وزارةالتعليم العالي
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كلية الهندسة

السلوك الانشائي للاعتاب الحديدية المركبة مختلفة الاشكال

رسالة
مقدمة إلى قسم الهندسة المدنية في جامعة ديالى كجزء من متطلبات نيل
درجة الماجستير في علوم الهندسة المدنية / إنشاءات

من قبل الطالبة
شهناز خالص جواد
(بكالوريوس هندسة مدنية ٢٠٠٠)

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حزيران ٢٠٢٠ ١٤٤٢

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Structural Behavior of Composite Steel Beams with Different Cross Section Shapes

A Thesis Submitted to Council of College of Engineering, University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

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June, 2020 **Dhul Qidah, 1442**

Chapter One

Introduction

1.1 Background

Composite steel-concrete beams (henceforth C.B) consisting of reinforced concrete slabs and steel girders are widely used in engineering applications. One can make use of the benefits of the two construction materials. Reinforced concrete is inexpensive massive and stiff whereas steel members are strong, light weight and easy to assemble (Yuna, et al. 2008). In the few past decades, steel and concrete composite structures have been increasingly used in the construction of buildings and bridges Zhao, et al. (2010). By taking advantages of different construction materials, the favorable structural behavior and economic cost could be achieved. In order to optimize the structural performance of composite structures, it is critical to ensure the shear connection between steel and concrete components Ranzi, et al. (2004). The shear connection is typically achieved by the installation of shear connectors(Zheng, et al. 2018).

The composite beam is often designed to have large dimensions of cross sections. With respect to buildings having the heavy load and wide column spacing, the high strength of engineering materials exhibits satisfactory performance. Composite beams with high strength steel and concrete are required to lessen the cross-section area. Shear connectors are designed in steel-concrete composite construction to transmit the longitudinal shear, to prevent separation of steel and concrete slabs and also to increase the structural efficiency of the whole system (Shariati, et al. 2012).

1.2 Composite Beams

Composite steel structures have been introduced for several years as one of the construction systems that are the most economical ones . Steel-concrete composite beams are used for a considerable time in buildings, constructions and bridges. Composite beams consist of a steel section and a reinforced concrete slab connected with shear connectors, as presented in Fig. (1- 1). Composite beam is common information that concrete is strong when subjected to compression but weak in tension, whereas steel is strong when subjected to tension but, slender steel members are sensitive to buckling under compressive forces. Therefore each material used is intended to take advantages of its positive qualities types composite steel-concrete structure is very effective and economical Hegger and Goralski, (2005).

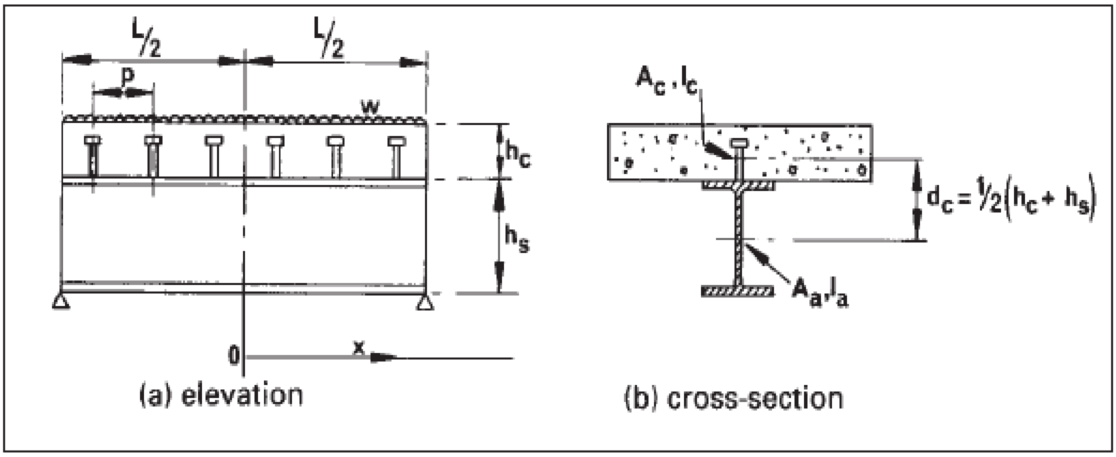


Figure (1-1) Simply-supported composite beam Johnson,(1994)

1.3 The Composite Action Achieved

To achieve a composite action between the concrete slab and the supporting steel beam, shear connectors are usually provided to transfer the horizontal shear force across the interface and to prevent any vertical separation. Full composite action is achieved when the shear connectors are able to take the full shear assuming that either the steel beam is fully plasticized or the effective concrete slab is stressed to its maximum capacity in compression whichever is less. When full interaction is not present, the beam is said to be partially composite.

