EVALUATION OF SHEAR CAPACITIES, BEHAVIOUR AND EFFECTS OF VARIATION OF CFS STRENGTH ON PROPOSED INNOVATIVE SHEAR TRANSFER ENHANCEMENT, BENT-UP TRIANGULAR TAB SHEAR TRANSFER (BTTST) FOR CFS-CONCRETE COMPOSITE BEAMS

MOHD IRWAN JUKI

GERAN STG
NO. VOT 0774

EXPERIMENTAL STUDY ON SHEAR BEHAVIOUR OF COLD-FORMED STEEL CONCRETE-COMPOSITE BEAM

Mohd Irwan bin Juki

Abstract Cold-formed steel structural member can be efficient in many applications where conventional hot rolled members prove uneconomic. For the composite beam system, the uses of cold-formed steel section offer the high flexibility in design and several advantages. This experimental is conducted to study the shear behaviour of cold-formed steel concrete composite beam. The experiment that been use is a primarily shear test which is three point load test of simply supported CFS-concrete composite beams subjected to a mid-span load. In order to fully understand the shear behaviour of cold-formed steel (CFS) concrete-composite beam section, a shear test program was carefully designed based on the key parameter required for shear test. Test specimen was designed to fail in shear prior to reach other section properties and to fully understand on shear behaviour of the beam. Test specimens were observed by the shear failure (shear yielding and shear buckling) occurred in the tests. Results of six companion's three point load test specimens are present herein, focusing on the shear behaviour of shear buckling and shear yielding and to compare the result shear. It is concluded that the used of BTTST can get appropriate strength.

Keywords: CFS, composite beam, shear behaviour, point load test

THE EFFECT OF COLD-FORMED STEEL STRENGTHS IN BENT-UP TRIANGULAR SHEAR TRANSFER (BTTST) ENHANCEMENT IN PRECAST COLD-FORMED STEEL CONCRETE COMPOSITE BEAM

Mohd Irwan Bin Juki

Abstract – The application of cold-formed steel (CFS)-concrete composite beam is limited in construction. This is largely due to thinness of this section. According that, new type shear connector purposed to develop application CFS composite beam. Bent-up triangular tab shear transfer (BTTST) was proposed by Irwan. This paper presents the test of shear capacity of BTTST conduct by push-out test. Results of twenty four companion push-out test speciments are presented herein, focusing on the strength of CFS and to compare the result shear capacity with shear capacity equation P_{tab}. The results show the specimens as compare with different strength of CFS in BTTST. It is concluded that must have optimum CFS strength used in BTTST to get appropriate strength.

Keywords: *cold-formed steel, Composite beams, Push-out test, Shear capacity, CFS strength.*

CONTENTS

CHAPTER I

INTRODUCTION

1.1 Introduction

There are two types steel used in the construction such as cold formed steel and hot rolled steel. But now cold formed steel proven more economic than the hot rolled steel and the need for using cold-formed section have shown tremendous increase in demand in Malaysia due to the policy changes that require the use of cold-formed steel sections for roof truss system by Public Works Department for most of the government projects (Mahmood et al., 2005)

In the construction industry, the cold-formed steel are been use widely in construction for flexural and shear strengthening. Nowadays, there are still many question that been asking neither for the understanding and confirmation. The situation means that there is a requirement for more experiment to give the result for the confirmation. The experiment is not only for the shear response comprehension but also for the theoretical approach to give more confirmation based from the experiment and research that have been done (Ianniruberto & Maura, 2001).

Cold-formed steel(CFS) is a steel product that is formed by bending a flat steel strip or sheet of uniform thickness, in cold state into shape that will support more load than flat sheet itself. The cold-formed steel section, which is regarded as steel strip with uniform profile along its length, is usually used in load bearing application. The thickness of such members usually ranges from 0.378mm to about 6.35mm (Mahmood et al., 2005). Generally, cold-formed steel sections have several advantages over hot rolled steel sections and timber trusses. The main advantages are no insect and fungal infection, increase in yield strength due to cold forming, speedy in construction and easy to erect, corrosion resistance by pre-galvanization or pre-coating, lower in production cost and higher in profit and variety of connection and jointing methods.

The use of cold-formed has been enhanced with concrete joined together as a composite beam. This beam has two different materials in which concrete that have compressive strength and steel have tensile strength. CFS type C channel placed back to back to produce I channel that joined with concrete slap.

To combine different materials in composite beam should have a connection called as a shear connector. Shear connector is a connection that acts on load on beam that holder between the concrete slab and steel beam due to the inadequate bonding between concrete slab and steel beam. Also push the shear between concrete and steel beam where the top part is holding the concrete slab and bottom part transfer the shear act in beam (Irwan et al., 2008). Many types of shear connector that has been introduced now like studs, channels, stiffened angles, and flat bars.

