



**PUSH OUT TEST USING
REINFORCEMENT BARS AS A SHEAR CONNECTOR
FOR COMPOSITE SYSTEM**

By

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ABSTRACT

In steel-concrete composite structures, the shear connectors are mostly used to transfer the longitudinal shear forces between the steel-concrete interfaces or to restrict longitudinal slipping and uplifting at the elements interface. This research paper assesses the feasibility of reinforcement bars as a shear connector in composite steel-concrete structures by using the push-out test. However, in the construction practice of our country due to various reasons, the application of composite structure, as well as shear connector, have not been dealt with in-depth. One of the main issues in our knowledge of composite structure is the material supply problem, this is also related to the development of the country even if they were made without shear connectors whether by lack of awareness or by negligence. Therefore, to reduce such things, this project investigates local materials that are easily available on site for composite structure.

This paper investigates reinforcement bars by experimental study of shear connectors in composite structures. The experimental investigation is conducted using six push-out test specimens with a new type of shear connector with diameters of 14 and 20mm reinforcement bars with concrete grade of C-20/25, C-25/30 & C-30/37. The test specimens were designed to study the effect of the following parameters on the ultimate load capacity: the height, the diameter of the shear connector, thickness of the concrete slab, profiled sheeting and the compressive strength of concrete. The experimental results were presented and discussed by focusing on the failure modes and load-slip behaviour.

Results are used to compare with those provided either by Standards, experimental work or found in the literature. The test phenomenon has shown that the shear capacity and ductility of shear connectors would significantly increase with the increment of diameter and compressive strength of concrete. It could be concluded that these steel-concrete composite beams connected by rebar connector show small deformation before failure, and so the failure modes were a brittle failure.

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NOTATIONS

H_p - Height of the steel profile decking

t - Thickness of concrete slab

d - Shear connector diameter

h_{sc} - Overall nominal height of stud/shear connector above flange

P_{Rk} - Characteristic value of the shear resistance of a single connector

δ_u - Maximum slip to failure

δ_{uk} - Characteristic value of slip capacity

P_{Rd} - Shear resistance of the welded headed studs

f_u - Shear connector ultimate tensile strength

f_{ck} - Characteristic cylinder compressive strength

f'_c - Compressive cylinder strength of concrete

E_c - Modulus of elasticity of concrete

γ_v - Partial safety factor for shear resistance

γ_c - Partial safety factor for concrete

K - Reduction factor

P_r - Shear resistance of the studs

b_o - Effective width of the slab decking

n_r - The number of stud connector in one rib

A_s - Cross-sectional area of stud connector

V_c - Shear strength due to concrete pull-out failure

A_c – Concrete pull-out failure surface area

Q_u - Ultimate shear capacity

ABBREVIATIONS

Re-bar - Reinforcement Bar

AAIT- Addis Ababa university institute of technology

ECAE- Ethiopian Conformity Assessment Enterprise

ACI - American Concrete Institute

AISC - American Institute of Steel Construction

ASCE - American Society of Civil Engineers

ASTM - American Society for Testing and Materials

BS - British Standards

CEN - European Committee for Standardization

HSC - High Strength Concrete

OPC - Ordinary Portland cement

Re-bar - Reinforcement Bar

SSD - Saturated Surface Dry

UTM - Universal Testing Machine

1. INTRODUCTION

1.1 GENERAL

In recent years, the composite steel-concrete structure is widely used for multi-storey buildings and composite concrete slabs and bridges by composite action of concrete slab and steel beam. Composite slab consisting of the profiled sheet used as long-term formwork during the construction phase and acts as an external reinforcement after construction. Contrasted with conventional concrete, better stiffness and strength is provided in the steel-concrete slab [4], The most usually used type of steel-concrete structure is made by providing a steel profile sheet at the base and concrete at the top when they combine to form the flexural composite member. This has been a successful construction practice for the past few years.

The composite behaviour between the profiled sheet and the concrete relies entirely on a reliable bond between their interfaces (fig 1.2 (b)). Accordingly, it will be secured by one or more of the following: [27]

- ✚ Mechanical interlock by using deformations in the profile sheet (indentations or embossments).
- ✚ Frictional interlock for re-entrant shape profiled sheet.
- ✚ End anchorages are provided by welded shear studs or one more sort of local connection between the concrete and the steel profile sheet.
- ✚ End anchorages by deformation of the ribs at the end of the profile sheeting.
- ✚ Natural bond of concrete and steel

The shear connectors are joined to the top flange of a steel beam across the profiled metal deck and recessed into the concrete slab to achieve integral action (fig 1.2). These shear connectors in composite girders transfer the longitudinal shear forces from the composite concrete slab to the steel girder. In addition, the transfer shear forces of these shear connectors are also resistant to uplifting forces through the interface of the composite concrete slab and steel beam due to the bending action.

The most commonly used form of shear connector is the headed shear stud (fig. 1.1) or the different forms of shear connections such as block, hoop and channel connections. Block and Hoop connectors and channel connectors are commonly used when large shear transfers are necessary, as an option for closely spaced shear studs. Stud connectors are that the welding system is simple and rapid, they provide a little obstruction to reinforcement in the concrete slab, and they have equivalent strength and stiffness in all directions to the stud. [1]

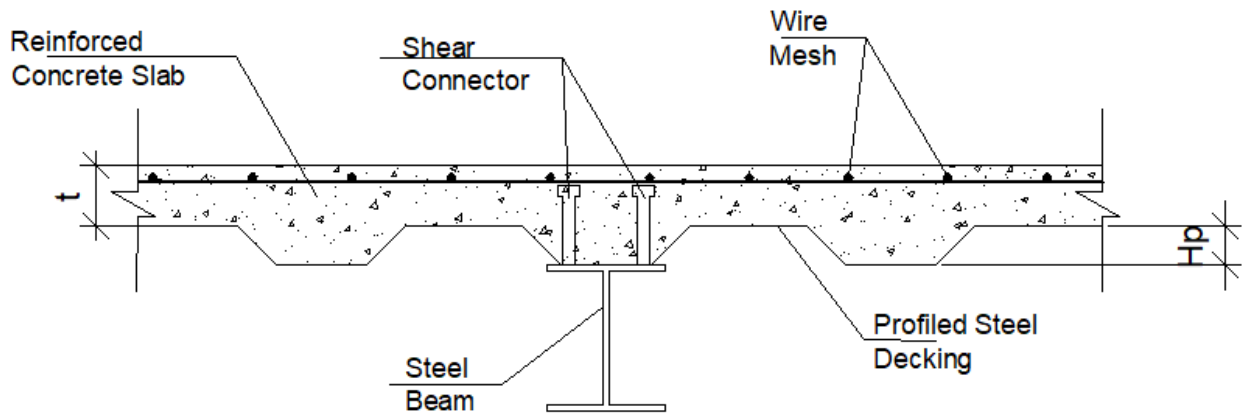
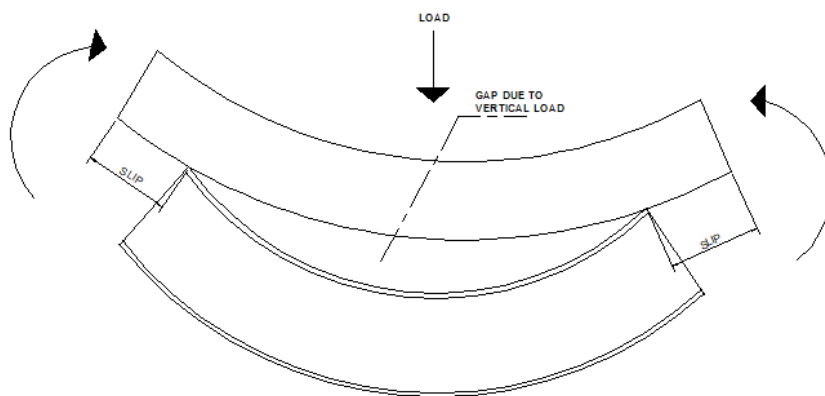
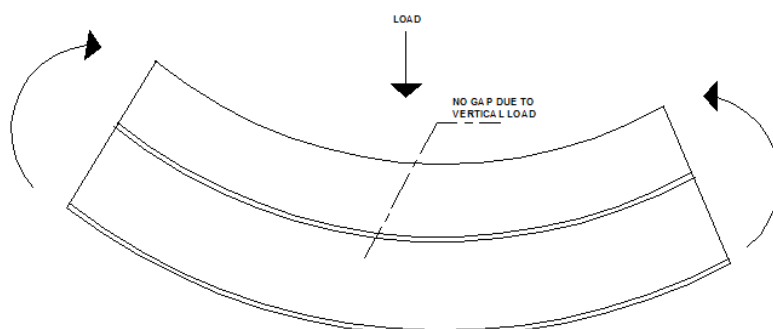


Fig 1.1) Steel -Concrete floor cross-section



a) No interaction between steel and concrete



b) Full interaction between steel and concrete

Fig 1.2): Deformed shape on a composite section

Deformed Rebar with hoop shape (fig 1.3) as a shear connector has the advantage to transfer the bond by adhesion or mechanical interlock by using ribs, lugs or indentations between the bar and the concrete compared to more commonly used headed shear stud. However, the shear capacity and behaviour of the rebar with hoop shape are not included on currently

available design codes and don't have a design equation like headed stud and channel shear connectors.



Fig 1.3): reinforcement bar shear connector with hoop shape

The main objective of the push-out experimental tests conducted in this paper is to determine shear connection capacity and load slip behaviour of rebar shear connectors with hoop shapes. The parameters studied in this experimental test are local sheeting geometry, diameter, and height of the hoop bar, the thickness of the slab, the strength of concrete and shear connection capacity. Shear connector failure and crushing of concrete are expected major types of failure in the composite

1.2. STATEMENT OF THE PROBLEM

The composite structure is a new concept in our country so far. To bring this innovation into practice it requires a ton of works, giving awareness's to the varied sectors of the society and conducting different investigations around it.

A composite slab with profiled steel decking has been demonstrated over the years to be one of the less difficult, faster, lighter, and economical constructions in composite systems. The system is very much acknowledged by the construction industry due to the many advantages over other types of floor systems. For a couple of years, the construction industry has been looking beyond the ordinary techniques and investigating for the better to prevail upon the present difficulties and consequently, composite slab construction is one of the practical alternatives. Recently in Ethiopia, many buildings, bridges were constructed by this floor system for instance mezzanine floor for warehouses, building expansion works, cafeterias and so on. However, they didn't consider the effect of shear connectors may be due to lack of knowledge, to minimize cost and unavailability of standard shear studs around construction sites. The shear connector is the most important component present in a composite slab where it interfaces with the steel and concrete in the composite structure.

The solution to this issue is introducing locally available, effective, and economical shear connectors like rebar, C-shape, I -shape, angle iron, and so on shear connectors while headed shear studs are required in large amounts for high load capacity and there is a limitation for the use in developing countries so it needs more working time and environment in Steel-

Concrete composite system and there are many types of research for headed studs not for others.

Reinforcement bars are more available in different diameters easily on construction sites. The composite slab can be successfully used for buildings as it meets all the requirements and demands fewer materials while shear studs need welding equipment like a gun. Ethiopia does not follow the advanced technology of the structural system, material usage, construction methods, and equipment as per the expected level therefore it will appreciate constructing modern technologies by using local materials.

1.3. OBJECTIVES OF THE STUDY

The inspiration of developing new materials for the shear transfer in composite structures is related to issues involving particular technological, economical or structural requirements. Hence, some other alternative shear connectors should be proposed for composite structures. The outcomes are to be contrasted with those provided by standards and to other data found in the literature.

The objectives are as follow;

- ✚ To describe the connection behaviour and to develop a system analyzes the contribution of the reinforcement bars as a shear connector to the shear capacity and the slip between the steel and the concrete.
- ✚ To study the influence of the shape, diameter, profile sheet and height of reinforcement bars as a shear connector in the composite system using the analysis of longitudinal slip in the concrete-steel interface
- ✚ To compare the shear strength capacity of the rebar shear connector with that of headed stud shear connectors given in specifications.

1.4. SCOPE AND LIMITATION OF STUDY

The extent of this paper is limited to the behaviour of reinforcement bars with hoop shape shear connectors in composite beams with and without local profiled metal decking slabs. This research was conducted using six specimen tests experimental by the push-out test are used to investigate shear connectors in steel and concrete composite structures. The research is limited only to buildings not for bridges due to the fatigue problems caused by live load and the push-out test determined the resistance to loading other than fatigue.

This paper is organized into five sections:

The first section gives a brief overview of the background on shear connectors in composite beams and the objective, limitation and scope of this thesis.

The review of past research associated with composite beams with or without profiled sheeting is presented in Chapter 2. The literature review is focused on experimental investigations of push-out tests with and without profiled sheeting along with some discussion of standard push test arrangement and design equations to determine the shear connector capacity.

In the third section, the methodology and arrangement of the push-out test experiment are presented. The experimental results of the push-out test are described in the third section. It also presents material test results, experiment setups, mode of failures and a summary of push-out test results.

A discussion of the push-out test results and the effect of different parameters on the behaviour of a shear connector is discussed in section four. A comparison of different strength prediction code equations of shear connectors is presented in this section.

The conclusions, recommendations and suggestions for future work are drawn in the final section.

2. LITERATURE REVIEW

2.1. INTRODUCTION

This chapter identifies and evaluates the previous relevant research related to composite beams with profiled sheeting and also focuses on experimental studies of different type of shear connectors in composite structures along with some discussion of standard push-out test arrangements and formula or design equations used in the professional codes to calculate the shear connector resistance. The main purpose is to identify gaps in the knowledge and understanding of the shear connector behaviour in steel-concrete composite beams with profiled sheeting.