1-4 Benefits of Composite Structures

Slabs of concrete in conventional composite structures are supported by steel beams . Two materials under load act independently if there is no mechanical connection between them. This causes a relative movement (slip) to occur at the interface. The slip between the steel beams and the concrete slab can be eliminated by providing a suitable connection between them. For this reason, the steel beams and the slab act as a composite beam and so the T-beam section obtained had been used in concrete structures for a long time. A number of benefits associated with composite structures are listed below: Ramyaa, et al. (2005).

1- The most effective steel and concrete employment is achieved.
2- Accomplished in composite structures compared with traditional constructions with respect to the remaining span and loading fixed, is a more economical steel section (as for height and weight are concerned).
3- Composite beams have less deflection than steel beams, because it has larger stiffness.
4- Composite construction does not need long time for construction due to using rolled steel section and pre-fabricated elements, rather than cast-in-situ concrete. That does not need a lot of reinforcement, and large areas of buildings can be cast quickly.
5- Large pliability in design process, pre-fabrication and construction scheduling in crowded areas.
6- The stiffness and bending strength of composite beams means that less height stories can be accomplished than in conventional construction. This may result in smaller heights of story, more room to provide services, a specified ceiling to floor zone and for

the same total height more numbers of storeies. This is particularly true for slim floor construction, whereby the depth of beam is contained within the slab depth.

7- Without reducing steel accompanying properties, it can be recycled repeatedly. Composite structures may be considered one of sustainable options. „Sustainability" is the most important factor for clients, and approximately 94% of all steel frame components can be either recycled or re-used upon demolition of a building Rackham and Couchman,(2009).

1.5 Shear Connectors

The purpose of shear connectors in a composite beam is to tie the slab and steel beam together and force them to act as a one unit. For this, the connectors must resist the horizontal shear force that develops between the slab and beam as the composite member is loaded, and they should prevent vertical separation or uplift of the concrete slab from the steel beam Vinnakota, et al.(2003) as shown in Fig. (1-2).

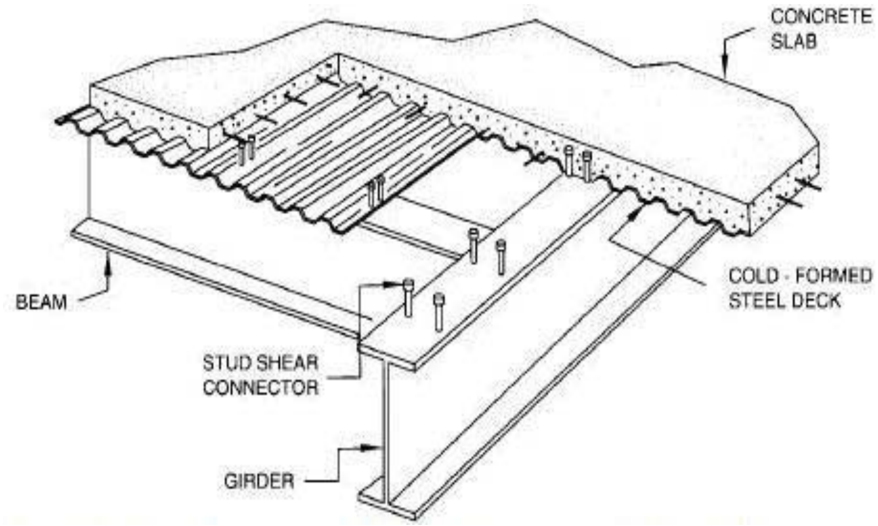
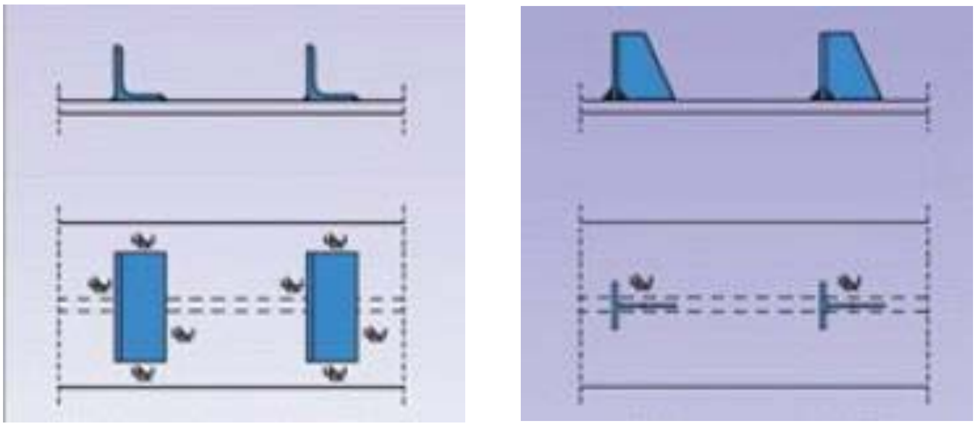