The new shear connector was purpose is bent-up triangular tabs shear transfer (BTTST) that still in study about the effect of shear connector. BTTST is the next type of Lakkavalli and Y.Liu Bent-up tabs shear transfer (LYLB) that used part of steel beam to make shear connector. From previous study, BTTST is among of economic and higher strength shear connector because use steel beam as a main part. BTTST that proposed by Irwan is bent up the triangle in specified size and angle from cold formed steel (Irwan et al., 2009).

1.2 Problem Statement

There are many type of shear connector use in composite beam that popular in construction like stud, channels, stiffened angles, and flat bars. This almost use for hot-rolled steel. There is variety of shapes, sizes and method of fixing and the choice is increasing to cater for changing demands. Shear connector that widely used in composite construction is studs that one economic types than another type (Irwan et al., 2008). The use of CFS sections as major structural members is still limited due to the lack of shear connector porposed for this steel section.

The design of this CFS structure is been state in BS 5950: Part 5 while for the composite steel and concrete structure is been state in clause BS 5950: Part 3. Many research have been done with the use of composite beam and cold-formed steel are been done. Shear behavior research have been done to the many commercial composite beam and common beam that been use in construction. But, there are very small amount of research has been done due to shear behavior for the CFS-concrete composite beam. Table 1.1 shows the research that has been done by previous researcher:

Table 1.1: Previous research about cold-formed steel (CFS)

Author/researcher	**Title**
J.M. Irwan, A.H Hanizah, I.Azmi, M.N.M. Soffi, M.G. Aruan	Static behavior of precast cold-formed steel-concrete composite beam with an innovative shear enhancement
G.J. Hancock	Cold-formed steel structure
Ariel Hanaor	Test of composite beams with cold-formed section
Tan Hean Seong	Behaviour Of Cold Formed Steel under axial compression force
J.M. Irwan	Development of Bent-up triangular tab shear transfer (BTTST) enhancement in cold-formed steel (CFS)-concrete composite beams
Mahmood M.T, Thong, C.m. & Tan. C.S.	Performance of Locally produced Cold-formed steel section for roof truss system
J.Rhodes, N.E. Shanmugam	Cold formed steel structure
M. Irwan J., Hanizah A.H., Azmi I., Bambang P., H.B Koh, Aruan M.G.	Shear Transfer Enhancement In Precast Cold-Formed Steel-Concrete Composite Beams: Effect of Bent-Up Tabs Types and Angles

An innovative shear transfer enhancement was provided called a bent-up triangular tab shear transfer (BTTST) was proposed by Irwan for CFS sections (Irwan et al., 2008). BTTST is a brand new type of shear connector that still in research. The parameters already study in BTTST is effect of BTTST itself for shear transfer enhancement, effect of concrete strength which the concrete grade is increased the load carrying capacity of push out specimen increases. Than study the effect of CFS section thickness which the bending capacity of the shear transfer enhancement increases with increasing shear area and also effect of BTTST angle which indicate that a higher ultimate shear strength, P_u can be achieved if the BTTST angle is increased (Irwan et al., 2009). To continue of this study is use another parameter that can affect the BTTST in shear transfer enhancement.

The main objective of the study is to determine and identify the shear behavior of a CFS-concrete composite beam with the experimental method using 3 point load test and analysis On the other hand, this study was continuing and inserts more information data for previous study in BTTST. To complete this, continue again study the effect of cold-formed steel strengths in bent-up triangular tabs shear transfer (BTTST) enhancement in precast cold-formed steel-concrete composite beams. In the end of this study can predict and know the either CFS strength that can affect the BTTST in composite beam.

1.3 Objective

The objectives of this study are:

1. To study the effect of cold-formed steel strengths in bent-up triangular tabs shear transfer (BTTST) enhancement in precast cold-formed steel-concrete composite beams.
2. To evaluate the shear behavior due to the shear failure mode occurred (shear buckling and shear yielding) from cold-formed steel concrete composite beam through complete composite 3 point load test and analysis

3. To determine the shear capacity of the cold-formed steel-concrete composite beams through experimental works.
4. To evaluate failure modes and shear capacity of BTTST in precast CFS-concrete composite beam.
5. To compare shear capacity in BTTST experimental results with result from shear capacity per BTTST equation, P_{tab} by Irwan et al., (2009).

1.4 Scope of Study

The experiment test is conducted on several mid span point load test specimen. The specimen had a concrete slab attached parallel to the steel beam which is a CFS. The 2m x 0.09m x 0.5m test specimen for slab concrete is use. Each specimen had a slab on one side of the cold formed steel C- section flanges. The slab cast horizontally. Six specimen will be tested which is three of the beam will be with BTTST connecter and the other three is without connector. The detail specimen can be seen in chapter 3 methodology. In order to fully understand about the shear behaviour of the CFS- concrete composite beam, the shear point load test experiment was carefully designed on the key parameter that will show the shear behaviour of the beam. Test specimens were design to fail in shear prior to reaching the parameter requirement. The result from the test will show the shear capacity of the beam and will identified the shear behavior parameter of the beam.