2.2. SHEAR CONNECTORS

Composite beam systems using a composite slab with profiled metal decking are a common and very economical type of construction nowadays. As many types of research confirmed that this type of construction is economical by savings in labour cost and construction time, lightweight and strong. The efficiency of a steel-concrete composite beam lies in guaranteeing composite action between the steel girder and composite slab. Steel beams, shear connectors and reinforced concrete slabs are the main components of a composite beam. Traditionally, solid concrete slabs have been used with steel beams to construct a composite beam. However, after the development of profile metal decking, that turned out to be more mainstream in current composite construction to improve the tensile strength of the concrete slab after the curing period of concrete. Profiled metal decking can be set either parallel or perpendicular to the steel beam according to the requirement of the buildings as shown in Figures 2-6 and 2-7. Shear connectors are then used to resist longitudinal shear forces across the steel-concrete interface and to prevent uplift of the concrete slab from the steel beam by joining the profiled metal decking to the steel beam which is welded through the profiled metal decking to steel flange.

The current research is mainly focused on the study of shear connectors. Shear connectors are available in a variety of shapes and sizes to replace welded headed studs since the 1930s such as the bar, spiral, T-section, perfobond rib shear connectors, H or I-shape and channel connectors. Before the invention of profiled metal decking, the channels shear connectors were used to a large extent in composite beams. However, the headed shear connectors are among the most widely used in today's construction industry due to the thorough deck welding process and available design rules for welded headed shear connectors. A typically headed shear connector is welded to the top flange of the steel beam. These headed shear connectors are available in different diameters varies from 13 to 25 mm and height ranging from 65 mm to 150 mm. According to Eurocode 4, the minimum ultimate tensile strength of the stud should be 450 N/mm² and they should have an elongation of 15%. Further, it is mentioned in this code that the stud should be welded and the minimum head diameter should be 1.5d and the head depth should be 0.4d, where d is the shank diameter of the stud. The headed shear stud is shown in Fig 2.1.

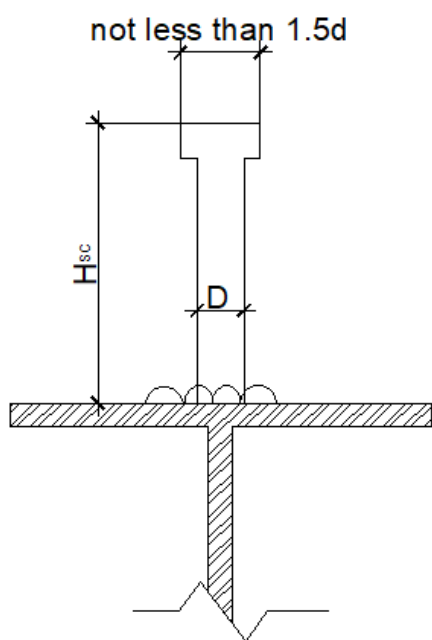


Fig 2.1): Headed shear stud according to EN 1994-1-1:2004

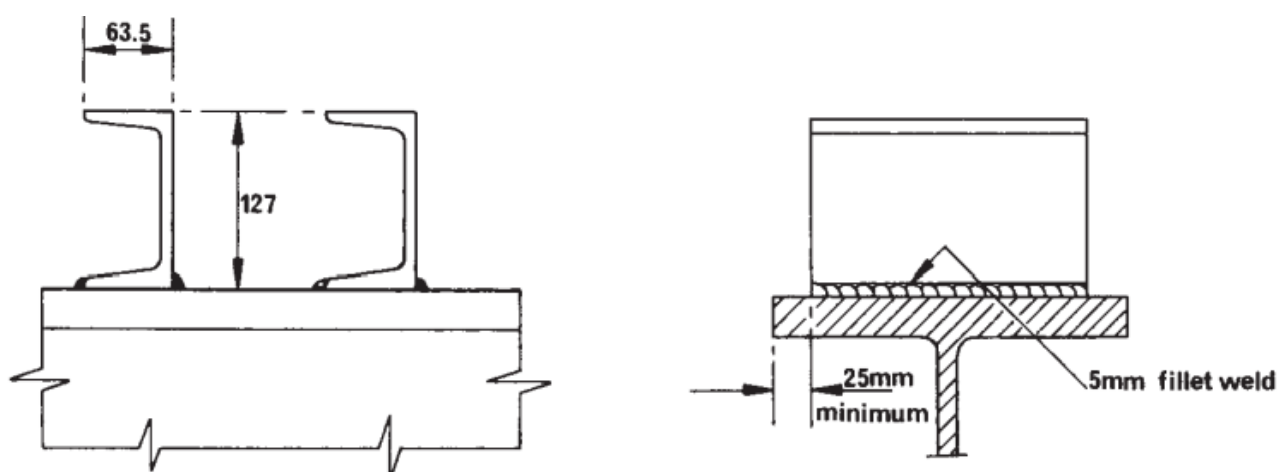


Fig 2.2): Channel connector (Ref: R.P. Johnson)

2.3. PUSH-OUT TEST TECHNIQUE

The push-out test technique has changed ever since it was introduced. This push-out test was established and used to determine the shear capacity of a shear connector and it consists of two identical concrete slabs connected to the steel beam with the help of shear studs and with vertical load applied to the top of the beam until it fails. The shear connector strength is the maximum vertical load applied to the push-out test divided by the total number of connectors. The existing standard push test arrangement has previously been developed by Lam (2007). The standard push test arrangement in Eurocode 4 was initially expected to study the

behaviour of headed shear studs in solid slabs. When the steel deck is available, provision is given in this code and need to be made in the standard push test arrangement. The standard push test arrangement according to Eurocode 4 is shown in Fig 2.3.

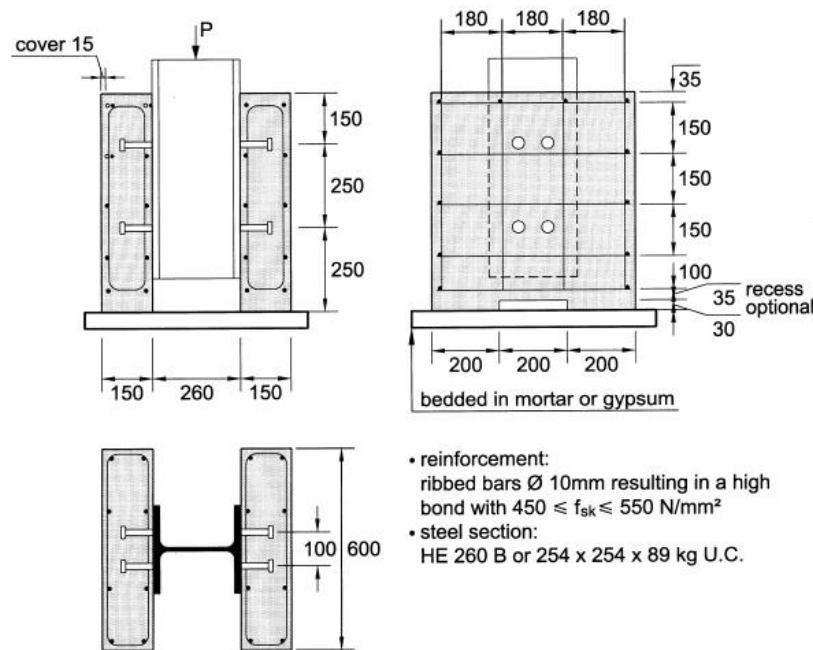


Fig 2.3): Standard push-out test specimen arrangement according to EN 1994-1-1:2004

According to Eurocode 4, the shear connector will be considered to be ductile if the slip at the steel-concrete interface reaches 6 mm after being determined from push tests. Large plastic deformation of the headed shear connector is characterized as good ductile behaviour. On the other hand, if the shear connector does not fulfil the limit of 6mm it is characterized as brittle behaviour of the headed shear connector have no sufficient deformation capacity. The slip capacity is the maximum slip measured at the characteristic load level as shown in Fig 2.4. The characteristic slip capacity P_{Rk} is taken as a minimum value of the slip capacity δu with 10% reduction or it can also be determined from the statistical analysis of push test results.

The load-slip relationship is influenced by many variables R.P. Johnson [1], including:

- ✚ Number of connectors in the test specimen,
- ✚ Mean longitudinal stress in the concrete slab surrounding the connectors,
- ✚ Size, arrangement and strength of slab reinforcement in the vicinity of the connectors,
- ✚ The thickness of concrete surrounding the connectors,
- ✚ Freedom of the base of each slab to move laterally, and so to impose uplift forces on the connectors,
- ✚ Bond at the steel-concrete interface,
- ✚ Strength of the concrete slab, and
- ✚ Degree of compaction of the concrete surrounding the base of each connector.

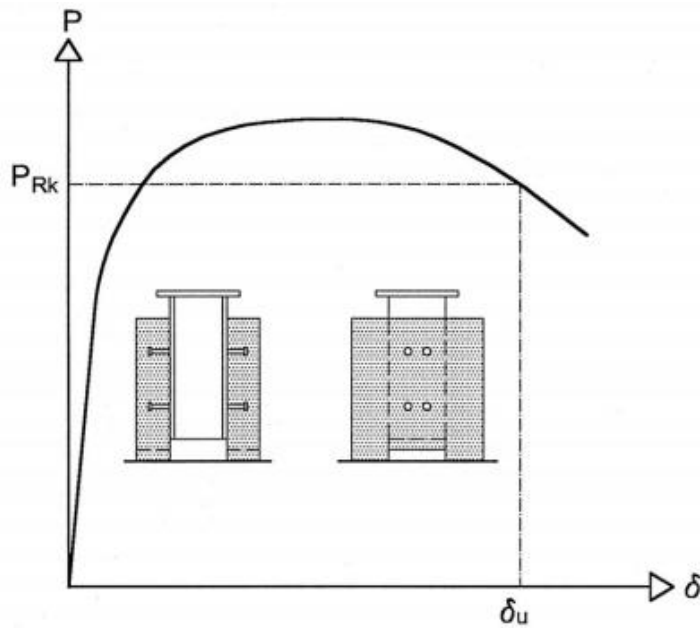


Fig 2.4): Determination of slip capacity, δ_u according to EN 1994-1-1:2004

An alternative method for the pushout technique is a British standard specimen arrangement with a small scale experiment with the size of the concrete slab (300x460x150mm).The British standards BS 5400-5 (fig 2.5) is adopted for the present investigation.

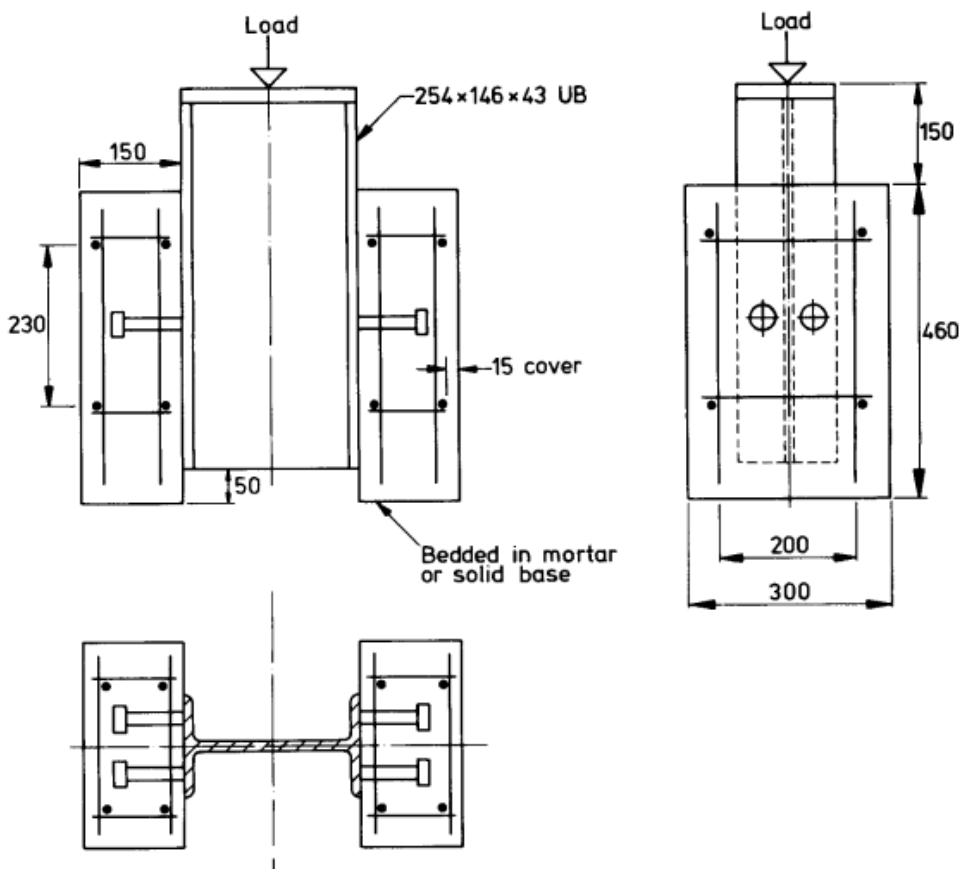


Fig 2.5): Standard push-out test specimen arrangement according to BS 5400-5:2005

2.4 DESIGN EQUATIONS FOR SHEAR STRENGTH

This section presents a review of different strength prediction equations for both composite beams with solid slabs and composite beams with profiled sheeting slabs whereas there is no design equation available for rebar shear connectors with hoop shape in composite construction. The equations utilized by various design codes are likewise clarified. There are two distinctive design equations are provided for the composite beam with profiled sheeting in transverse and parallel to the axis of the steel beam.

Eurocode 4 gives two distinct conditions equations one for the solid concrete slab and the other equation for using metal profiled decking

2.4.1. SHEAR CONNECTORS IN SOLID SLAB

The strength of the shear connection is mostly impacted by stud diameter, height and tensile strength of the connector, compressive strength and the elastic modulus of concrete. The shear forces are resisted by bending, tension or shearing at the base of the shear connection. The shear connector's base transmits the horizontal shear forces acting at the interface, while the head prevents the uplifting of the slab. The plastic deformation happens after reaching the ultimate strength of the stud.