Figure (1-2) Typical Shear Connection in Composite Structure Shahabi, et al.(2015)

Shear connectors can be divided into three categories:

1. Rigid Type

The rigid type is very stiff and they sustain only a small deformation while carrying out the shear force. The resistance has been derived from bearing stress on concrete, but it fails due to concrete crushing. Samples of connector are short bars, angles, and T-sections. Hooped bars are also used with these connectors as anchorage devices to stop vertical separation. These connectors types are shown in Fig. (1-3-a) Ibrahim, et al. (2016).

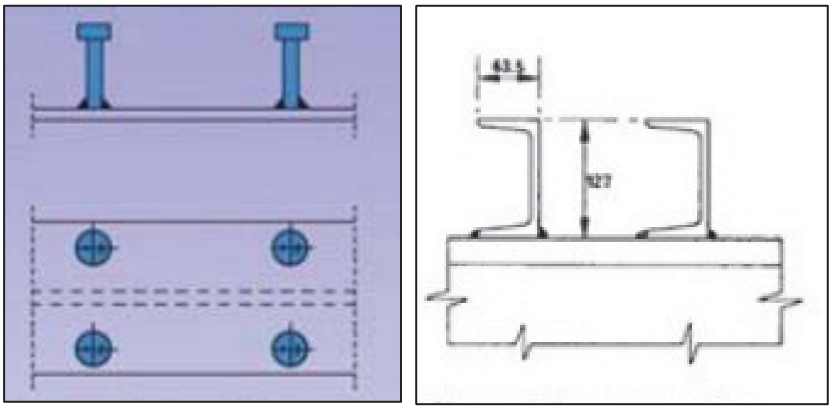


Figure(1-3-a)Shear Connectors(Angle and T) Pashan,(2006)

2. Flexible Type

The most common connectors used under this type are headed studs and channels. These connectors are welded to the steel beam flange. Their stress resistances are derived from bending and subjected to large deformation before failure.

In common flexible connectors as shown in Fig. (1-3-b) the most used type is stud connectors. The shank of studs and the weld part close to steel beam carry out the shear loads while the head resists to the uplift Ibrahim, et al. (2016).



Figure(1-3-b):Shear Connectors(Headed Stud and Chanel) Pashan,(2006)

3. Bond or Anchorage Type

The resistance of bond connectors is derived from the bond and anchorage effect as shown in Fig. (1-3-c) Ibrahim, et al. (2016).

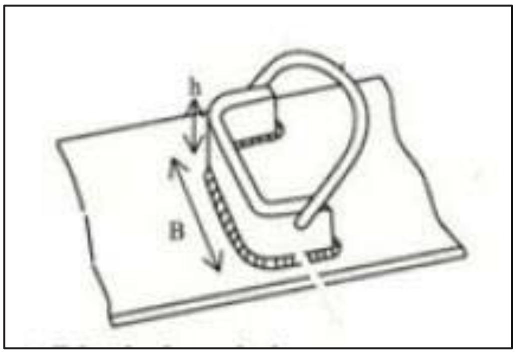


Figure (1-3-c): Shear Connectors (Block Dowel Type) Pashan, (2006)

1.6 Properties of Shear Connectors

The most effective shear connector property in design is the relationship between the transmitted shear load and the interface slip between steel beams and the concrete slab. The load-slip relation may ideally be got from push-out tests on composite beams. Different types of push- out test can be used to obtain much data on shear connectors Johnson, (1994). One of these methods is the "standard push test" which is defined by Eurocode 4 (2004) as shown in Fig. (1-4) Eurocode 4 (2004).

The load-slip relation is influenced by many parameters as follows:

1- The number of shear connectors in the specimen.

2- Longitudinal stress in the concrete slab surrounding the connectors.
3- The number of bars diameter of bars and slab reinforcement strength near the connectors.
4- Thickness of concrete that surrounding the connectors.
5- Freedom of each slab to lateral movement.
6- Friction at the interface of steel beam and concrete slab.
7- Strength of the concrete slab.
8- Quantity of compaction of the concrete at base of the shear connectors.