The other part of this study only focuses on BTTST connector that new type of shear connector was purposed by Irwan et al., (2008). This BTTST was made in size dimension 30mm × 30mm and angle up of shear transfer enhancement is 60°. Then study on effect of CFS strength in BTTST enhancement in precast cold-formed steel-concrete composite beams. Specimen and test based on Irwan push-out test specimen (Irwan et al., 2008 & Irwan et al., 2009).

CHAPTER II

LITERATURE REVIEW

2.1 Cold-formed Steel (CFS) Structure

Cold-formed steel structure are the structure that are made by bending the flat sheets of steel at specific temperature into certain shape to support load more than flat ordinary flat sheet (Hanaor, 2007). The CFS member generally forms by roll-forming machines, press brake or folding operation. This type of member are another type of steel structure that been use in construction beside by using the more familiar hot-rolled steel member (Irwan et al., 2008).

The product of cold-formed steel seems to be fixing to be use in construction on both high rise and low rise buildings. In high rise building, the usage of CFS as a roof and floor decks, steel joists, wall panels, door and window frames, and sandwich panel partitions built out of cold-formed steel sections have been successfully used ,while in low-rise building the CFS is use as primary or secondary framing (Gracia, 2007). The strength of the flat sheet after bending is more than the flat sheet itself at the room temperature. The usual thickness for such of the members is in range from 0.378 mm to 6.35 mm (Seong, 2008).

Several way are been use to make this CFS such as folding, press breaking and cold rolling (Gracia, 2007). In folding process, there are very limited in application. The sheet of material are been folding to produce short length and simple geometry specimen. The more widely used process is press-breaking; this is because more variety of cross-sectional form can be produced. This process has limitations on the profile geometry that can be formed and, more importantly, on the lengths of sections that can be produced. For large quantities product, the cold rolling process is been use. The initial tooling costs are high but the subsequent labor content is low. For the composite beam system, the use of cold formed steel section offer the high flexibility in design and several advantage

Cold-formed steel (CFS) products find extensive application in modern construction in both low-rise and high-rise steel buildings. Primary as well as secondary framing members in low-rise construction using cold-formed steel sections, while in tall buildings, roof and floor decks, steel joists, wall panels, door and window frames, and sandwich panel partitions built out of cold-formed steel sections have been successfully used (Seong, 2008). From bending a flat sheet of steel were made CFS into shape that will support more load than the flat sheet itself at room temperature. The thickness of such members usually ranges from 0.378 mm to about 6.35 mm (Mahmood et al., 2005).

2.2 Ways to make CFS

There are several ways to make this CFS, such as folding, press-braking and cold rolling (Seong, 2008).

a. Folding is the simplest process, in which specimens of short length and of simple geometry are produced from a sheet of material by folding a series of bends. This process has very limited application.

b. Press-braking is more widely used, and a greater variety of cross-sectional forms can be produced by this process. Here a section is formed from a length of strip by pressing the strip between shaped dies to form the profile shape. Usually each bend is formed separately. This process has limitations on the profile geometry that can be formed and, more importantly, on the lengths of sections that can be produced.

c. The major cold-forming process used to produce sections where very large quantities of a given shape are required is cold rolling. In this process strip material is formed into the desired profile shape by feeding it continuously through successive pairs of rolls. Each pair of rolls brings the form of the strip progressively closer to the final profile shape. The number of pairs of rolls required depends on the thickness of the material and the complexity of the profile to be formed. The initial tooling costs are high but the subsequent labour content is low.

2.3 The advantages of CFS

For the composite beam system, the use of cold-formed steel section offer the high flexibility in design and several advantages (Hanaor, 2000). The purpose of using this CFS section is because it have many advantage than general hot-rolled and timber trusses that been use in construction. There several advantage of using CFS section is listed below (Mahmood et al., 2005):

i. No Insect and Fungal Infection:

Can decrease the risk of material to curing and maintenance cost which are necessary for timber. The problem that effected by insect and infection also can be avoided.

ii. Consistency and Accuracy of Profile :

The manufacturing process of cold rolling can be maintained and can be repeated as long as required. The consistency and accuracy of the profile can easily be achieved by the use of computer control system. Not like a in a timber case, the quality of the CFS section can be efficiently be controlled in the factory easily.

iii. Versatility of Profile Shape :

This CFS section can be produce and design almost any designed cross-sectional shape. The member can be designed such as T-section, C section dam section and hat section. The size, length, shape thickness can easily be designed and it also can be designed from the viewpoint of beauty, economy, efficiency, or any combination of these. It also can be easily being controlled in the production line.

