Ministry of Higher Education

and Scientific Research

University of Diyala

College of Engineering

Steel/Rubber Shear Connectors Behaviour under Elevated Temperature Using Direct Shear Test

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

BY

Ola Khalis Ali

(B.Sc. Civil Engineering, 2021)

Supervised by

Prof. Amer M. Ibrahim. Ph.D

2024 A.D. **Iraq** **1446 A.H.**

ABSTRACT

Shear connectors are the most important part of the composite structural members as they connect two different materials with each other and play an essential role in transferring shear loads and distributing them among the parts of the composite member. Therefore, the process of developing and improving its behaviour is very crucial and worth researching, especially in structures exposed to earthquake and fire conditions.

This study investigates improving the behaviour of steel shear connectors in composite structures using rubber coverings, particularly under high temperature. Twenty-seven specimens cast and tested under static loading using direct shear test. Variables included concrete compressive strength (26 MPa and 55 MPa), rubber thickness (50%, 75% and 100% of the bolt diameter), rubber shape (cylindrical and elliptical), and rubber location (nut, mid and head of bolt). The effects of high temperatures (100 ℃ and 200℃) were also studied.

The direct shear test is one of the simplest tests used to measure the shear strength of soils, and in some studies it is used to check the shear strength of reinforced concrete material. But in this study, this test will be used to measure the shear strength of bolts which connecting two materials.

The main findings show that rubber increases the deformation of the shear connectors before failure, improving shear strength, durability and ductility. The optimal rubber thickness is 50% (4 mm) of the bolt diameter, increasing longitudinal displacement by 54% and shear strength by 20.9% with normal strength concrete.

For the effect of temperature, the temperature 100 °C has a positive effect, especially with high concrete strength. The temperature 200 °C has a negative effect on the shear strength and deformation due to increased

connector softening. After using more than one shape and location of the rubber, it is concluded that the shape of the elliptical rubber is better than the cylindrical shape in terms of increasing strength by 155% and deformation by 48%.

The optimal rubber location is at nut, between the concrete and steel because rubber is strong in compression and weak in tensile areas.

Chapter One

Introduction

1.1 General

One of the most economical structural systems is the composite structure. This system consists of more than one shape , made up of more than one material such as conventional composite sections which consist of a reinforced concrete part and a cold- formed steel (I-section) part, its connected together by shear connection (Mubarak, 2016) , as shown in Figure 1.1 (Mohammed, 2018).

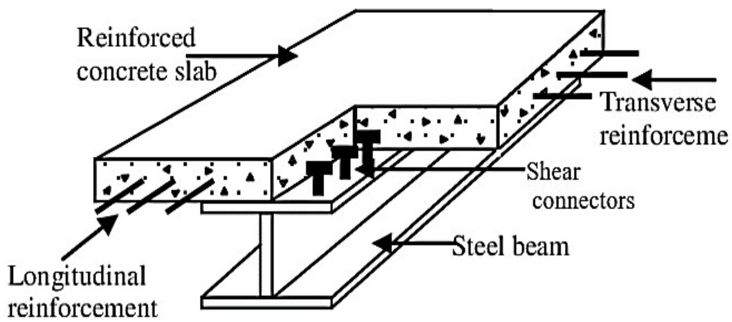

Figure 1.1 Composite Beam Ingredients (Mohammed, 2018)

This mixture between the two most common building materials (i.e. concrete and steel) in the same member provides a better structural performance because of the perfect properties of these materials. Compared to conventional beams, composite beams have numerous benefits. The steel section is small in size but carries high loads. Consequently, the total height of building and the weight of steel required decrease and lead to decreasing the direct cost (Amit, 2006). The idea of composite beam is that the steel section works as tension element and in the same time the concrete part enhances both the rigidity and the resistance of the steel section. Thus one of them complete the other as for as properties are concerned. The composite action is done by the shear connection between placed the two sections (concrete slab and steel beam) which is the main component in composite beam. Shear connectors are allowed to transfer loads between the reinforced concrete and structural steel. In addition, its contribute to resistance withdrawal forces normal to the steel-concrete interface (Mubarak, 2016). High strength and stiffness are required in shear connectors to ensure load transfer between the two sections. Therefore, improving the properties of shear connectors is extremely important because it affects the overall performance of the composite beam.