The maximum capacity of studs may be recorded when the concrete around the connectors fail, or the stud shear was off if strong concrete is used, Johnson, (1994)

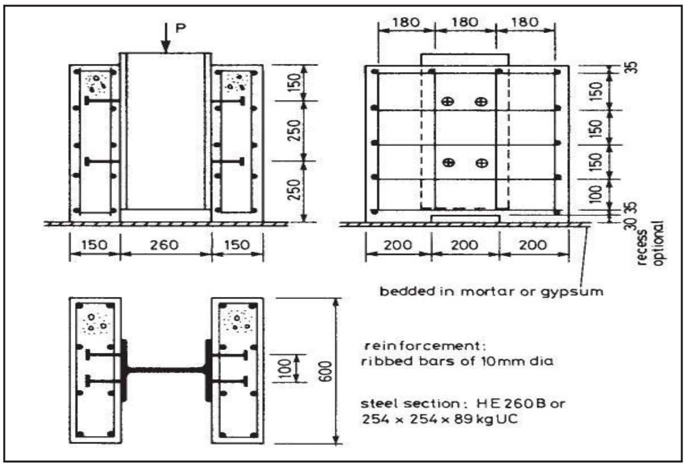


Figure (1-4): Test Specimen for Standard Push out Test, Eurocode 4 (2004)

1.7 Hollow Steel Section (HSS)

Circular and square HSS have very efficient shapes for this multiple-axis loading as they have identical geometry along two or more cross-sectional axes and thus they uniform the strength of physical characteristics. This makes them a good choice for columns also they have excellent resistance to torsion. The hollow steel section (henceforth HSS) can be used as beams. Although wide flange or I-beam shapes are in many cases very efficient structural shapes for these applications but hollow steel sections have superior resistance to the lateral torsional buckling.

The flat square surfaces for a rectangular hollow steel section can ease construction as well as they are something preferred for architectural aesthetics in exposed structures, yet elliptical hollow steel sections becomes more popular in exposed structures for the same visual reasons. Fig. (1-5) shows Rectangular Hollow Steel Section.

Figure (1-5): Rectangular Hollow Steel Section (New Millennium Building)

1.8 Main Advantages of Hollow Steel Section(HSS)

- The hollow steel section has greater strength-to-weight ratios than wide flange W And HP shapes. So, for the HSS we need less steel by weight to do the job and less weight equals less cost.

- The HSS is particularly well suited to all types of column applications because it has excellent compression as well as support characteristics and superior torsional resistance .

- The HSS is made from steel, one of the world's most recyclable and recycled materials. The uniform shape of the hollow steel section makes it well suited for architecturally exposed applications and easy to fabricate (Tata steel company).

• However increasing the strength to weight ratio as mentioned earlier leads to reducing the use of materials and allowing greater span buildings. This enhances the structural efficiency and reduces cost, Pashan, (2006).

• Finally, reducing the surface area rather than open sections allows for reduced clean up and painting. Wall thicknesses and the wide variety of the shapes are available (IS 11384-1985) .

1.9 Problem of Study

Some of unfavorable aspects in the structural behavior of I- steel sections example buckling and heavy weight, lead us to complete the study that works to suggest new sections and to investigate their structural and service behavior done by the researcher Ibrahim, et al (2018). The study also works to propose a new hollow steel section with constant depth and study its effect on(square, rectangular and trapezoidal) hollow steel sections. Therefore, it is necessary to study the effect of constant area on these hollow steel sections which are added to the circular and trapezoidal hollow steel sections and to compare all these sections with the I-steel section. Suggesting the best section instead of the traditional I-sections helps to study the possibility of these sections, to provide some extra services in addition to the structural basic function.

1.10 Research Objectives

1- Structural objectives: The investigation of composite beams with different steel hollow section shapes (Square, Rectangular ,circular, Hexagonal and trapezoidal) will be established by carrying out the results of the ultimate load capacity, failure mode, load-deflection behavior, deflection profiles, end slip, crack pattern, concrete compressive strain, strain profiles, steel strain and plastic moment capacity.

2- Service advantages: The availability of various shapes for hollow steel section in buildings allows using them as service instruments. Hollow steel sections can be used as electrical pipes, sewerage, and transports of soft materials like oil products, water, in addition to saving the requirements of design and construction.