iv. Corrosion Resistance by Pre-galvanization or Pre-coating :

The CFS section can be pre-galvanizes or pre-coated with material such as zinc to give corrosion resistance and give attractive finish surface. The coating usually gives attractive finish and can reduce the requirement of painting the frame again on site.

v. Variety of Connection and Jointing Methods :

This cold-formed section can be use of all conventional method of connection or joint methods, such as riveting, bolting, welding, screwing, and adhesive material that suitable for cold-formed section.

vi. Speedy in Construction and Easy to Erect :

The use of cold formed steel section can reduced the curing time of concrete construction and this CFS section has better advantage than general hot–rolled steel section because these CFS section can be erected or cut with light and easy machine to handle. It can save the energy of the worker because usually it only needs one or two worker to do it.

vii. Increase in Yield Strength Due to Cold Forming

The cold forming process introduces local work hardening in the strip being formed in the vicinity of the formed corners. This local work hardening may result in an increment of ultimate yield strength at the corners. From the local increasing yield strength, the yield strength can be 25% much greater than usual yield strength of expected design strength.

viii. Minimum Use of Material

For the cold-formed steel section, the use of material is very thin since the material usage for given strength or stiffness requirement of cold-formed steel is to be much more less than the smallest hot- rolled section, the material thickness and cross sectional geometries can be controlled to achieve minimum material weight usage.

ix. Lower in Production Cost and Higher in Profit

In manufacturing the steel section by using cold rolled process, cost involve is to purchasing rolling machine and steel strip coils. The cost can be easily covered by the mass of production of the section. This is due to high demand of the CFS section as the construction material. Therefore, the investment required is relatively lower and the return back is sooner than most of other construction materials.

2.4 Composite Beam

A structural member composed of two or more dissimilar materials joined together to act as a unit in which the resulting system is stronger than the sum of its parts. The many other kinds of composite beam include steel-wood, wood-concrete, and plastic-concrete or advanced composite materials–concrete. In this case of study is composite beam that joint together between material concrete and steel (CFS). CFS type C channel placed back to back to produce I channel that joined with concrete slap.

In construction today, composite steel concrete girder are widely use in constructing building and bridge as the structural element in flexure. Composite beams as defined here are different from beams made from fiber-reinforced polymeric materials (Hanaor, 2000).

The composite beam has two main benefits first, by joining the two part of any material together, the system is became stronger the sum of its usual part. The second benefits is the properties of each material that been compose together can be more stronger from the composition

There are two main benefits of composite action in structural members. First, by rigidly joining the two parts together, the resulting system is stronger than the sum of its parts. Second, composite action can better utilize the properties of each constituent material. In steel-concrete composite beams, for example, the concrete is assumed to take most or all of the compression while the steel takes all the tension (Garcia, 2007).

In structural system for both multistory steel structure and bridge, steel concrete composite beam have been long recognized as one of the most economical material. For concrete, it is known as suitable material for slab because it mass and stiffness can reduce deflection and vibration and it also can provide fire protection. For the underneath system of the slab, steel is often been use because it can offer superior strength-weight and stiffness-weight ratio, easy for handling and rapid construction cycles. Since both the steel and concrete are already present in the structures, it is logical to connect them together to better utilize their strength and stiffness (Hanaor, 2000).

2.4.1 Type of composite beam

Composite beam usually consist of "I" section acting structurally with a concrete slab means of shear connectors attached to the top flange of the steel section. The beam usually designs to be simple supported beam. The effective part of the slab is use as part of composite section on neither side (Gracia, 2007).

There are two main group of composite beam that been use in construction which is primary beam and secondary beam. This properties of primary and secondary beam are important to be use to choose the proper "I" steel section to be use.

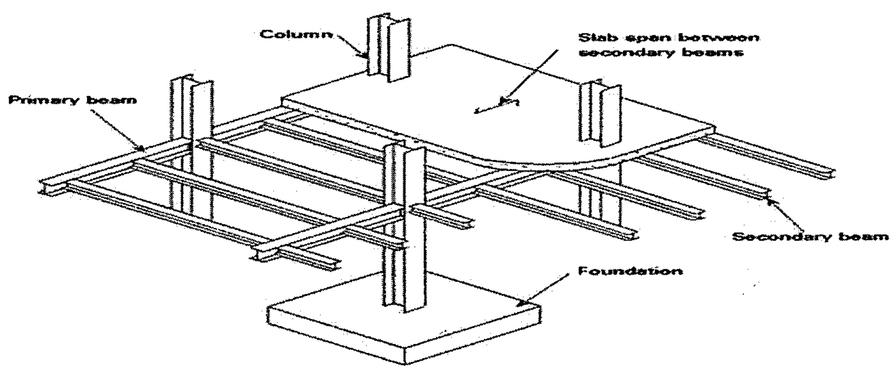

Figure 2.1: Primary and secondary beam (Gracia, 2007)

