Fig.4.19. (a,b,c,d) Comparison of Failure Pattern

Chapter 5: CONCLUSIONS

5.1 KEY FINDINGS

The standard push-out experiment is executed accordance to the BS5400 in this study's experimental assessment of the structural functionality of inclined headed shear stud in steel-concrete composite structure. The findings from this experimental investigation are listed below:

1. The ultimate shear strength of perpendicularly placed headed shear stud as obtained from testing study is 95.31 KN. According to CSA S6-14, BNBC-2020 & AASHTO LRFD recommended design equations, the maximum shear strength of the same headed shear stud is 63.53 KN, 72.97 KN & 63.53 KN respectively. So, all the Design codes offer a cautious approximation of ultimate shear strength of headed stud.

2. When the headed shear connector is inclined along the direction of loading, the maximum shear loads carried through the identical headed shear stud for 15-degree, 30-degree & 45-degree inclination, are 73.00 KN, 59.50 KN & 47.23 KN respectively. So due inclination of the headed shear connector the ultimate shear force carrying ability is decreased by 23.38 %, 37.57 % & 50.45 % for 15, 30 & 45-degree inclination respectively as compared to perpendicular one.

3. The maximum slips of a headed shear stud for 90-degree, 15-degree, 30-degree & 45-degree inclination are formed as 12.83mm, 17.58 mm, 19.95 mm & 16.29 mm respectively. So due to the inclination of the headed shear stud, the maximum slip values are observed to be increased for all the headed shear connector and are well above the minimum value of recommended 6 mm as per the Eurocode-4. Hence, the behaviour of

perpendicular and all the inclined headed shear stud may be considered as ductile.

4. Considering the shear resistance capacity, perpendicularly oriented shear stud is formed as compared to inclined shear connector. But considering the ductility behaviour, 30-degree inclined headed shear stud showed better performance particularly. Hence, inclined shear keys may be a better choice for enhanced ductility of steel concrete composite structures.

5.2 RECOMMENDATIONS FOR FUTURE STUDY

Followings are the recommendations for future study related to this:

1. In this study only 16 mm diameter headed shear stud is considered. Performance of inclined headed shear stud having diameter larger or smaller than 16 mm may be investigated.
2. Throughout this experimental research, push-out experiment sample was prepared as per BS5400 which contains total 4 nos. of headed shear stud on two sides. Future numerical and experimental study can be conducted considering EC4 guideline for push-out test specimen where total 8 nos. of headed shear stud on two sides are used.
3. Structural performance of headed shear stud having inclination opposite to the direction of loading can be investigated.
4. Structural performance of inclined headed shear stud can be investigated considering the difference between the concrete's compressive strength and the headed shear stud's yield strength.
5. Performance of inclined headed shear stud having larger embedment length in concrete can be investigated numerically and experimentally.

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