In the most recent proposal of Euro code 4, EN 1994-1-1 clause 6.6.3.1 [12], the shear resistance of a headed stud is determined by

$$P_{Rd} = \frac{0.8F_u \pi d^2}{\gamma} \frac{1}{4}$$

$$P_{Rd} = \frac{0.29d^2(F_{ck}E_{cm})}{\gamma} 0.5$$

Whichever is smaller

Where, the units are N, mm;

d=diameter of the studs;

F_u = ultimate tensile strength of stud;

F_{ck} =compressive strength of concrete cylinders;

E_c = elastic modulus of concrete; the partial safety factor should be taken as 1.25;

$$\alpha = 0.2 \left(\frac{H_{sc}}{d} + 1 \right) < 1 \text{ and}$$

H_{sc} = height of the stud

2.4.2. SHEAR CONNECTORS USED WITH PROFILED STEEL SHEETING

The most common use of modern trapezoidal profiled sheeting with a central stiffening rib at the bottom of the trough has led to studs being set askew. Thus, shear connectors have to be placed either in the favourable (strong) or unfavourable (weak) position (fig 2.6). The favourable position of the stud is the location where the zone of concrete is larger in front of the stud in its load-bearing direction than the region behind it. The stud is considered to be strong in a favourable position and weak in an unfavourable position. Right now, there is no provision for the position of the stud whether is favourable or not in Eurocode 4. However, the American code AISC (2005) considers the position of the shear connector by introducing the position influence factor, which is 0.75 for favourably positioned studs and 0.6 for unfavourably positioned studs, in its shear connector resistance prediction equation.

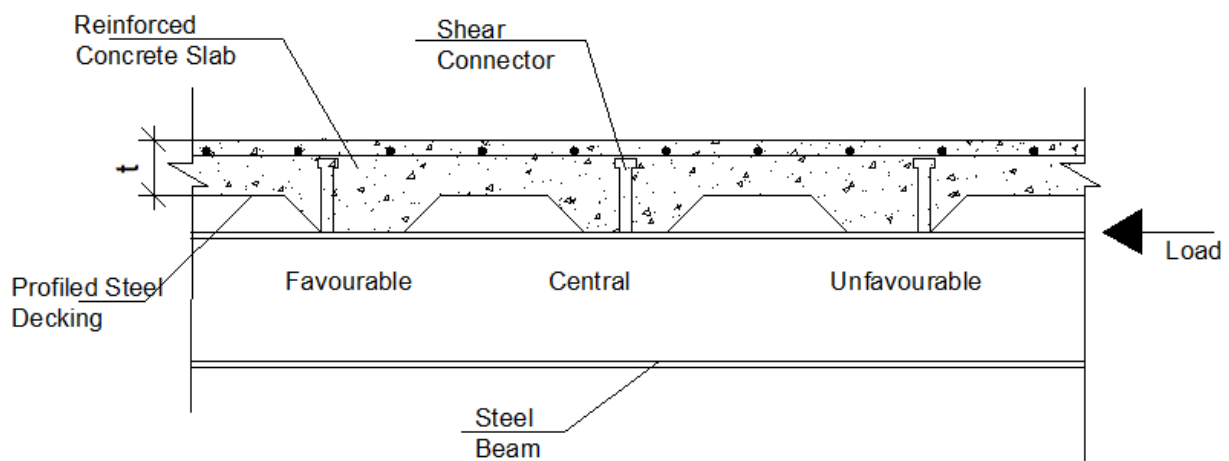


Fig 2.6): Favourable and Unfavourable Position of shear connector

Trapezoidal profiled sheet metal reduces the load slip capacity of the headed shear stud [3]. To take into account the weakening effect of the profiled sheeting, the most popular approach has been to apply a reduction factor to the shear connector resistance of push tests with solid slabs. Early equations for the shear connector strength were primarily for composite beams with solid slabs and were based on the results from push tests. The equation for the strength of the shear connector embedded in the profiled sheeting slab, which is based on the application of empirical reduction factor to the solid slab shear connector strength (P_{Rd}), is given in Equation.

The reduction factor (K_t) depends on the direction of metal profile decking lay down at the steel flange. Either it is parallel or transverse to the direction of the steel beam as shown in the figure below

$$P = K P_{RD}$$

a) Sheeting with ribs parallel to the supporting beams

$$K_l = \frac{0.6}{(nr)^{0.5}} \frac{b_o}{h_p} \left(\frac{H_{sc}}{h_p} - 1 \right) < 1.0$$

Where,

H_{sc} = height of the stud but not greater than $h_p + 75$ mm

H_p = height of the steel profile decking

b_o = effective width of the slab;

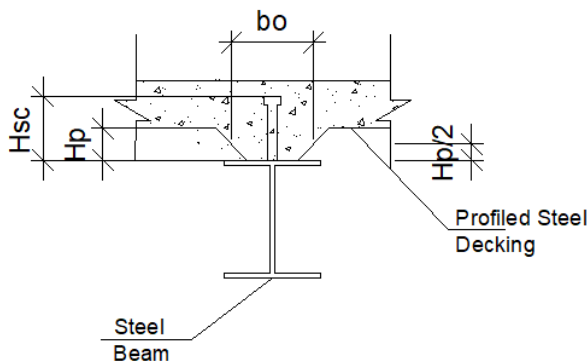


Fig 2.7): Composite Beam with profiled steel sheeting parallel to the beam according to EN

b) Sheeting with ribs transverse to the supporting beams:

$$K_t = \frac{0.7}{(nr)^{0.5}} \frac{b_o}{h_p} \left(\frac{H_{sc}}{h_p} - 1 \right) < 1.0$$

Where,

n_r = is the number of stud connectors in one rib at a beam intersection, not to exceed 2 in computations

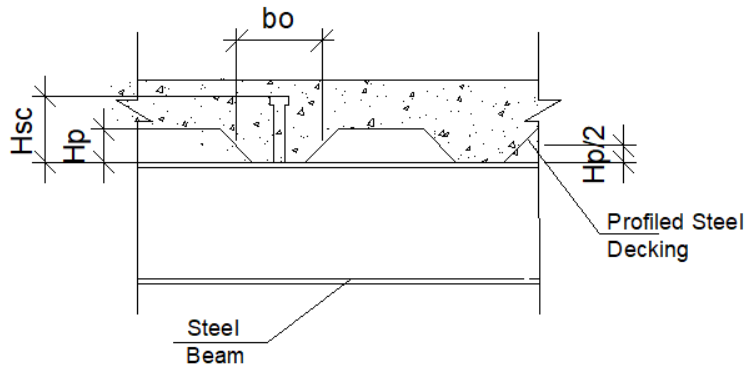


Fig 2.8): Composite Beam with profiled steel sheeting transverse to the beam according to EN

2.5. REVIEW OF PREVIOUS STUDIES ON BEHAVIOUR OF SHEAR CONNECTOR

This portion of this chapter reviews previous research used in the design of different shear connectors and factors that affect the resistance of the shear connector. Concrete strength and shear connector shape and dimensions are the main factors affecting the resistance of the shear connector in the push-out test. However, different investigators are available for several concepts which affect the strength of shear connectors which were assessed in those studies. The parameters include the strength of concrete, types of shear connectors, type of connectors steel grade, location of shear connectors, concrete configuration, diameter, and the number of shear connectors. In general, this part summarized the structural characteristics stated from the experimental studies and then proposed different parameters to investigate rebar shear connectors with hoop shape behaviour.

2.5.1 CONCRETE STRENGTH

S. Swaminathan, A. Siva, R. Senthil and Kinson Prabu [4], Investigated on Shear Connectors in Steel-concrete Composite Deck Slabs. The capacity to transfer longitudinal shear force by shear connectors mostly relies upon the strength of concrete against longitudinal cracking and the mechanical properties of the shear connectors. The connection between the two materials is generally accomplished by utilizing steel connectors, which might have various shapes. R.P. Johnson [1], expressed that practically all connectors are therefore so shaped that they provide resistance to uplift as well as to slip. Uplift forces are smaller than shear forces that it is not normally important to calculate or estimate them for design purposes, given that connectors with some uplift resistances are used.

Experimental studies carried out by Johnson [1] indicated that the concrete strength influences the mode of failure of shear connection between steel and concrete as well as failure load. H.B. Shim and K.S. Chung & S.H. Jang [5] studied the behaviour of shear studs in high strength concrete by push-out test. They found that the strength of concrete

significantly affects the load-slip behaviour and shear connector capacity. They mentioned that the load-slip curve and shear capacity of the shear stud is currently obtained from the experimental push-off test. Although the push-off test provides a clear insight into the behaviour of these connectors, the tests are relatively time-consuming and expensive. Hence analytical models are required for the analysis.

In 2012, Amar Prakash, N. Anandavalli, C. K. Madheswaran, N. Lakshmanan [6], experimented on the HSS studs having ultimate strength of 900 MPa and yield strength of 680 MPa with studs 20 mm diameter and 30 mm head diameter are used to test the effect of shear strength and stiffness of high strength steel (HSS) stud connectors push-out specimens which dimensions as suggested by BS5440. They concluded that the cross-sectional area of a headed stud connector is directly corresponding to its ultimate shear strength is influenced to a great extent by the concrete's compressive strength and modulus of elasticity.

J.G. Ollgaard, R.G.Slutter, J.W.Fisher[8] are concluded the shear strength of stud connectors embedded in normal-weight and lightweight concrete was primarily influenced by the compressive strength and the modulus of elasticity of the concrete. In their experiment on the capacity and behaviour of stud shear connectors, two distinct types of normal weight concrete and three types of lightweight concrete were examined.

The following empirical function described the test outcomes:

$$Q_u = 1.106 A_s f_c^{0.3} E_c^{0.44} \quad \text{Or}$$

$$Q_u = \frac{1}{2} A_s \sqrt{f_c E_c}$$

Where, f_c is the concrete compressive strength (ksi),
 E_c = the *Young's* modulus (ksi), and
 A_s = the cross-sectional area of the stud shear connector (in²).

2.5.2 SHAPE OF SHEAR CONNECTOR

Raj PV, Sathiya Bama P, M.E [9], presented an analytical and experimental investigation of shear connectors and they summarized the bolt and the stud type shear connectors were not that much effective as the channel shear connectors. The Channel shear connectors have more load carrying capacity when compared to the Stud type and Bolt type shear connectors. In this study, only the channel shear connectors had withstood the maximum load in both analytical study and experimental study. Therefore, the channel shear connectors have the ultimate shear capacity. Therefore, using a channel shear connector could be a good alternative. The channel connector has a higher load-carrying capacity than a stud connector. As a result, a few channel connectors will replace a large number of headed studs However, the disadvantage of angles and perfbonds is the difficulty of placing the steel bars through the connector openings and the rib holes. (Aida Mazoz, Abdelkader Benanane, and Messaoud Titoum 10)

Driscoll, G.C, &Slutter, R.G [11], tested Pushout specimen for stud 0.5 inch through 0.75 inch diameters. It was found that when the ratio of the studs having a height to diameter ratio less than 4.2 are penalized because of the possibility of their ultimate strength being reduced by fracture of the concrete. Stud pulling out is a suitable value for studs with height to diameter ratios greater than 4.2.

S.W.Liu&Y.Q.Liu [12] also studied on stud shear connector with a stud height of 100,200,300&400mm which influences the mechanical performance of the stud connector. If the stud height is increased stud failure is observed and better ductility is achieved similarly for short studs concrete failure with lower strength observed.

A deformed rebar shear connector with a hoop shape has the advantage to transfer bond forces by mechanical interlock rather than a plain bar because behaviours of reinforced concrete structures are highly dependent on the interaction between steel and concrete. Guohua Xing, Cheng Zhou, Tao Wu & BoquanLiu[15], investigated the bond stress experienced by plain bars is quite lower than that of the deformed bars given equal structural characteristics and details. Averagely, plain bars appeared to develop only 18.3% of the bond stress of deformed bars due to exhibited lug or other surface deformation.

Mohammed Hosainul Kabir [14], in his research on L-shape Rebar shear connector, recommended that a diameter not less than 16 mm can be effectively used in composite beams to transfer the longitudinal shear at the steel-concrete interface. He has performed sixteen push-out specimens with a parameter of study of height, length, the diameter of the rebar connector and concrete compressive strength. Finally, from experiment found a specimen with 40 MPa concrete the increase in ultimate capacity was found to be 69%, 105% and 118% when the rebar diameter is increased from 10 mm to 12 mm, 16 mm and 20 mm, respectively

2.5.3 PROFILED SHEET

Namdeo Adkuji, Girish Narayanroo [2], in this study slab created by composite interaction between the concrete and steel with embossments to improve their shear bond characteristics. However, it falls under longitudinal shear bond due to the complicated phenomenon of shear behaviour. To prevent the slip between the two members shear connectors are used. They argue that shear connectors have more stiffening capacity than using embossment. Without a shear connector, the bond is generally insufficient to ensure composite action up to failure. It is thus necessary to employ mechanical means or so-called shear transferring devices to achieve positive interlocking b/n the two materials.

B.S Jayas & Mel Hossain [16], researched the behaviour of headed studs in composite beams with ribbed metal decks perpendicular and parallel to the steel beam according to 18 full-size push-out tests and 4 pull-out tests. The main parameters were the longitudinal spacing of the studs and rib geometry of metal decks. Pull out failure modes were observed in push-out tests in specimens with a perpendicular metal deck. It was further observed that the stud spacing did not have much influence on the stud strength for tests with perpendicular metal decks. It was recommended that concrete failures for studs spaced less than six diameters should be

checked in the design and the shear capacity of the stud is dependent on the deck geometry and stud layout rather than on the longitudinal stud spacing.

[16] Proposed two separate empirical equations and, according to the linear regression analysis, for 38mm and 76mm decks heights.