1.2 Shear Connectors Function

The link between two materials different in many properties to produce a member working as single section is not easy but it can be achieved by using a mechanical connection. Shear connectors play a significant role in limiting the longitudinal displacement that occurs between the reinforced concrete element and structural steel. Moreover, shear force transfers along steel-concrete interface by these connectors (Institute for steel development & growth INSDAG, n.d.)

1.3 Types of Shear Connectors

1.3.1 Stiff Shear Connector

When applying the shear stress, the stiff connector types barely slightly deform because of their extreme stiffness. Their resistance comes from putting stress on concrete, and when the concrete gets crushed, they give out. Angles, short bars, and T-sections are typical examples of these connector types. In order to prevent vertical separation, hooped bars are also utilized as anchorage devices with these connectors. In Figure 1.2, these connector types are displayed.

1.3.2 Flexible Shear Connector

Channels and headed studs are the most often utilized connectors under this type. The steel beam flange and these connectors are bonded together.

They undergo significant deformation prior to failure resulting in stress resistances that are obtained through bending. Figure 1.2 shows common types of connectors. Stud connectors are the most popular type. The shear stresses are carried out by the stud shank and the welded area near the steel beam, and the head resists the uplift.

1.3.3 Bolted Shear Connector

It is one of the important types of shear connectors that are characterized by the possibility of disjoint and replacing one of the parts if damage occurs. This is considered an economic advantage that meets the requirements of sustainability. The method of connecting it in steel-concrete composite beam is by immersing the part that contains the head with reinforced concrete, while the other end is outside of the steel part in which the nut is connected. There is more than one type of bolts is used among them are a bolt without embedded nut or an anchor bolt, a single-nut embedded bolt and a double-nut embedded bolt (Nadiah Loqman, 2018).