2.4.2 The advantages of Composite Beam

Generally, cold-formed steel sections have several advantages over hot rolled steel sections and timber trusses. The main advantages are listed as follows (Mahmood et al., 2005):

i. No Insect and Fungal Infection

The problems such as rot and decompositions because of insect and fungal infections are eliminated. Therefore, the material curing and maintenance costs, which are necessary for timber, could be eliminated as well.

ii. Consistency and Accuracy of Profile

The nature of manufacturing process of cold rolling includes the ability of the desired profile to be maintained and repeated for as long as required with minimum tolerances. By the use of computer control system, the consistency and accuracy of the profile can easily be achieved. The quality of the section can be efficiently controlled in the factory, and does not depend on environmental factor as in the case of timber.

iii. Versatility of Profile Shape

Almost any desired cross-sectional shapes can be produced by cold rolling, such as T-section, C-section, Z-section, dam section, and hat section. The size, length, shape, and thickness can easily be met as the production can automatically be controlled in the production line.

iv. Corrosion Resistance by Pre-galvanization or Pre-coating

The steel material may be pre-galvanized or pre-coated with materials such as zinc hi-ten to enhance its corrosion resistance and attractive surface finish. The coating gives the truss an attractive silver finish and avoids the messy requirement of painting the frames on site.

v. Variety of Connection and Jointing Methods

All conventional methods of connecting components such as riveting, bolting, welding, screwing, and adhesives material are suitable for cold-formed section.

vi. Speedy in Construction and Easy to Erect

Generally, steel construction has eliminated the curing time which is inevitable in concrete construction. The use of cold-formed steel section has a better advantage since it can be cut and erected with very light machine and need only one or the most, two workers to install it.

vii. Increases in Yield Strength Due to Cold Forming

The cold forming process introduces local work hardening in the strip being formed in the vicinity of the formed corners. This local work hardening may result in an increment of ultimate yield strength of about 25% from its expected design strength.

viii. Minimum Use of Material

Since the material used can be very thin in comparison with the lowest thickness limit of hot rolled steel sections, it therefore allows the material usage for a given strength or stiffness requirement to be much less than that of the smallest hot rolled sections. The material thickness, or even the cross-sectional geometries, could be controlled to achieve the structural features with minimum material weight.

ix. Lower in Production Cost and Higher in Profit

The manufacturing costs involve the purchasing of the rolling machine and the steel strip coils in cold rolled process. The cost of the machine can be easily recovered in the continuous mass production of the section. The cold formed steel roof truss system, which is in great demand and not enough supply locally can be considered as having a good potential as a construction material. Therefore, the investment required is relatively lower and the return back is sooner than most of other construction materials.

2.5 Beam shear behaviour

Reinforced beams must be designed for shear as well as bending. Maximum shear forces generally occur near supports. Shear failure is actually a diagonal tension failure that is brittle in nature and should be avoided (Hancock, 2003). To better understand diagonal tension considers the basic mechanics of a beam with no shear web reinforcing is shown in Figure 2.2 below:

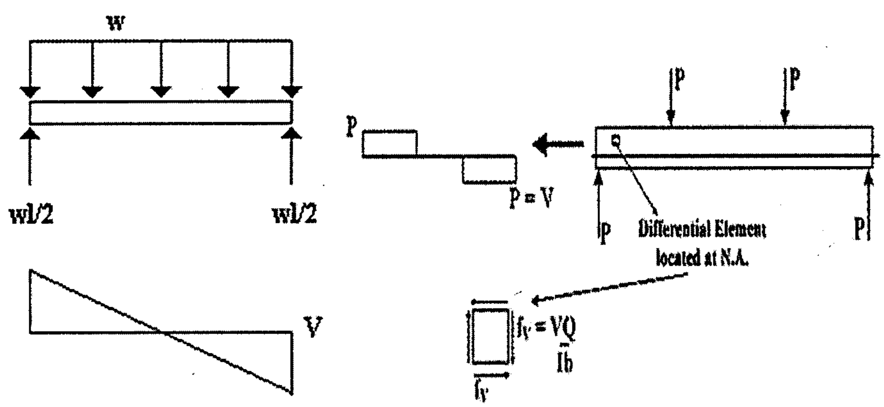

Figure 2.2: Diagonal tension of beam (Hancock, 2003)

Recall from Mohr's circle - an equivalent state of stress different than that shown above is obtained by rotating the differential element 45°.This rotated element yields principal tension and compressive stresses which are occurring simultaneously with the previous maximum f_v state of VQ / Ib. The example of rotated element yield principal tension is been shown in Figure 2.3 below:

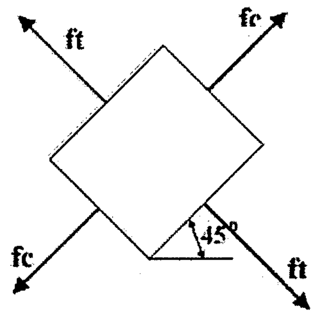

Figure 2.3: Rotated element yield principal diagram (Hancock, 2003)

In general this f_t will exceed the inherent tensile strength of beam, before f_v exceeds beam shear strength. When this happens, diagonal cracks, originating at the support begin to occur and grow with increases in beam loading. The three general modes of shear failure in beams are shown in Figure 2.4:

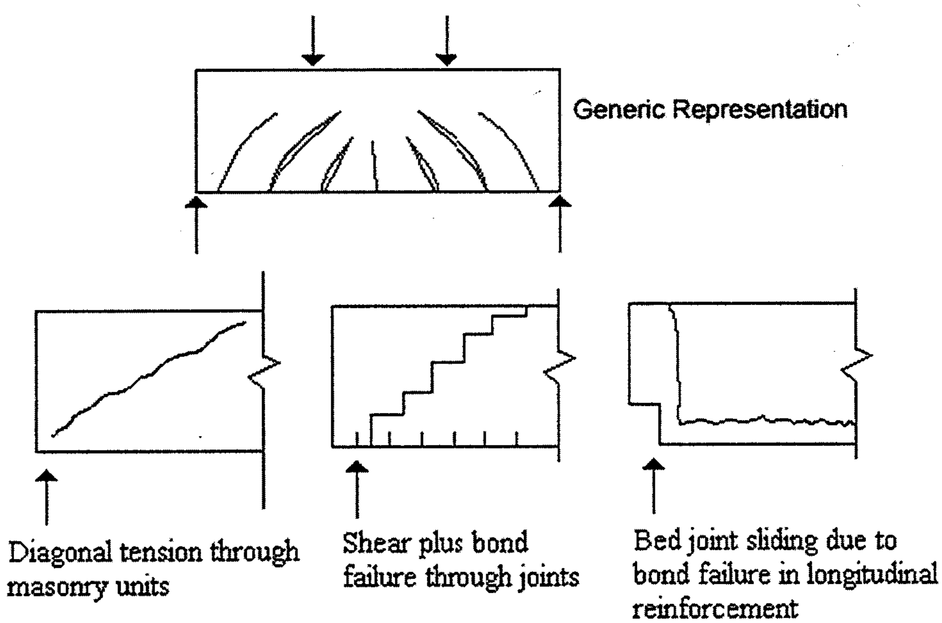

Figure 2.4: General modes of shear failure in beams (Hancock, 2003)

When the diagonal cracking is occur the propagation of the tensile cracks is not resisted by the longitudinal flexural steel. Under slight increases of load, the diagonal cracks will spread into the compression zone, reducing the compression area to an ineffective amount; resulting in beam collapse. This potential for failure by diagonal tension is quantified in terms of shear stress:

1) Compare f_v to F_v
2) $f_v = V / b\,j\,d$
3) $F_v = 1.0\sqrt{f'm} \leq 50 psi$ for flexural members without shear reinforcement

2.6 Shear connector

In composite beams, shear connectors are commonly used to transfer longitudinal shear forces across the steel–concrete interface .Composite action can be obtained through mechanical connection commonly provided by headed studs or channel shear connectors (Hanaor, 2000). Although the common type of shear connector is the headed stud, some older generations of shear connectors such as channel and T section are also gaining resurgence. A channel shear connector has a higher load carrying capacity than a stud shear connector and there are new proposed shear transfer enhancement called bent-up triangular tab shear transfer (BTTST) (Irwan et al., 2008).

Commonly, Shear connector is function as the holder between the concrete slab and steel beam due to the inadequate bonding between concrete slab and steel beam (Hanaor, 2000). Shear connectors also behave to resist horizontal shear between concrete slab and steel beam where the bottom part of the shear connector transfers the horizontal shear and the top part of the shear connector is functioning to hold the concrete slab from the steel beam (Irwan et al., 2008). Types of shear connectors include studs, channels, stiffened angles, and flat bars, variety of shapes, sizes and method of fixing and the choice is increasing to cater for changing demands. Because of both the variety and the complex mechanism by which the shear is transferred, the material properties of mechanical shear connectors are always determined empirically. However, they all have certain fundamental behavioral similarities like have limited ductility and apply a highly concentrated load into the concrete element, since there is have to fulfill a number of requirements, as follows:

1. They must transfer direct shear at their bases.
2. They must create a tensile link into the concrete.
3. They must be economic to manufacture and fix.