For a 76mm deck:

$$V_C = 0.35\lambda\sqrt{f_c A_c} < Q_u$$

For a 38mm deck:

$$V_C = 0.61\lambda\sqrt{f_c A_c} < Q_u$$

Where;

V_c = shear strength due to concrete pull-out failure (N)

f_c = concrete compressive strength (Mpa)

A_c = concrete Pull-out failure surface area

1 for normal concrete

0.85 for semi-low concrete

0.75 for structural low concrete

Q_u =Ultimate shear strength from [8]

Rufael Redie [17], Studied the suitability of local sheet profiles for the production of steel deck reinforced composite slabs for Ethiopian construction practice. This research concluded that locally manufactured profiled steel sheet and concrete composite slab construction for the building is economical in comparison to conventional slab construction techniques until now. Therefore, it is advantageous for local construction industries in terms of direct cost and construction time saving to incorporate this new technique for future development.

2.5.4 DIAMETER OF SHEAR CONNECTOR

The shear capacity of the shear connector is proportional to its cross-sectional area as the above empirical function described [8]. Sameh S.Badie, Mahder K.Tadros [12], experimented on large studs in bridge decks. They used studs instead of the regularly used ones. The larger (31.8 mm (10/8 inch) studs showed 30% less slippage at ultimate load than the smaller studs which commonly used 19.1 mm (3/4 inch) and 22.2 mm (7/8 inch) studs.

Qian Wang, Yuqing Liu, Jie Luo & Jean-Paul Lebet [20], performed 12 push-out test specimens of stud shear connectors with large diameters (22mm, 25mm and 30mm) and high strength. Shear resistance of 30 mm studs was 39.6% higher than specimens with 22 mm studs hence The author recommended using large diameter and high strength studs to improve on the composite construction, reduce the time of construction and make the steel and the concrete work together better

2.5.5 NUMBER OR SPACING OF SHEAR CONNECTOR

To further develop shear connection strength and slip between steel and concrete one solution is to increase the number of connectors or decrease spacing. Hugh Robinson [21] analysed 17

different types of shear connections for the parallel and perpendicular metal deck. He establishes that the slip and the strength of pair of studs per rib were 1.3 times higher than that for a single stud per rib.

2.5.6 ARRANGEMENT OF SHEAR CONNECTORS

Stephen J Hicks, 4m span composite beam and companion push tests were undertaken to investigate the load-slip performance of various stud connectors set in the favourable, unfavourable and central positions (fig2.6). The tests indicated that the resistance of a pair stud per rib was better than three studs per rib and design equations in BS 5950-3.1 and ANSI/AISC 360-10 were unconservative by up to 45%. As a direct result of this work, an alteration was made to BS 5950-3.1 in 2010. Furthermore, great ductility was achieved in push tests with favourable studs. The characteristic resistance of centrally welded shear connectors, obtained from the beam tests experiment, showed close agreement with the characteristic resistance anticipated from BS 5950-3.1 the resistance obtained from the beam test was higher than push tests by 46% and also the ductility by 269%. On the other hand, the shear connector resistance for pair studs was almost the same as both beam and push tests.

2.5.7 EFFECT OF TRANSVERSE REINFORCEMENT

A.L.Smith & G.H.Couchman[23], investigated the effect of mesh position, transverse spacing of shear connector number of the shear connector and slab depth in 27 push-out tests. They founded that the transverse spacing of the shear connectors has a little effect on the resistance and also shear connector resistance increased with an increase in the slab depth. They noticed that placing the transverse reinforcement on top of the ribbed deck increases the shear strength of studs by 30% than placing the transverse reinforcement in the top layer.

2.6. SUMMARY AND CONCLUSIONS

The main objective of this paper is to develop a new type of shear connector and to study its behaviour in the composite push out model welded through profile sheeting. The experiment key variables selected for this research in the parametric study include the effect of the concrete strength, height of shear connector, and diameter of rebar shear connector and the shape of locally available profiled sheeting.

3. DESCRIPTION OF EXPERIMENT

3.1 INTRODUCTION

This part describes the main experimental work carried out to investigate the feasibility of reinforcement shear connectors in composite structures as an alternative to welded shear connectors using the push-out test. This chapter includes the push-out test setup, test parameters, Material properties and test results. The main parameters conducted in this experimental study were the effect of concrete strength, the diameter of shear connectors, thickness of concrete and the profile sheet metal.

3.2 PUSH-OUT TEST SETUP

As shown in fig 3.1, the experiment consisted of two identical reinforced concrete slabs connected to the flanges of a steel beam due to shear connectors, two dial gauges and a 50-ton hydraulic jack. 10mm wire meshes have placed both faces of concrete are anchored by welding, shear connectors welded to the steel profile before they are embedded by concreting. The concrete specimen was located on the testing rig under the centre of a 50-ton hydraulic jack. A spreader steel plate was used between the hydraulic jack and the steel section to distribute the load evenly on the specimen. The shear load produced along the surface between the concrete slab and the steel beam flange because of this vertical load will transfer to the concrete slabs through shear connectors.

To calculate the displacement two dial gauges were located on the top of the concrete to find the slip between the concrete slab and steel beam. The experimental test setup as shown in Fig 3.1 the increased in vertical load caused the movement of the composite concrete slab relative to the steel beam leading to failure of the specimen. Finally, slip correspondingly to the vertical load plotted.

Hot rolled beam section (HEA 160) proposed in this project. The relative displacement between the steel girder beam and the concrete slabs versus applied load will record for each test

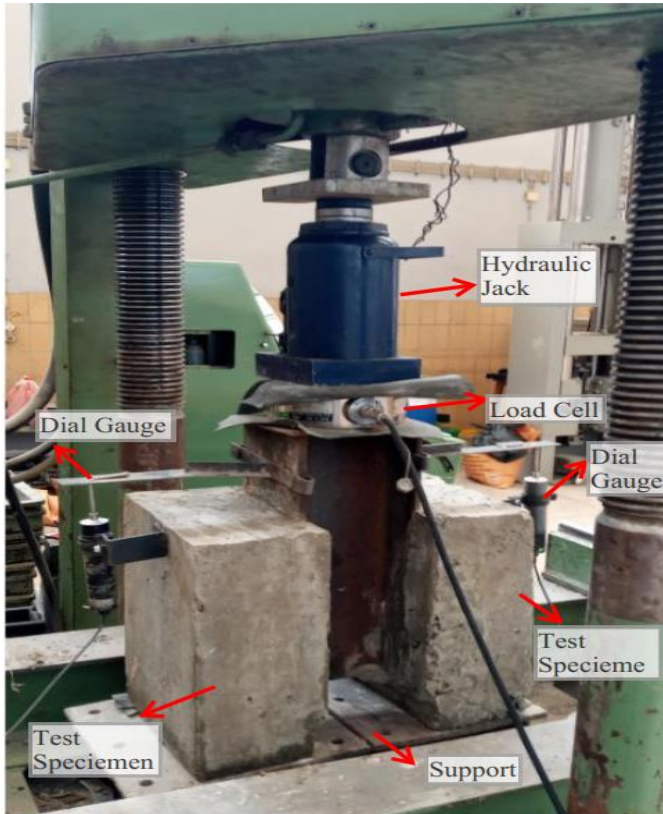


Fig 3.1): Experimental test setup

3.3 TEST SPECIMEN

3.3.1 DESCRIPTION OF TEST SPECIMENS

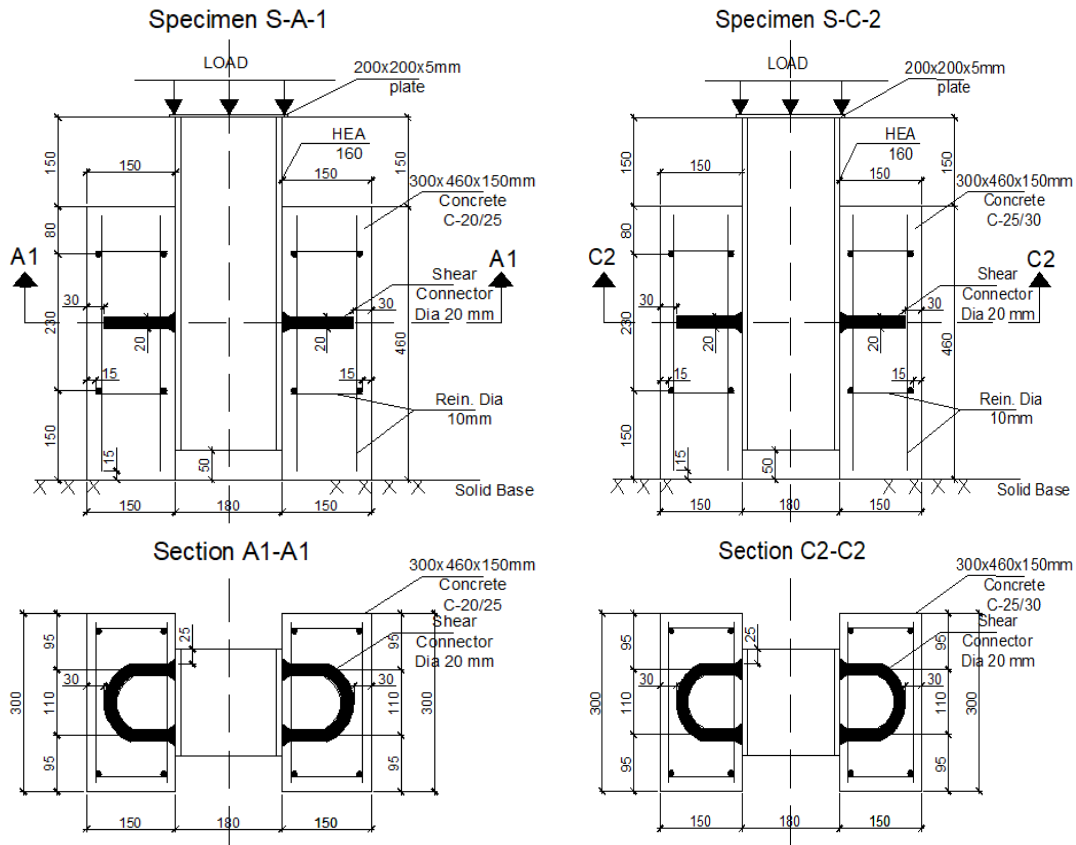
To determine the influence of steel profile sheet and connector geometries on the shear strength of connectors embedded in the concrete slab and on shear strength and failure modes, push-out tests were conducted. The experimental program consisted of six push-out tests. As has already been mentioned, the whole experimental procedure is performed to the specifications of BS 5400-5:2005 rather than used Euro code 4 to minimize the difficulties from the weight of specimens of concrete.

No.	Test Specimen	Diameter(mm)	Concrete Slab Thickness(mm)	Concrete Cube Strength, (Mpa)	Profile Sheet	Specimen Comparison Parameter
1	S-A-1	20	150	26.88	NO	A-All condition
2	S-C-2	20	150	32.02	NO	C-Concrete strength
3	S-C-3	20	150	39.91	NO	C-Concrete strength
4	S-P-4	20	150	26.88	YES	P-Profile sheet
5	S-D-5	14	150	26.88	NO	D-Rebar diameter
6	S-T-6	20	110	26.88	NO	T-Thickness of concrete

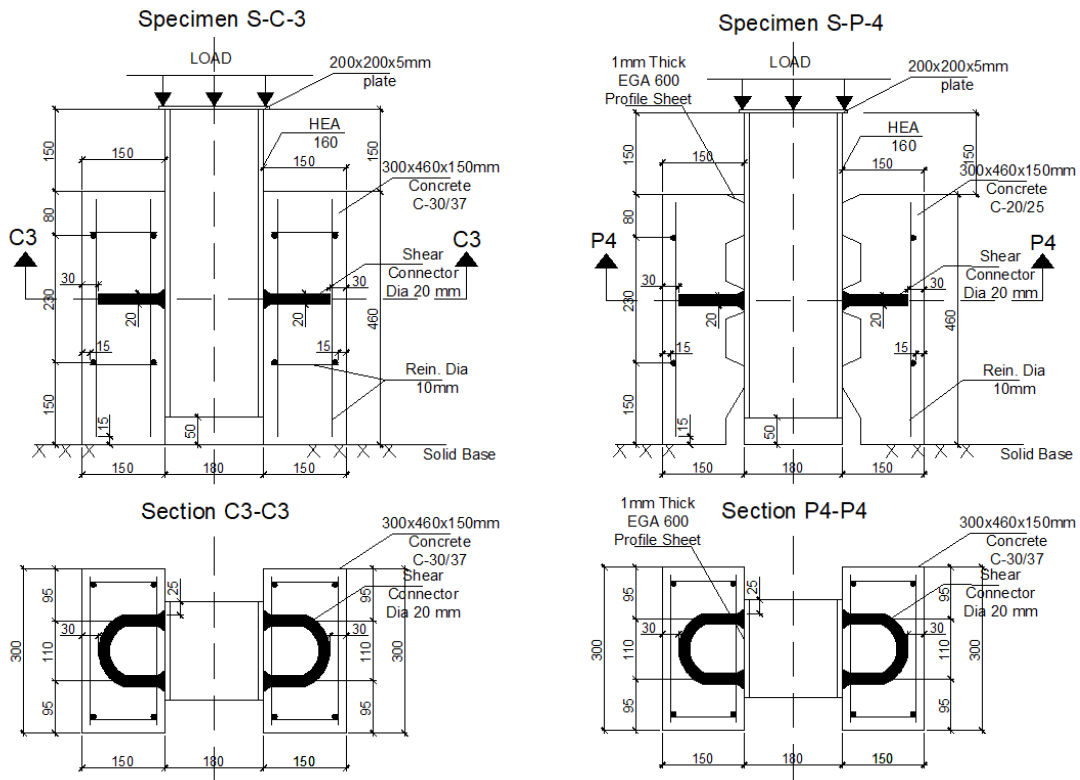
Table 3.1: Specimen preparation

NOTE:

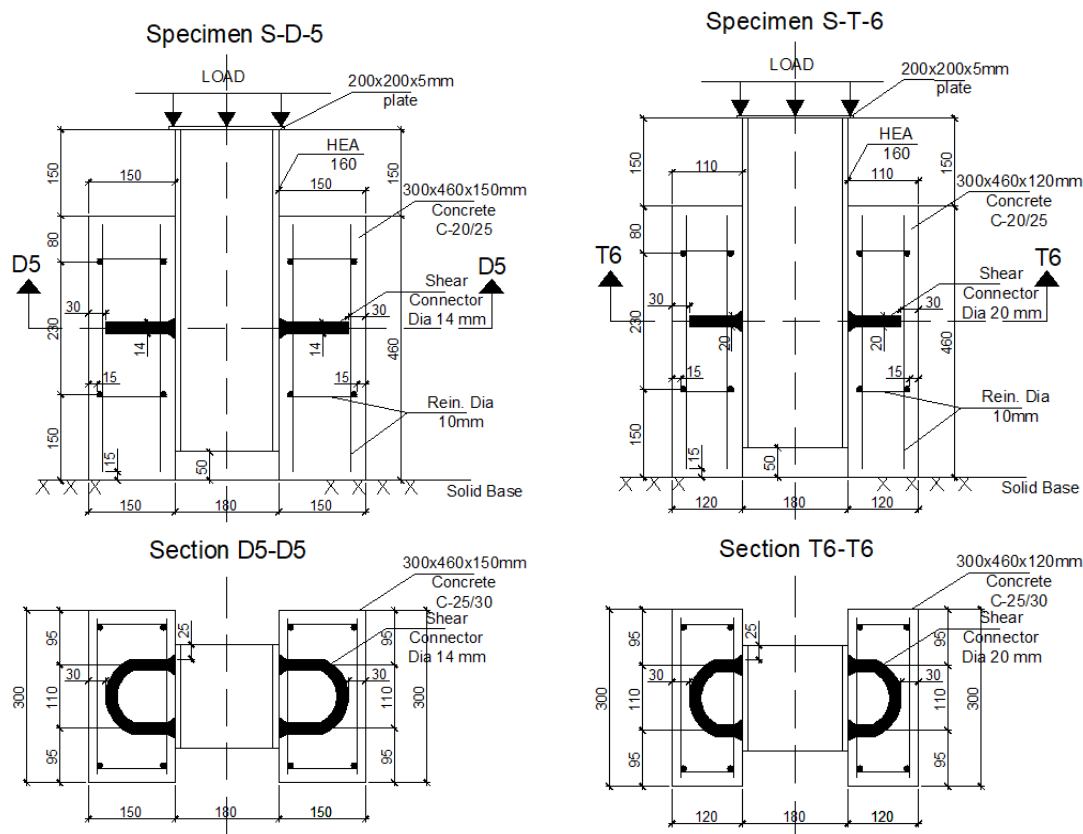
- ✚ The thickness of profile sheet is 1mm so that it is practicable to weld shear connectors to sheeting metal *EUROCODE 4* [27]
- ✚ Ultimate tensile strength of shear connector f_u between 450-600 N/mm² and min elongations of 15%. [27]
- ✚ The overall depth of the composite slab shall not be less than 90 mm, and the topping not less than 50 mm. [27]
- ✚ The spacing of the reinforcement bars should not exceed $2h$ and 350 mm and the amount of reinforcement in both directions should be not less than 80 mm²/m. [27]. 10 mm diameter bar is used to reinforce the slab in both directions.
- ✚ The concrete cover above the head of the shear connector for the solid slab is 30mm thick. *EUROCODES 2* [28]



a) S-A-1 & S-C-2



b) S-C-3 & S-P-4



c) S-D-5 & S-T-6

Fig 3.2): Specimen Details, a), b) and c)

The specimens consisted of six push-out tests grouped in four parameters. The test specimens were designed to study the effect of the following parameters on the ultimate load capacity: the diameter of reinforcement bar connector, the thickness of concrete, the compressive strength of concrete and also the effect of profile sheet metal. Details of each push-out specimen are provided in fig 3.1 with the dimensions of specimens, the compressive strength of concrete slab and provided profile sheet metal. As an illustration, fig 3.1 shows four tests were selected from the nominal C20/25 concrete compressive strength class, and two tests from the nominal C25/30 & C30/37 class according to EN-1992-1-1 [28], four 150mm thick solid concretes and one profiled sheet specimens with one 110mm thickness concrete are used for comparative study.

3.3.2 MATERIAL PROPERTIES

For the fulfilment of the research the following materials are used:

3.3.2.1 REINFORCEMENT BAR SHEAR CONNECTOR

In composite systems, shear connectors have a high load carrying capacity and offer large resistance for failure by shearing. The type of connector proposed for the analysis was “HOOP” shape reinforcement bars by considering shear, uplift pressures, and Ease of operation during construction. And also, no specific skill is required for welding shear connectors to produce concrete slabs. The detail is shown in fig 3.4.

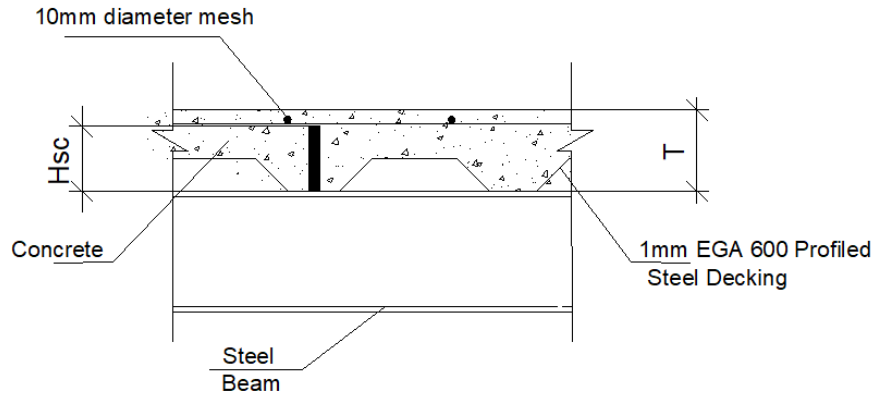


Fig 3.3): Composite Beam section detail with profiled steel sheeting transverse to the beam according to BS

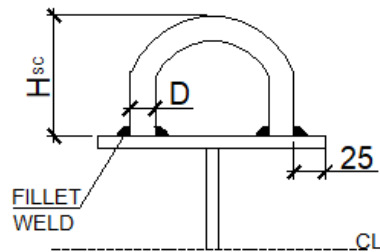


Fig 3.4): Shear connector geometry

The rebar shear connector highly depends on the bond strength between the rebar and the concrete and its mechanical properties. Bond strength is influenced by its physical structure, the thickness of the concrete cover, and any possible coatings on the steel, bond strength can be improved with bars that are ribbed or deformed, while this develops a more bearing surface in contact with the concrete.

The mechanical properties of shear connectors, minimum values are generally given in most of the specifications based on various experiments, are yield strength, ultimate strength (or maximum tensile strength), and elongation as parameters for characterization.

Tensile tests of rebar samples were carried out under displacement-controlled mode to capture the complete stress-strain curves. The instrument used for testing is Universal Testing Machine (UTM) with a loading capacity is 200 tons, and the strain rate for this testing is 12.5 mm/minute, based on ASTM A370 [28].

The test has shown qualified mechanical properties with the yield strength over 500 MPa, ultimate tensile strength over 620MPa, and elongation rate over 23%. The mechanical properties of steel reinforcing bars for each diameter are summarized in ANNEX B of this thesis.

Tested Diameter	Yield Load (KN)	Failure Load (KN)	Yield Strength (Mpa)	Ultimate Strength (Mpa)
10.00	38.70	47.90	492.99	610.19
14.00	77.17	95.76	501.54	622.38
20.00	164.37	208.36	523.46	663.57

Table 3.2: Mechanical properties of steel reinforcement bars

3.3.2.3 CONCRETE

Concrete is the most practical construction material which is high in compression and low in tension. The concrete strength is the main factor affecting the behavior of shear connections and influences the mode of failure of shear connection between steel and concrete as well as failure load. The Area of the concrete slab for this push out specimen was taken as 300x460 mm width while the depth of the concrete slab is equal to the stud height plus 30 mm of concrete cover

The concrete is composed of cement, sand, gravel, and or admixtures. Several proportioning methods are available to decide the proportion of raw materials. The one described here is based on the weight method from the American Concrete Institute [30]. In order to use this method, certain physical properties of the materials were determined in the AAU laboratory before designing the mixtures. These are as follows:

1. Bulk-specific gravities and percent of moisture present in the saturated surface dry (SSD) condition for both the coarse and fine aggregates.
2. Rodded unit weight of the coarse aggregates.
3. Fineness modulus of the fine aggregates.
4. Free moisture is present in both the coarse and the fine aggregates.

The following procedures are followed ACI Method of Concrete Mix Design

1. Choice of a slump; The slump was intended to be 75 – 100mm from table 6.3.1[30]
2. Choice of a maximum size of aggregate; the maximum size of aggregate is 40mm, which was taken from the gradation of the aggregates.
3. Estimation of mixing water and air content From Table 6.3.3[30], the recommended mixing water amount is 160 kg/m³, and the air content recommended is since no admixture or any other air-entraining mechanism used corresponds to 1.0%.
4. Selection of water-cement or water-cementitious material ratio; According to Table 6.3.4 [30] w/c ratio to give a 28-day compressive strength of 25,30,37 MPa is 0.62,0.55,0.48 respectively.
5. Calculation of cement content
6. Estimation of coarse aggregate content
7. Estimation of fine aggregate content
8. Adjustments for aggregate moisture
9. Trial Batch Adjustments

Maximum size of aggregate	40mm						
Slump	30-50						
Coarse Aggregates		Fine Aggregates					
Bulk specific Gravity	2.66	Fineness Modulus	2.92				
% Absorption	1.64	Bulk Specific Gravity	2.62				
Dry Rodded Density (kg/m ³)	1636.3	% Absorption	1.7				
No.	Grade	Water content (kg/m ³)	Water/Cement	Cement(kg/m ³)	CA(kg/m ³)	FA(kg/m ³)	W: C: CA: FA Ratio
1	C20/25	160	0.62	258.0645161	1160.8685	841.0670305	0.62:1:4.50:3.26
2	C25/30	160	0.55	290.9090909	1160.8685	808.2224557	0.55:1:3.99:2.78
3	C30/37	160	0.48	333.3333333	1160.8685	765.7982133	0.48:1:3.48:2.29

Table 3.3: Quantities of raw materials for concrete mixture

The compressive strength of C20/25, C25/30, and C30/37MPa were carried out using the above proportions. The properties of the concrete in the trial mix were compared through cube tests and by taking the average value (table 3.1) of three cube (100x100x100 mm) specimens casted at the same time as the concrete slabs. Finally, the mix design was corrected as per the results.



Fig 3.5): Cube test for concrete strength determination

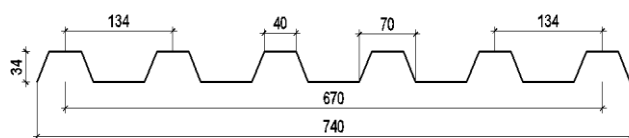
3.3.2.3 COLD FORMED PROFILED SHEET

Cold formed steel sheet is a lightweight material with many advantages such as high durability, structural performance, and structural economy. One of the main advantages of this construction technique is that its economic benefit. However, local industries have been fabricating steel profiles, it has been using for vehicle bodies and mainly for roofing and cladding purposes. These profiles are also suitable to implement steel-concrete composite slab construction technology. However, this technology does not practice in Ethiopia due to different reasons. The entire locally manufactured profiled steel sheets' have different standard forms. These forms of profile sheets such as EGA-300, EGA-400, EGA-500, EGA-600 & EGA-700 have been used for different purpose.

There are two commonly used types of decking profiles, the re-entrant profile, and the trapezoidal profile. The shape of the profile is controlled by several points. Some of these points are:

- ✚ End anchorages are provided by welded shear studs or one more sort of local connection
- ✚ The requirement to increase the efficiency of the cross-section in bending
- ✚ The requirement to develop sufficient composite action with the concrete by use of indentations or by the shape of the profile itself
- ✚ Well-organized transfer of shear

In this experiment, 1 mm thickness of EGA 600 trapezoidal profiled sheets is selected to relating with standard profile sheet and according to *EUROCODE 4* [27]. The dimension of profiled sheets is 740 mm x 1 mm (length and thickness) respectively. The details of the profiled sheet are shown in fig 3.6.



EGA 600

Fig 3.6): Geometry and property of Steel deck

Galvanized steel sheet (kality steel industry)	
Thickness	1mm
Area	1000mm ²
Weight	7.85kg/m
Moment of inertia	200111 mm ⁴
Section modulus	200111 mm ³
I _{xx} per meter width	270420

S_{xx} per meter width	1422
--------------------------	------

Table 3.3: Material properties of profile sheet



Fig 3.7): EGA 600 cold formed profiled sheet

The test has shown the yield strength was 340 MPa, tensile strength over 448MPa, and elongation rate over 20%. The mechanical properties of the profiled sheet are summarized in ANNEX C of this paper. The laboratory test was conducted by ECAE.

3.3.2.3 TRANSVERSE REINFORCEMENT BAR

For the specimen, 10 mm diameter bars are used in both directions by welded connection to reinforce the slab according to BS 5400-5[29] (fig 2.5). The main function of steel is to resist the cracks that occur due to shrinkage and temperature. Reinforcements in concrete slabs enhance the ductility and shear capacity of the composite system. It implies that, by using transverse reinforcement in the concrete blocks of specimen, the shear strength and ductility of the composite system are increased. For cracking reasons, transverse reinforcement should be provided above internal supports. Practically, the minimum amounts re-bars in composite structure are given by Eurocode 4 [27] such as 0.2% of the area of concrete above the sheeting for un-propped construction, and 0.4% if propping is used.

Tensile test of these 10mm diameter steel samples is included in the ANNEX B of this paper.