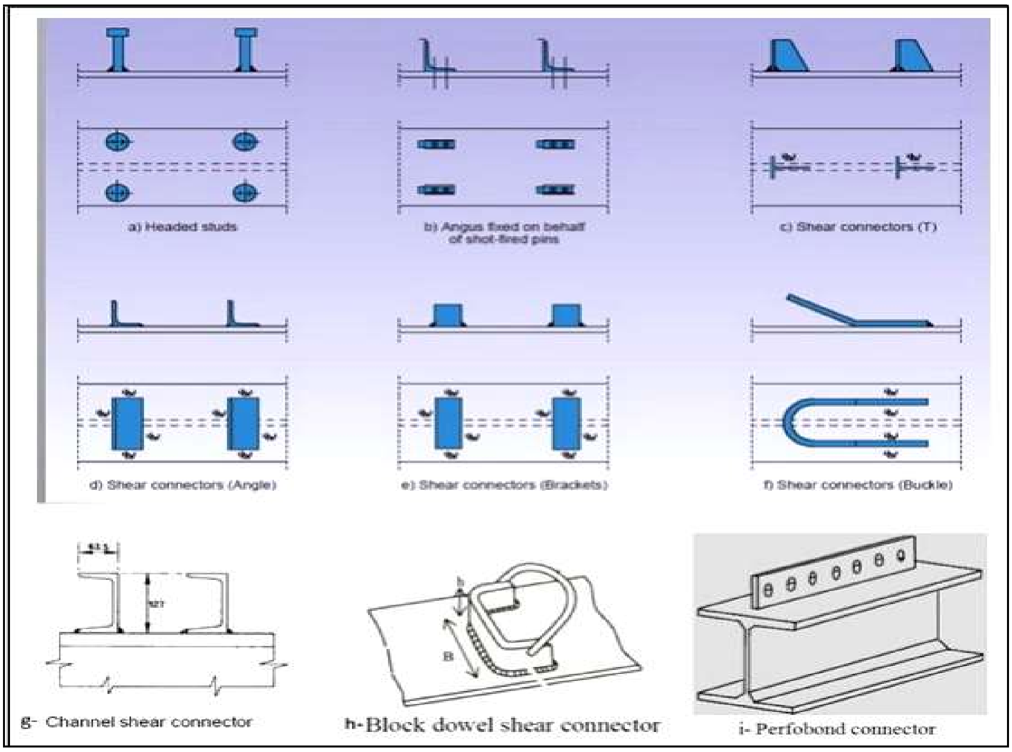

Figure 1.2 Types of Shear Connector (Amit, 2006) and (Group, 2005)

1.4 Importance of Bolted Shear Connectors

Medium-rise structures have comparatively short structural lifetimes and must be demolished as a result of changes in urban land use (Barros, 2017). So, in recent years, sustainable buildings have been turned to and most research has become concerned with the issue of sustainability (Xinpei Liu, 2017). In composite structural members, the use of detachable bolts meets the requirements of sustainability through the advantages of the possibility of removing them at the end of the building life. Their use will be considered as being economical because they do not require the demolition of the entire building. Plus the possibility of using them in the composite beam in which precast concrete is used (Bradford, 2013). There are many types of demountable shear bonds as shown in Fig. 1.3. The researchers have examined and tested with a push-out test, or so-called double shear test.

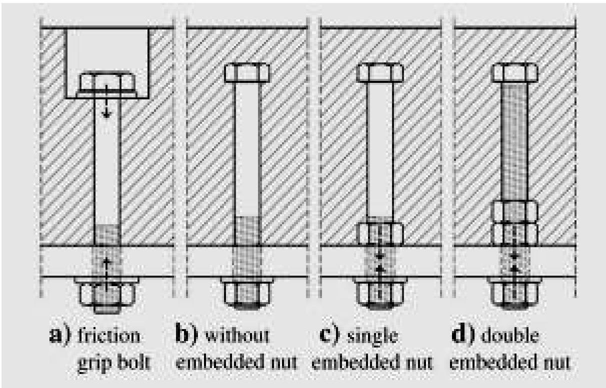

Figure 1.3 Various Types of Demountable Shear Connector (Marko Pavlović, 2013)

1.5 Use of Rubber in Shear Connectors

Steel shear connectors are used to connect composite parts of the push-out inspection model due to the fact that these connectors have high rigidity, which leads to either the failure of the concrete part or the failure of the brittle connector. In addition, the frequent occurrence of earthquakes worldwide in general and in Iraq in particular, leads researchers to find techniques and materials to dampen the impact of earthquakes. One of these materials is the use of rubber in the connection area linking the various structural members because it is usually considered the weakest area in steel buildings and steel structural members. There is a lot of research on rubber behaviour, including the study of **Suhaib J Ali (2020)** which was on the behaviour of rubber-coated shear ties to connect the bridge with the shaft under the influence of a semi-static periodic load. Also Bozhou-**Zhuang (2019)** verified the deformation performance of rubber sleeve steel bonds used to connect a steel part (I-section) with two parts of reinforced concrete under a variable periodic load using an outward push check.

1.6 Single Shear Test

It is the simplest type of shear tests which is used to check the shear resistance of materials. It is used to check the shear of soils as shown in Figure (1.4). The ASTM standard D-3080, "Standard Method for Direct Shear Test on Soils under Consolidated Drained Conditions," addresses direct shear testing (Lai, 2004). Moreover, it has been used in some research to examine the shear strength of reinforced concrete and this examination is done by applying a vertical force to a Z- shaped reinforced concrete **(Pengtao Wu, 2019 and Chuanxi Li, 2019)** as shown in Figure (1.5). In a composite beam, the push-out test is used to examine its shear capacity that contains two blocks of reinforced concrete connected to steel I-section by headed stud connectors according Eurocode 4. But in this study the single shear test has been used. Reducing the examination specimen's weight and making its application simpler are the goals of this test.