Stud is one of the economic types of shear connectors widely used in the composite construction. In building construction the studs are welded through the steel deck into the structural steel framing; in bridge construction the studs are welded directly to the framing. The head of the stud is intended to resist the pull out force while the shank of the stud and the welding are intended to resist the horizontal force. Such ductile behaviour makes shear force redistribution at the steel-concrete interface possible and allows for partial shear connection. In addition, headed studs may be spaced uniformly along the beam length between critical cross-sections.

2.7 Type of shear connector

There are quite different types of shear connectors, some welded and other nailed connectors. Welded connectors were commonly used in composite construction, but with the development of the use of thinner steel sheets, it has been necessary the use of nailed instead of welded. The choice of a specific type of connector is based on its ultimate resistance which depends not only on its own properties, also on the concrete grade used (Gracia, 2007).

2.7.1 Headed studs

The standard dimensions of headed studs are Ø 19 mm and a length of 125 mm. The behaviour of the headed studs does not vary a lot when concrete properties are changed. Their load capacity is much lower than that of perfobondstrip and T-shape connectors, and it is always around the same value although fibre concrete, light weight concrete or higher strength concrete is used. Headed studs characteristic resistance is lower than that of perfobondstrip and T-shape connectors, and it depends on the number of studs used (see Figure 2.5)

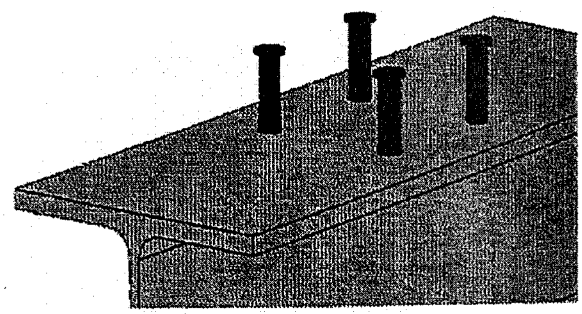

Figure 2.5: Headed studs (Gracia, 2007)

2.7.2 Oscillating perfobondstrip

Oscillating perfobondstrip with a height of 100 mm, a thickness of 8 mm, 5 holes Ø 50 mm and bend in 1.5 wave with an amplitude of 110 mm. Its curve form will give a better force transfer between steel and concrete compared with a straight one. The load capacity of this type of connector is larger than for example that of the headed studs and T-shape connectors, but in the case of ordinary strength and normal weight concrete, its performance is a bit disappointing due to a fast drop of the load capacity after the peak.

But this behaviour disappears if light weight concrete, concrete with fibers or a high strength is used, and in these cases oscillating perfobondstrip connectors behave very well. Oscillating perfobondstrip connectors have also a higher characteristic resistance than others connectors as headed studs and T-shape connectors, and should be taken into account that the failure modes are different for lower and higher concrete strength (see Figure 2.6).

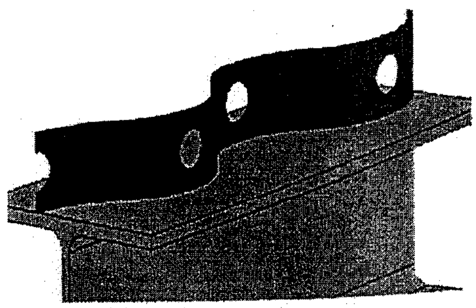

Figure 2.6: Oscillating perfobondstrip (Gracia, 2007)

2.7.3 Continuous perfobondstrip

Continuous perfobondstrip with a height of 100 mm, a thickness of 12 mm and 5 holes Ø 50 mm. The evolution in the behaviour of the continuous perfobondstrip, according to the change in concrete properties, is similar to oscillating perfobondstrip, but always archiving lower load capacity and characteristic resistance (see Figure 2.7).

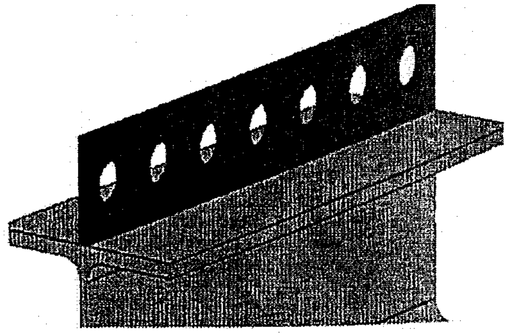

Figure 2.7: Continuous perfobondstrip (Gracia, 2007)

2.7.4 Waveform strip

Waveform strip with a width of 50 mm, a thickness of 6 mm and bend in 2 waves with amplitude 110 mm. Welded with prop-welds Ø 25 mm. It had a very disappointing behaviour in tests. Due to that its use is not recommended (see Figure2.8).