3.3.3 SPECIMEN PREPARATION

All of the push-out specimens are cast in a vertical position to reduce the chance for variation in concrete strength from one slab to another since the specimens have small sizes and reduce time to the execution of the test, as well. All concrete with slabs of 110 mm and 150 mm thicknesses specimen are cured in water, for 28 days, before testing. The height and width of the slabs are 300 mm and 460 mm respectively, in all of the specimens. In all specimens, the wire meshes were placed on the top of the profiled sheeting or both faces on the solid slab. After the shear connector was welded on-site through the flange since preheating was needed because the weld is small in extent, the concrete wooden formwork was constructed with a size of 300 x 460mm.fig 3.8 However to make sure for welding bend test was provided as shown in fig 6.1 Then pouring in the form followed by proper mechanical vibrator after oiling the steel flange and formwork. Fig 6.5 the composite slab leaves for hardening for a day. The testing was done to obtain the load-slip curve. General procedure in pictures summarized in the ANNEX A of this paper.



Fig 3.8): formwork preparation for solid concrete



Fig3.9) specimens after casting of concrete

4 RESULT AND DISCUSSION

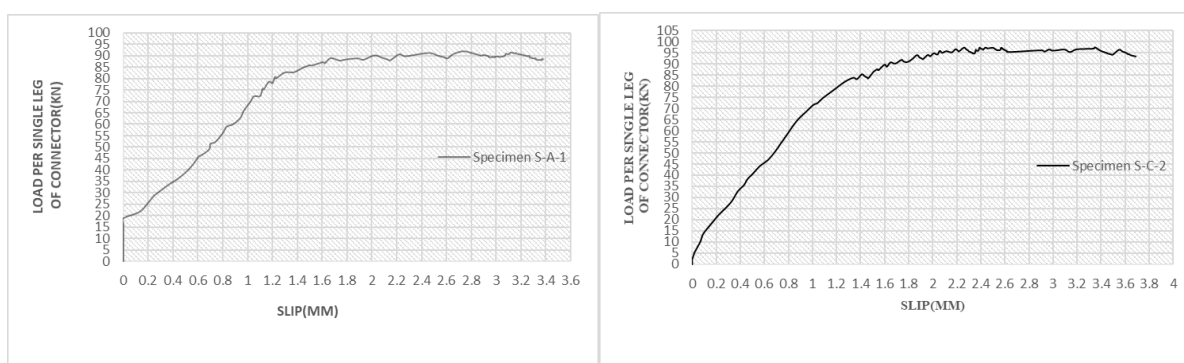
4.1 ULTIMATE LOAD CAPACITY AND LOAD-SLIP BEHAVIOUR

The behavior of rebar shear connectors in composite structures was investigated through push-out tests and the results are presented in Table 4.1. The main purpose of the experiments was to examine load slip behavior, maximum shear capacity and observe modes of failure.

Test Specimen	Maximum Shear Capacity (KN)	Maximum Shear Leg of Shear Connector	Maximum Slip(mm)	Mode of failure
S-A-1	364.4	91.10	3.16	concrete
S-C-2	390.37	97.59	3.35	concrete
S-C-3	394.41	98.60	4.31	combined
S-P-4	383.65	95.91	5.31	concrete
S-D-5	252.35	63.08	3.10	combined
S-T-6	308.12	77.03	1.44	concrete

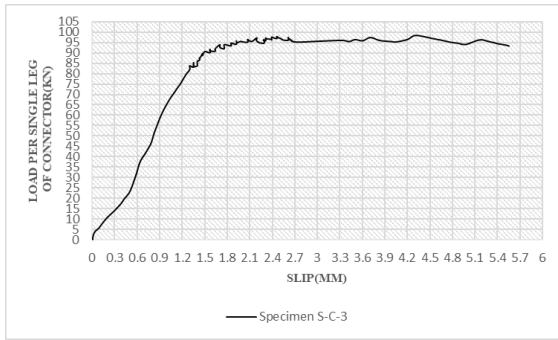
Table 4.1: Experimental results (ultimate load carrying capacity of reinforcement)

The load-slip curves were obtained to analyse the static performance of these rebar connectors, and which have an important basis for analysing the mechanical behaviour of the connector and to reflect the change of mechanical performance of connector during the process of push-out test. The load-slip curves of all the push-out specimens in this test are shown in Fig 4.1.

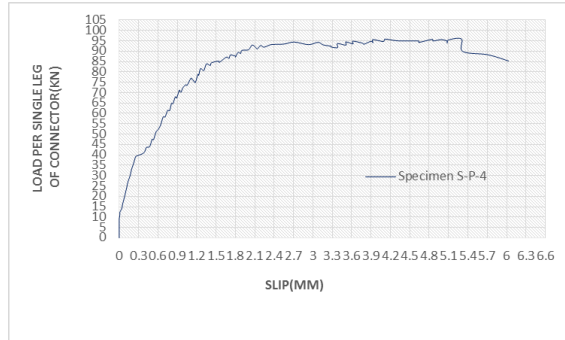


a) Specimen S-A-1

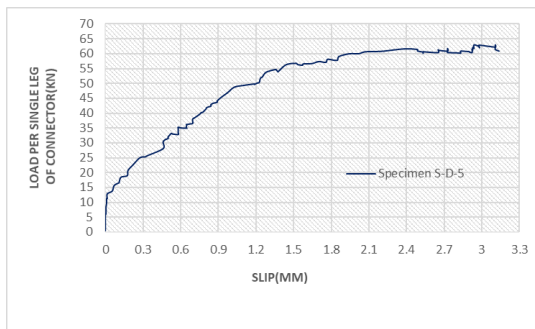
b) Specimen S-C-2



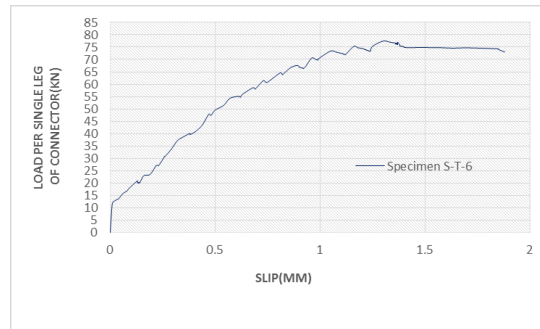
c) Specimen S-C-3



d) Specimen S-P-4



e) Specimen S-D-5



f) Specimen S-T-6

Fig. 4.1): Load-deflection curve

According to Qi, J.N.; Wang, J.Q.; Li, M.; Chen, L. [26], the push-out specimen was in the elastic deformation stage when the slip is 0.2 mm, and it was in the elastic-plastic deformation stage when the slip reaches 2 mm. Hence, to describe the effects of test parameters on the static performance of the rebar shear connector, the comparisons of the load-slip curves of specimens with different test parameters are separately shown below. The effects of concrete strength, connector diameter, connector height and effect of the profiled sheet on the static performance of shear connector are given below

4.1.1 EFFECTS OF CONCRETE STRENGTH ON STATIC PERFORMANCE

Concrete strength is one of the parameters which affect the shear resistance of the rebar shear connector and failure mode. Three specimens of different concrete strengths were studied. Fig. 4.2 shows the effect of concrete strength on the load-slip behaviour of the push-out test specimens with concrete strength of C20/25, C25/30 and C30/37 MPa respectively. From the load per slip relationship for the push-out specimens in Specimen S-A-1, S-C-2 & S-C-3, it can be seen from Fig. 4.2 that the capacity of the shear connection increase with the increase of concrete strength. For a 20 mm diameter rebar connector increasing the concrete strength from 25 to 30 MPa resulted in a 7.12% increase in the ultimate load along with 6.0% difference in the slip to failure. Similarly, when the concrete strength increases from 25 to 37 MPa, the ultimate load capacity was found to be increased by 8.23% and 36.39% increment

in slip value. Therefore, it may be concluded that the use of high strength concrete could better play the performance of the shear connectors and improve the shear capacity of the whole structure.

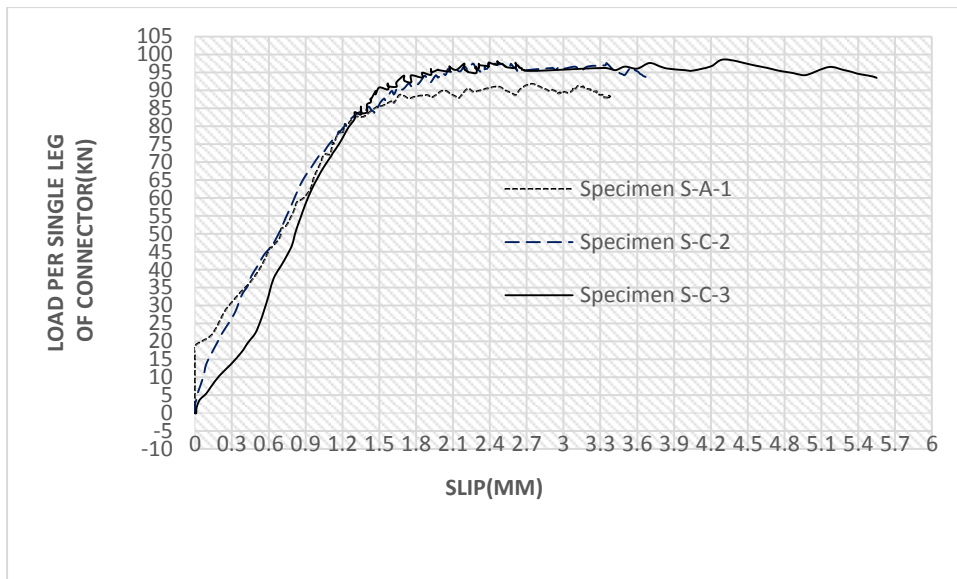


Fig. 4.2): Load-deflection curve comparison for specimen S-A-1, S-C-2 & S-C-3

4.1.2 EFFECTS OF DIAMETER ON STATIC PERFORMANCE

As can be seen from fig 4.3, two different diameters of 14mm and 20mm shear connectors were used in the push-out tests. Take the specimens S-A-1, the shear capacity was 44.4 % higher than that of S-D-5 and the ductility of S-A-1 increased by 1.935%. However, both specimens show brittle failure behaviour as observed from the load-slip curve and maximum characteristic slips (less than 6mm). The increase in the ultimate capacity and ductility of the test specimens is due to the larger cross-sectional area of the rebar connector with a larger diameter. Therefore, in the construction of a composite structure, large diameter shear connectors could be appropriately selected to improve the overall mechanical properties of the structure.

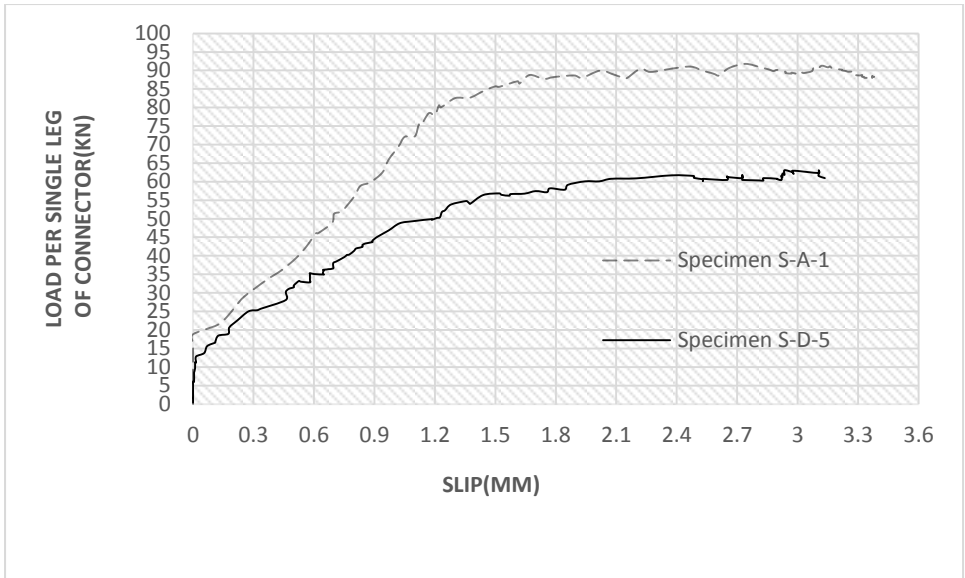


Fig. 4.3): Load-deflection curve comparison for specimen S-A-1, & S-D-5

4.1.3 EFFECTS OF RE-BAR HEIGHT ON STATIC PERFORMANCE

From the comparison load-slip curves of specimen S-A-1 & S-T-6 with different height of connector embedded in concrete is shown in Fig 4.4. It can be seen that the curve of the 120 mm height Connector is generally above the curves of the 80 mm height connector. For specimen S-A-1 with 120mm height the ultimate capacity was found to be 15.44% higher and by 54.43 % higher as compared to the specimen S-T-6. This phenomenon indicated that the increment of connector height would slightly improve the shear capacity but would increase the ductility of connectors more.

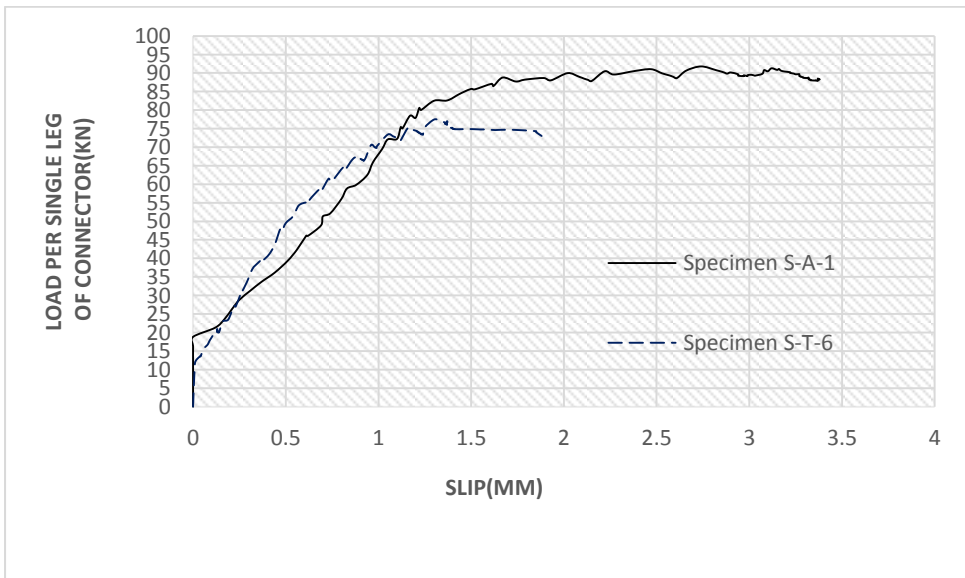


Fig. 4.4): Load-deflection curve comparison for specimen S-A-1, & S-T-6

4.1.4 EFFECTS OF PROFILED SHEETING ON STATIC PERFORMANCE

The comparison load-slip curves of specimen S-A-1 & S-P-4 with profiled sheeting or without profiled sheeting is shown in Fig 4.4. It has been seen from the figure the ultimate load of S-P-4 increases by 5.28% in the load vs slip curve. There is no significant effect of locally manufactured profiled sheeting on the ultimate shear capacity of the shear connector but the failure slip at the steel-concrete interface for specimen S-P-4 was found to be 68% higher as compared to the specimen S-A-1.