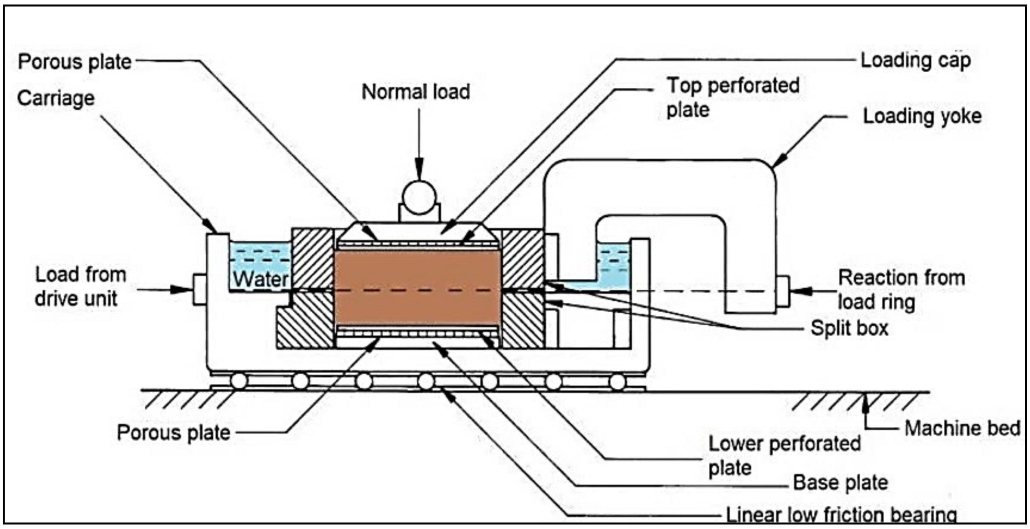

Figure (1.4): Photo for Direct Shear Test of Soil (Epps., 2011)

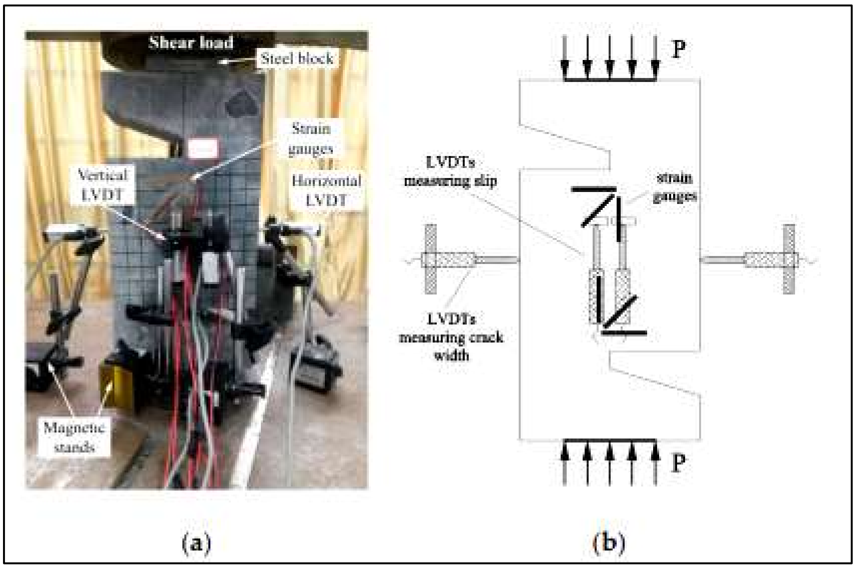

Figure (1.5): Direct Shear Test of Concrete (a) Test set up (b) Plan of the Transducers (Chuanxi Li, 2019)

1.7 Problem Statement of Study

Fires raise the temperature of the buildings, which impacts the properties of the composite sections because heat weakens the load transmission to the section compounds through the shear connections. Furthermore, the high stiffness of bolted shear connectors may result in unexpected concrete failure; therefore, a method to increase this section's flexibility, decrease stress in the bonding areas, increase the shear connectors' failure time by covering the bolts with rubber, and examine how they behave under temperature changes is required.