1.11 Methodology

The experimental program of this study consists of preparing six specimens of composite beams with different cross hollow steel section shapes (Square, Rectangular, circular, Hexagonal and trapezoidal) and the steel I- section. As well as twelve specimens of a push out test. Moreover, the specimens are tested before and after failure by using one type of shear connectors which is perfobond.

The experimental results are analyzed and discussed. Besides, the comparative discussion include comparing the results of the specimens that have been tested in the experimental work with the results of different international standard codes concerning same action (using formulas).

1.12 Parameters

In this study only one variable parameter is adopted which is the shape of hollow steel section (square, rectangular, circular, hexagonal and trapezoidal). All of these sections have the same constant area , type of shear connector (Perfobond) as well as thickness of hollow steel section is (4 mm). These are important for estimating the structural behavior of the reinforced composite beam.

The perfobond connector is first used in 1987. It has a larger bearing capacity than the stud and most widely used in composite structure now.

Perfobond could be less affected by fatigue load and more conveniently is applied in construction than in studs Liu, (2005). Various tests are done for Perfobond, Oguellofor,(1990) ; Hosaka,(2002).

1.13 Layout of the Thesis

The present study contains six chapters as delineated below:

Chapter One highlights a general introduction and a brief overview of civil engineering structures, composite beams and their advantages, problem of study, research objectives, methodology and layout of the thesis.

Chapter Two presents a brief overview of some previous studies and researches which shed light on the uses of hollow steel sections and the behavior of composite beams.

Chapter Three generally, reviews the methodology of experimental groups including the specimen tests used in this study. It also presents the plan of the study that is used for the completion of the tests, dimensions and sizes of the specimens as well as the devices.

Chapter Four provides the results obtained from the pilot experimental program are dealt with. The results discussed are based on applicability of different international standard codes.

Chapter Five shows theoretical comparisons between the experimental ultimate loads and the specified loads that are calculated according to different international codes. Besides, it presents a suggested formula to predict the moment capacity of composite beams with specified five hollow steel sections.

Chapter Six deals with the conclusions of the study and provides a set of recommendations that are proposed for future studies.

Abstract

The experimental work of this thesis consists of two series. The first consists of six specimens of reinforcement concrete composite beams having dimensions of (2000*400*130)mm. The second consists of twelve specimens (two specimens for each type of hollow steel section) of standard push out test consisting of two parts of concrete slab whose height is 450 mm, width is 400 mm and thickness of is 100 mm, these two parts have been connected together by a steel hollow section. The study aims to evaluate the structural behavior including ultimate load and mode of failure of reinforcement concrete composite beams which are fabricated and tested under static loading conditions. The specimens test of composite beams and push out tests provided information about the resistance of the shear connectors used in this study and the corresponding load-slip relationship, from which the shear stiffness of the connectors can be calculated. The division of the experimental specimens depends on the steel beam section shape (square, rectangular, circular, hexagonal and trapezoidal) and a steel I-section, with approximate area.

Steel section dimension for(I-section, square, rectangular, circular, hexagonal and trapezoidal) is (1300,1536,1376,1370,1440 and 1360) respectively.

The work used one type of shear connector which is Perfobond. The number of holes in the perfobond is 32 with a diameter of 35mm and the uniform spacing between them is 60 mm from center to center. Two positions of linear variable differential transformer (henceforth LVDT) are determined with accurately (0.0001 mm) for composite beams. Two positions (LVDT) for push out test specimen in the right and left sides of concrete slab whose base are placed on hollow steel section watch .A

device is developed for the two sides of concrete slab to measure the slip of each side and then take the reading rate.

The results show that all beams specimens under the load fail by crashing in concrete flange at the compression region knowing that the load is recorded by the test machine which is dropped suddenly with an increase in deflection. At the load of 70 kN to 125 kN for specimens of composite beams, the end slip is observed. After the load exceedes 150 kN, the deflection in mid-span increases rapidly and the number of cracks begins to increase. At top surface of the concrete slab along the center line around the point load, a longitudinal crack appears in all specimens at about (70%) of the ultimate load. The failure mode of the composite beam specimens is a ductile one.

The composite beam with a circular hollow steel section have more ultimate strength than composite beams with (square ,rectangular , hexagonal and trapezoidal) hollow steel section shapes. The test results show a good approximation between the experimental results and the calculated ones from the proposed formula on the one hand when the coefficient of determination of this results is (0.76) and the appreciated convergence between these results and European code (Eurocode4, 2004) on the other hand. The suggested formula takes into consideration the type of steel section in calculating the plastic moment of the concrete composite beams with hollow steel sections.