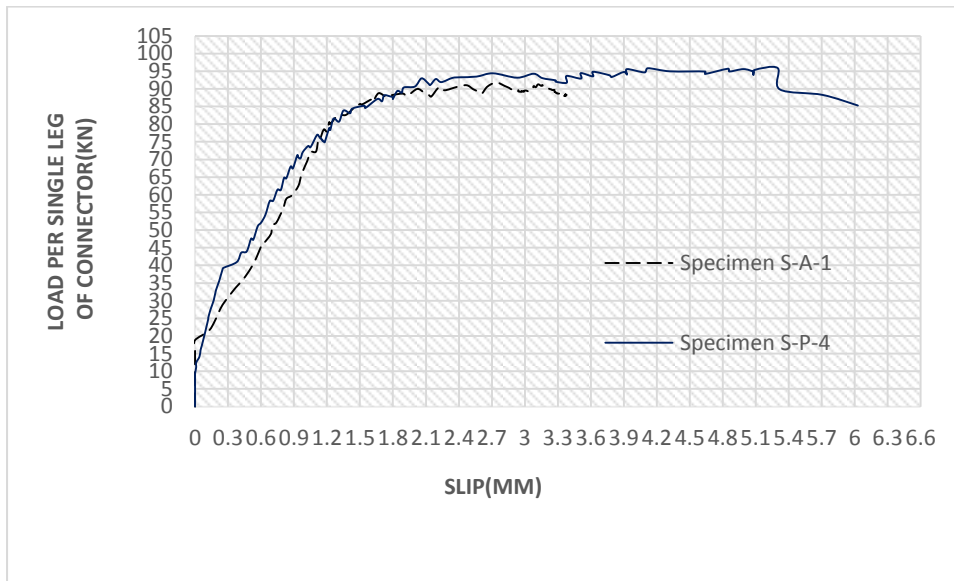


Fig. 4.5): Load-deflection curve comparison for specimen S-A-1, & S-P-4

4.2 FAILURE MODES

There are three modes of failure of composite beams with connectors: concrete failure, connector failure and combined failure of concrete and connectors, among which connector failure can be divided into failure from the shank and the weld. In this test, the combined failure and concrete failure modes were observed. The following failure modes shown below are observed after the push-out test conducted for different parameters of the rebar shear connector.



Fig 4.6): failure mode of Specimen S-A-1



Fig 4.7): failure mode of Specimen S-C-2

In specimens S-A-1 & S-C-2, concrete crushing has occurred, followed by cracking and splitting of the concrete. The shear strength of test specimens reaches to shear failure of concrete were relatively higher than that of the specimens reach to connector failure. In case of shear failure of the concrete beam, after it reaches peak load, strength is reduced drastically. A typical cracking pattern in the concrete is shown in fig 4.6, fig 4.7.



Fig 4.8): failure mode of Specimen S-C-3

It can be seen from fig 4.8 that there is not much visual crack that occurred on the concrete, and the different phenomenon is observed in the other specimens. Because, the failure modes of the specimen were combined connector-concrete failure and it is because that specimen S-C-5 had high strength and cracking resistance. In addition, it is noted that the connectors in specimen S-C-3 specimen fractured from the weld. The reason for this phenomenon is that the connector and the connector with 20mm diameter have high strengths which resulted in the weld became a weak point. Therefore, in the construction of a composite beam, it is necessary to ensure that the weld has enough strength to prevent structural damage caused by the weld in use. It is observed that if the concrete strength is higher, then the behaviour is becoming ductile.



Fig 4.9): failure mode of Specimen S-P-4

In this test, the de-bonding was observed between the profiled metal decking and the concrete in the early stage. Concrete breakout at the boundary between solid slab and steel deck shown in fig 4.9 which called Shear failure of concrete. It is seen that there is an enhancement in displacement or ductility due to steel decking. This specimen had relatively good ductile behaviour and the slips at the failure were recorded as 5.31 mm but its characteristics slip was less than 6mm so that it shows brittle behaviour. The possible cause for this was its shape of profile decking or due to the single layer of reinforcement which could not give enough strength in the concrete and connector.



Fig 4.10): failure mode of Specimen S-D-5



Fig 4.11): failure mode of Specimen S-T-6

As shown in figure 4.10 of Specimen S-D-5, during the loading process, some cracks or a local premature failure developed at the base concrete block, because of this reason the shear connection failure did not exhibit real shear capacity when the cracks continued with the

increase of load. The cracks on concrete were mainly diagonal cracks and vertical splitting cracks. The test ended with the connectors being bend because the size of the connector is smaller but they are not completely breakout. These phenomena indicated that the concrete beam would be damaged before the connector bend, and the smaller the connector diameter was, the more serious the damage both of the concrete beam and connector would be.

From fig.4.11 it is understood that concrete is separated from the steel section along with the thickness of concrete and no deformations are made in connectors. Therefore, Specimen S-T-6 shows a typical view of concrete failure type. In case of this kind of concrete failure in shear, after it reaches peak load, strength is reduced drastically.

4.3 COMPARISON WITH DESIGN CODES AND STANDARDS

A comparison between the experimentally obtained rebar shear capacity and Euro code 4, EN 1994-1-1 clause 6.6.3.1 [12], specifies that the shear strength (P_{RD}) predicted capacity is presented in Table 4.2. The results of the 6 specimens involving single rebar connector embedded in solid concrete slabs evaluated by following:

$$P_{Rd} = \frac{0.8F_u \pi d^2}{\gamma} \frac{1}{4}$$

$$P_{Rd} = \frac{0.29d^2 \sqrt{F_{ck} E_c m d}}{\gamma}$$

It is recommended the minimum value obtained for above equations, is consider as characteristic resistance of the stud.

Where, the units are N, mm;

d=diameter of the studs;

F_u = ultimate tensile strength of stud; F_u = 663.57Mpa for diameter 20, 622.38 for diameter 14mm respectively

F_{ck} =compressive strength of concrete cylinders;

E_c = elastic modulus of concrete;

γ = the partial safety factor should be taken as 1 (because it is compared to experimental results);

$$\alpha = 0.2 \left(\frac{H_{sc}}{d} + 1 \right) < 1 \text{ and}$$

H_{sc} =height of the stud

The Euro code 4, EN 1994-1-1 equation for the calculation of the design strength of headed stud shear connector (P_r) in composite beams with profiled steel sheeting perpendicular to the steel beam is given by:

The reduction factor (K_t) for metal profile decking transverse to the supporting steel beam were calculated using;

$$P_r = K_t P_{RD}$$

$$K_t = \frac{0.7}{(n_r)^{0.5}} \frac{b_o}{h_p} \left(\frac{H_{sc}}{h_p} - 1 \right) < 1.0$$

Where,

n_r = is the number of stud connectors in one rib at a beam intersection, not to exceed 2 in computations ;

H_{sc} =height of the stud but not greater than $h_p + 75$ mm;

H_p =height of the steel profile decking;

b_o =effective width of the slab;

Test Specimen	Concrete Cube strength (Mpa)	Diameter of connector(m)	Maximum Shear Capacity (KN/single leg of rebar connector)(KN)	Final Resistance of shear connector as per EC4(KN)	Ratio PRD,expe/PRD, EC	Check for Outlier		
S-A-1	26.88	20	91.1	89.80	1.01	Q2	0.98	
S-C-2	32.02	20	97.59	102.90	0.95	Q1	0.86	
S-C-3	39.91	20	98.6	115.13	0.86	Q3	1.07	
S-P-4	26.88	20	95.91	89.80	1.07	IQR	0.21	
S-D-5	26.88	14	63.08	44.00	1.43	LB=Q1-1.5 IQR	0.54	
S-T-6	26.88	20	77.03	89.80	0.86	UB=Q3+1.5 IQR	1.39	
					Mean	0.95		
					SD	0.08		

Table 4.2: Comparison of Experimental (ultimate load carrying capacity of reinforcement) and EC 4 predicted results

NOTE:

- ✚ For this data set, S-D-5 is the outlier (outside of the fence) which affects the mean significantly. Therefore, specimen S-D-5 is eliminated from the sample.

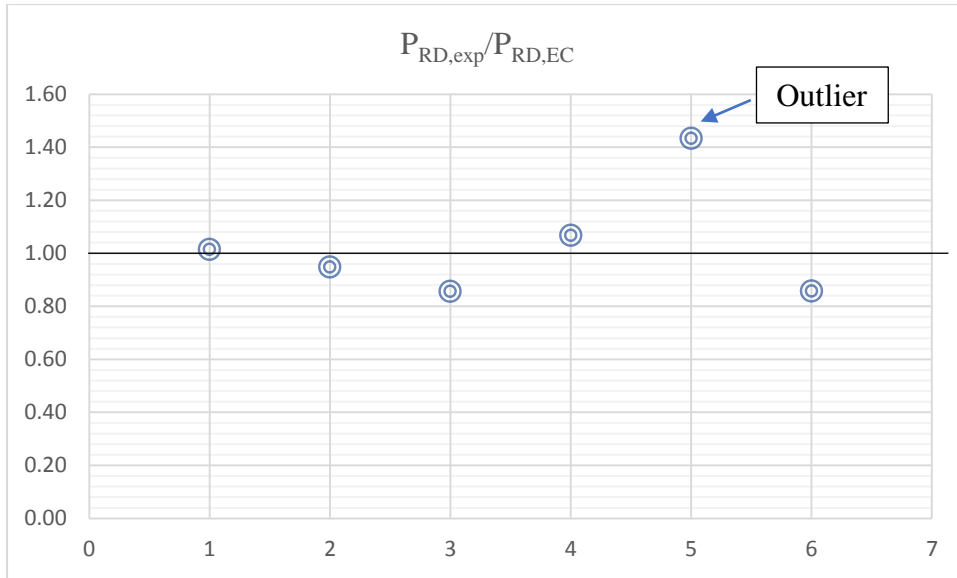


Fig 4.12): Ratio for Experimental results and Eurocode predicted

As observed from Table 4.2 and fig 4.12, a comparison of experimental and code predicted capacities for all test specimens are obtained. In general, the EUROCODE 4 formula gives a good correlation of ultimate load per rebar connector except for the 14 mm diameter connector. This figure demonstrates that the Eurocode specified equation for stud connectors underestimated the experimental capacities for rebar connectors. Therefore, to apply the Eurocode equation for rebar connector a correction factor of 0.95 is proposed Whereas according to AISC-LRFD [31] equation correction factor of 0.8 is proposed(see table 4.3) Finally, it is recommended that, the deformed rebar connectors with diameter 20 mm can be effectively used in composite beams to transfer the longitudinal shear at the steel-concrete interface.

AISC-LRFD [31] provides the following empirical function described the test outcomes:

$$Q_n = \frac{1}{2} A_{sc} \sqrt{f'_c E_c} < A_{sc} F_u$$

Where, Q_n = the nominal stud connector shear strength (N),
 f'_c = is the concrete compressive strength (Mpa),
 E_c = the Young's modulus (Mpa),
 A_s = the cross-sectional area of the stud shear connector (mm^2),
 F_u = the ultimate stud shear connector tensile strength (mm^2),

Test Specimen	Concrete Cube strength (Mpa)	Diameter of connector(mm)	Maximum Shear Capacity (KN/single leg of rebar connector)(KN)	Final Resistance of shear connector as per AISC(KN)	Ratio PRD,expe/PRD, AISC	Check for Outlier	
S-A-1	26.88	20.00	91.10	121.53	0.75	Q2	0.73
S-C-2	32.02	20.00	97.59	139.27	0.70	Q1	0.63
S-C-3	39.91	20.00	98.60	155.83	0.63	Q3	0.79
S-P-4	26.88	20.00	95.91	121.53	0.79	IQR	0.16
S-D-5	26.88	14.00	63.08	59.55	1.06	Q1-1.5 IQR	0.40
S-T-6	26.88	20.00	77.03	121.53	0.63	Q3+1.5 IQR	1.02
					Mean	0.70	
					SD	0.06	

Table 4.3: Comparison of Experimental (ultimate load carrying capacity of reinforcement) and AISC-LRFD predicted results

NOTE:

- For this data set, S-D-5 is the outlier (outside of the fence) which affects the mean significantly. Therefore, specimen S-D-5 is eliminated from the sample.