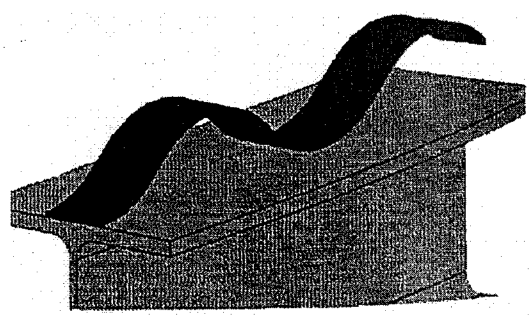

Figure 2.8: Waveform strip (Gracia, 2007)

2.7.5 T-shape connectors

A section with a length of 300 mm of a standard T-shape 120 welded to the beam. T-shape connectors performed very well compared to headed studs. T-shape connectors achieve the same load capacity as oscillating perfobondstrip, but have a much larger ductility. This type of connectors show an increase in their load capacity and ductility if the concrete used is with fibers, light weight concrete or a higher strength concrete. For the T-shape connectors, the concrete is no longer decisive, but the strength of the connector itself. Without considering the perfobondstrip, the T-shape connectors have the highest characteristic resistance and the mode of failure changes for different concrete strengths
(see Figure 2.9).

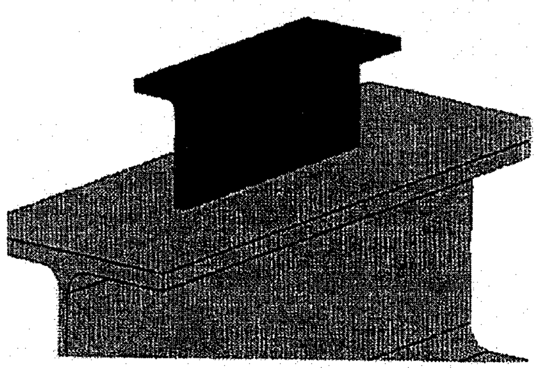

Figure 2.9: T-shape connector (Gracia, 2007)

2.7.6 Hilti HVB shear connectors

Hilti HVB shear connectors can be found between the nailed shear connectors which are presented as an alternative to welded headed studs connectors for composite beams. Hilti HVB shear connectors are cold formed angle shear connectors, fixed by two powder-actuated fasteners driven with a powder-actuated tool, placed on one leg of the angle. It is possible to use one, two or three connectors in each steel decking rib, depending on the requirements (see Figure 2.10).

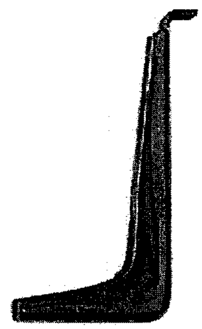

Figure 2.10: Hilti HVB shear connector (Gracia, 2007)

2.7.7 Profiled shear connectors

Profiled shear connectors are a type of nailed strip shear connectors. There are two elements with the same importance in the nailed shear connector system, the strip shear connector itself and the powder-actuated fasteners. The strip is formed by folding a flat zinc-coated steel sheet with a thickness in the range of 1.0 to 2.0 mm. The distance between the two troughs of the trapezoidal strip connector has to be chosen to fit to the geometry of the decking, in composite beams. The legs of the connector have to be higher than the metal deck and they act as a diagonal reinforcement of the concrete rib. The strip connector is fixed to the beam flange by power-actuated fasteners. The connectors are designed to be used with automatic installation systems. Push-out tests results indicate that optimized profiled strip shear connectors will achieve ultimate resistance in the range of 20 KN per fastener and also sufficient ductility to allow plastic beam design (see Figure 2.11).

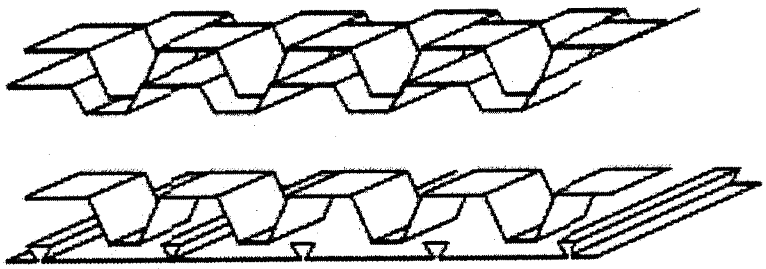

Figure 2.11: Profiled shear connector (Gracia, 2007)

2.8 Failure mode in shear

2.8.1 Diagonal tension failure

The shear failure is always in the span when the ratio a/d in 2. The diagonal crack starts from the last flexural crack and turn gradually into crack more inclined under the shear loading as note in fig. 2.12. This crack not comes immediately to failure, although in some of the longer shear span this either he crack will appear first before suddenly cause failure. The diagonal crack encounter resistance as it moves up into compression zone and stop at some point such as mark 1 in figure 2.2. With further load, the crack extend at a very flat slope and cause failure to the beam possibly from point 2.before reaching critical failure more inclined crack will appear like no 3 in the figure at least to steel level and after that the no 4 crack will appear (Goh, 2009):

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