1.8 Objectives of Study

This study aims at examining how the rubberized steel connection in the composite section behaves structurally under high temperatures using a single shear test. In addition, it investigates numerous parameters that can influence the composite connector’s performance through:

1. Studying the effect of compressive strength of concrete on the shear connector’s behaviour without rubber.
2. Studying the effect of the rubber on the shear connector’s behaviour.
3. Investigating the effect of thickness of rubber on the bearing capacity of the shear connectors.
4. Checking the effect of the shape of rubber on the shear load capacity of the composite sections
5. Studying the effect of rubber positions and which is the most effective place.
6. Studying the effect of temperature on rubberized shear connections behaviour.

1.9 Scope of Investigation

This study is mainly designed to investigate the effect of the parameters on the behaviour of shear conductors that link two different materials, i.e., reinforced concrete and steel to perform the composite action as shown below:

1. Type of utilized test is a direct shear one and the static load is considered.

2. Different compressive strength of reinforced concrete part (**26MPa** and **55MPa**) with a steel shear connector is also considered.
3. Three percentages of cylindrical rubber thickness are examined in case of normal concrete and high strength concrete. These percentages are (**50% d**, **75% d** and **100% d**) where **d** is the bolt diameter.
4. The parameters above are retested at (**100 ℃** and **200 ℃**).
5. After determining the effective rubber thickness and temperature, as well as evaluating this parameter at ambient temperature and at (**100 ℃** and **200 ℃**), another shape of rubber was tested using normal strength concrete.
6. A comparative analysis will be conducted between two shapes of rubber situated at the nut of the bolt. The effective shape of the rubber, maintaining a consistent effective thickness, has been positioned at (head and mid) of bolt, utilizing 200 ℃ temperature and standard concrete.

1.10 Methodology

A pilot program is conducted on twenty-seven specimens using direct shear test of the variables taken in this study ranging from the change of rubber thickness to the change of concrete resistance and to change the location and shape of the rubber. These tests are conducted by applying a static load on a composite section in the Z-shaped form and specific dimensions depending on previous studies (Chuanxi Li, 2019 and Pengtao Wu, 2019). The information needed to identify how the study's parameters affect the behaviour of shear connections is obtained by the use of LVDTs and strain gauge.

Furthermore, specimens having an identical parameter are heated to high temperatures and then cooled down gradually. This allows studying the impact of heat on rubberized connection behaviour, how it affects the overall performance of the composite section in terms of strain at the connector area, transverse and longitudinal displacement and load bearing capacity.

1.11 Outline Study

This study is divided into five chapters described as follows:

1. **Chapter one :** Provides a general introduction to the composite beam, types of shear link and their importance, the use of rubber in conductors, the direct shear test, the research problem, and the main objectives of the thesis, the research methodology and the research limitations.
2. **Chapter two:** offers a general summary of previous studies achieved on the push-out test, the direct shear test, the use of rubber in connectors and the effect of using temperature on shear connectors.
3. **Chapter three:** describes the experimental work of this thesis including plates manufacturing and design of bolts. Details of specimens, properties of materials and test program are also presented.
4. **Chapter four:** presents the results of experimental tests and discusses them in details.
5. **Chapter five:** displays the main conclusions drawn from the study with suitable recommendations for future work.

وزارة التعليم العالي والبحث العلمي

جامعــة ديـــالى

كليـة الهندســـة

سلوك روابط القص (الحديد/المطاط) تحت تأثير ارتفاع درجة الحرارة باستخدام فحص القص المباشر

رسالة مقدمـــة إلى مجلس كليـــة الهندســـة / جامعـــة ديالى

وهي جزء من متطلبات نيل درجة الماجستير في علوم الهندســـة المدنيـــة/الهندسة الإنشائية

تقدم بها الطالبة

علا خالص علي

بكالوريوس هندسة مدنية

بإشراف

أ.د. عامر محمد ابراهيم

1446هـ العـــراق 2024م