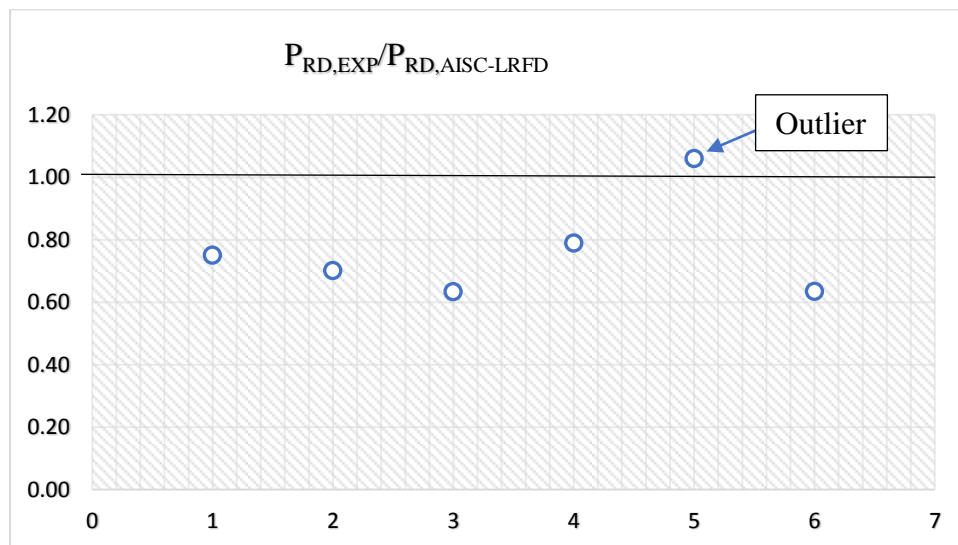


Fig 4.13): Ratio for Experimental results and AISC-LRFD predicted

5. CONCLUSION AND RECOMMENDATION

5.1 CONCLUSIONS

This paper has investigated reinforcement bars as a shear connector by minimizing possible failures as much as possible, such as problems occur with welding, segregation of concrete due to over-vibration or compaction, quality problem of each material and also specimen size and weight based on Eurocode 4 - Part 1.1 and BS 5950: Part 4 (1994).

From the above experimental results, the following observations and conclusions are made:

- ✚ Experimental results confirmed that the use of rebar shear connectors with large diameters and high strength can simplify the composite structure, save the construction time and make the steel and the concrete work together better. In future composite structures, it will be one of the common shear connectors.
- ✚ The static performance of rebar connectors depends mainly on the concrete strength.
- ✚ The shear connector embedded in high strength concrete slab had significant shear capacity compared to the shear connector embedded in low strength concrete slab. With the diameter and height of the shear connector increasing, the shear capacity and slip of re-bar connectors increased and the ductility increased as well.
- ✚ The influence of locally manufactured profile was slight and there is some limitation observed on local trapezoidal profile sheet such as available deck height (H_p) limited to 34mm as others used to maximum deck size, compared to re-entrant shape susceptible to 'brittle' failure due to less on fictional interlock and there is no assurance the quality of sheet for deck slab only produced for roofing and claddings in our country.
- ✚ All specimens in the push-out tests failed by the concrete or combined failure of concrete and connectors. Some diagonal and splitting cracks occurred on the surfaces of the specimens, and the number of cracks increased with lower concrete strength.
- ✚ Push-out test data was carried out and values of shear strength are compared with that recommended by Eurocode 4 and AISC-LRFD (NSR-98) equation. Eurocode 4 compared to experimental results showed that the average shear strength of rebar shear connectors used in this study was found overestimated by 5% and 30% by AISC-LRFD equation. Therefore new design equation provided by concrete contribution of rebar shear connector is calculated as follows:

$$P_{Rd} = \frac{0.275d^2 \sqrt{F'_c E_{cm} d}}{\gamma} \dots\dots\dots \text{from Euro code 4}$$

$$Q_n = 0.35 A_s \sqrt{F'_c E_c} < A_{sc} F_u \dots\dots\dots \text{from AISC-LRFD}$$

5.2 RECOMMENDATIONS

The following recommendations are put forward by the author for future research:

- ✚ It was observed that shear connectors in push-out specimens showed a brittle performance. Any brittleness exhibited in the push test is a result of low concrete strength, the thickness of concrete and also lack of standard profiled sheet for study in the standard push specimen. To remedy this situation, further experiments are required by increase the number of parameters with change concrete grade to higher, using standard profiled sheeting and compare with the full-scale composite beam. So that, it may exhibit excellent ductility with slip capacities exceeding the limits.
- ✚ The paper planned that the push-out test experiment would be done with the UTM machine but due to the sudden damage of the machine, it had to work carefully using a hydraulic jack with constant load increment to get the results. It may have an unpredictable effect on the failure mode of the specimen outcome. Thus, further experimental studies are needed in this area.
- ✚ Further improvements are needed to be investigated by change the shape of profiled sheet embedded in the RC slab of the push-out specimen.

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ANNEX A –SPECIMEN PREPARATION



*Fig 6.1): performing bend test
(To ensure the quality of welding)*



*Fig 6.2): 10mm diameter transverse reinforcement
welding at intersection*



Fig 6.3): formwork preparation for solid concrete



Fig 6.4): formwork preparation for composite concrete slab with single layer of wire mesh



Fig 6.5): oiling the steel and formwork



Fig 6.6) pouring and compacting of concrete by using mechanical vibrator



Fig 6.7) specimens after casting of concrete

ANNEX B – TENSION TEST OF STEEL REINFORCING BAR

Student



AAiT

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Addis Ababa University
Addis Ababa, Ethiopia

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ኢ.ኢ.አ. ፓላንና ትኩረት
Tel. 011- 1 2324-37
E-mail info@ceng.aait.edu.et

CONSTRUCTION MATERIALS TESTING LABORATORY

Client: ABEL TSEGAYE
 Consultant: _____
 Contractor: _____
 Project: _____
 Supplier: _____

Date Received:-
Date Tested:-

Test required:-

- Tensile strength
- Yield strength
- Elongation
- Diameter
- Mass per length

X
X
X
X
X



Appointment Date _____

Receipt No _____

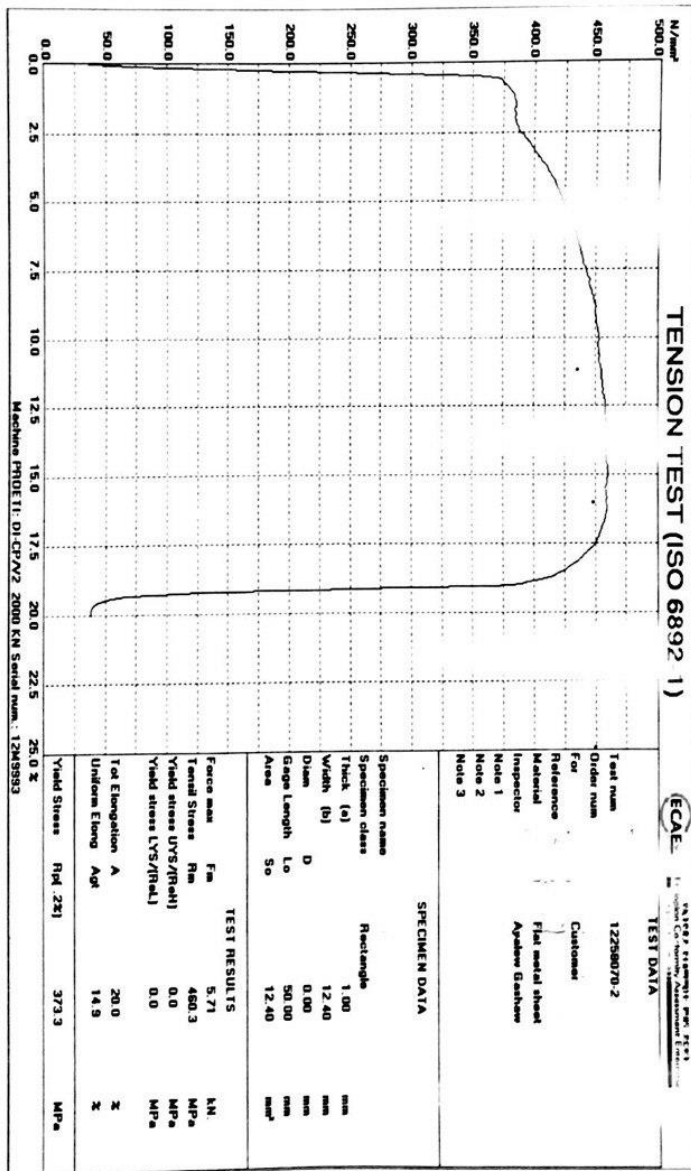
SUMMARY OF TEST RESULTS

Specimen No	Diameter		Yield load [kN]	Failure Load [kN]	Elongation [%]	Mass/length kg/m	Length	REMARK
	D1, [mm]	D2, [mm]						
6-1								
6-2								
6-3								
8-1								
8-2								
8-3								
10-1	12.7	10.8	232.3	477.5	23.1	614.7	101.8	
10-2	12.7	10.64	228.5	477.9	23.4	617.4	100	L
10-3	12.7	10.67	229.3	477.3	23.6	613.0	101.5	
12-1								
12-2								
12-3								
14-1	13.32	14.27	76.0	96.5	23.7	1177.7	100	
14-2	13.32	14.24	76.2	96.3	23.7	1221.7	102.5	L
14-3	13.34	14.27	72.5	94.5	23.3	1187.0	100	
16-1								
16-2								
16-3								
20-1	19.125	20.86	162.5	212.6	23.2	1571.8	101	
20-2	19.225	20.76	164.3	204.7	23.4	1367.2	102	L
20-3	19.40	20.82	162.3	202.3	23.5	1366.4	101	
24-1	23.17	24.90	251.7	299.5	23.3	262.4	112	
24-2	23.144	25.00	253.8	298.8	23.4	2593.4	109	L
24-3	23.17	24.98	254.0	296.3	23.7	2432.8	102	
28-1								
28-2								
28-3								
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30-2								
30-3								
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Client/Consultant Name _____
 Contact person _____
 Telephone No _____

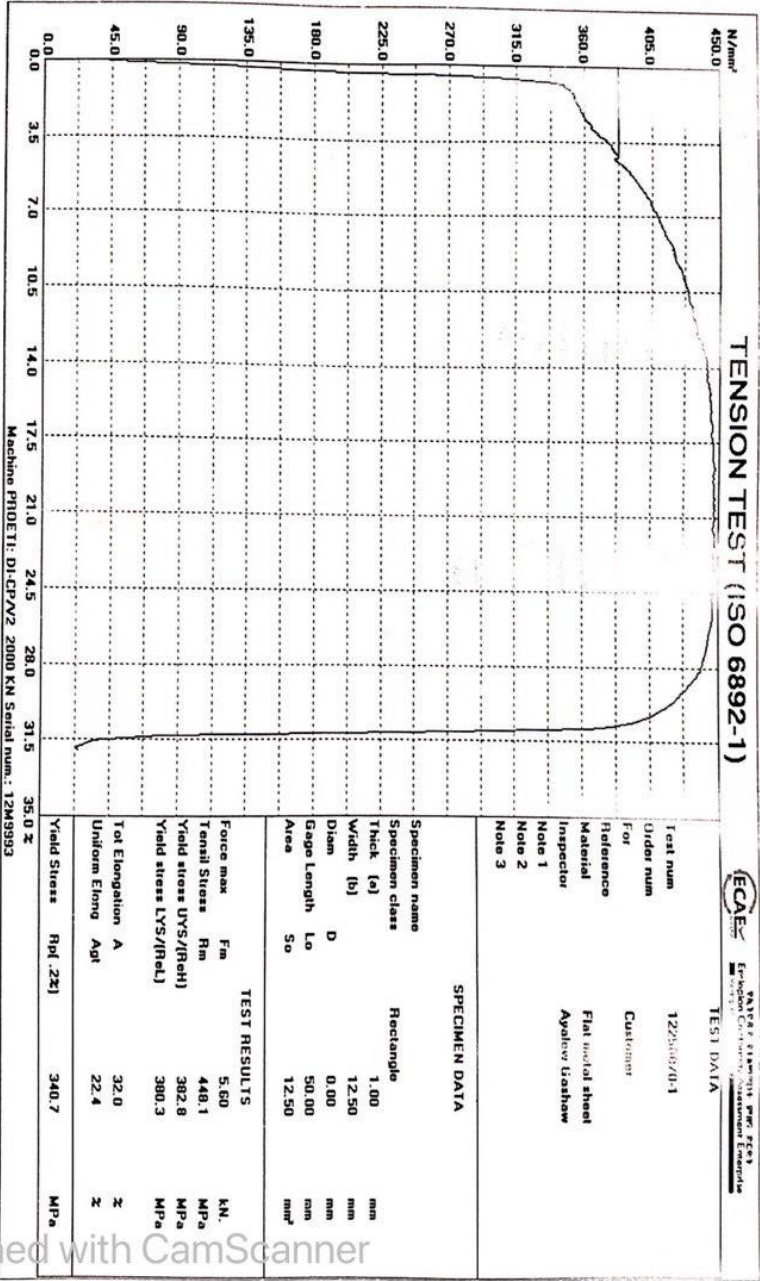
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ANNEX C – DETERMENATION OF YIELD AND TENSILE STRENGTH OF METALIC MATERIAL



TENSION TEST (ISO 6892-1)

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 EN 10002-88
 EN 10002-89
 EN 10002-90
 EN 10002-91
 EN 10002-92
 EN 10002-93
 EN 10002-94
 EN 10002-95
 EN 10002-96
 EN 10002-97
 EN 10002-98
 EN 10002-99
 EN 10002-100



TEST DATA	
Test num	122806/0-1
Order num	Customer
For	
Reference	Flat metal sheet
Material	Ayalew Teashaw
Inspector	
Note 1	
Note 2	
Note 3	

SPECIMEN DATA	
Specimen name	Rectangle
Specimen class	
Thick. (a)	1.00 mm
Width (b)	12.50 mm
Diam	0.00 mm
Gage Length	50.00 mm
Area	12.50 mm²

TEST RESULTS		
Force max	Fm	5.60 kN
Tensile Stress	Rm	448.1 MPa
Yield stress UYS/(ReH)		382.8 MPa
Yield stress LYS/(ReL)		380.3 MPa
Tot Elongation A		32.0 %
Uniform Elong	Agt	22.4 %
Yield Stress	Rpl.2x1	340.7 MPa

Machine PRODETI: DI-CPV2 2000 KN Serial num.: 12M9993