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Load-Slip Relationship in Modified Push-Out Test (Experimental Work)

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Abstract

In this work, a modified push-out test is proposed to study the load-slip relationship in steel-concrete-steel sandwich beams. This relation is one of the most important factors that are required in the analysis and design of steel-concrete-steel sandwich beams with partial interaction. The diameter of the connector is assumed to be variable while the other parameters are kept constants. The modification in this test in comparison with the standard test concentrated on the use of steel tube- concrete slab- steel tube instead of concrete slab- steel (I-Section)- concrete slab (in Standard Test) in order to be more compatible than the standard test in modelling the steel-concrete-steel sandwich or double-skin beams. The stud is suggested to be threaded along the whole length, connected to the tube by a nut (the separation between the layers is eliminated and only interlayer slip is assumed to exist) and the connector passes to the other tube through the concrete slab (thus the connector is subjected to double shear force). These cases maximize the function of this stud. Five dial gages are used; one at the base, and two at each side in order to measure the slip at each stud. An experimental relationship of load-slip is carried out to simulate the behaviour of this type of connection in steel-concrete-steel sandwich construction.

Keywords: Composite Structures, Composite Beams, **Push**-Out Test, Steel-Concrete-Steel, Sandwich Beams, Double-Skin Beam, Double Shear Connectors, Bi-Steel Plate.

علاقة القوة-الانزلاق في فحص الدفع المعدل (دراسة عملية)

الخلاصة

في هذا البحث،تم اقتراح طريقه معدله لفحص الدفع لدراسة علاقة القوة-الانزلاق في العتبة السندويجية حديد-كونكريت-حديد. هذه العلاقة هي واحدة من اهم العوامل المطلوبة في تحليل وتصميم العتبة السندويجية حديد-كونكريت-حديد ذات الترابط الجزئي. قطر الرابط فرض ليكون متغيرا بينما العوامل الاخرى بقيت ثوابت. التعديل في هذا الفحص بالمقارنة مع الفحص القياسي

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تركز على استعمال تجميع من أنبوب مربع حديدي-شريحة كونكريتية-أنبوب مربع حديدي بدلا من شريحة كونكريتية-حديد(مقطع-I)-شريحة كونكريتية(في الفحص القياسي) لكي يكون أكثر ملائمة من الفحص القياسي في نمذجة العتبة السندويجية حديد-كونكريت-حديد أو العتبة مزدوجة الصفيحة. الرابط أقترح أن يكون مسننا في الطول كله، ومربوطا الى الانبوب بواسطة الصامولة (الانفصال بين الطبقات ألغي وبقي فقط الزحف بين الطبقات) ويمر الرابط الى النبوب الاخر من خلال شريحة الكونكريت(بذلك يكون الرابط متعرضا الى قوة قص مزدوجة). هذه الحالات تزيد من وظيفة الرابط. خمسة مقاييس وضعت ، واحد في القاعدة، وأثنان في كل جهه من أجل قياس الزحف في موقع الرابط. تم أستخراج علاقة عملية تربط القوة مع الانزلاق لنمذجة سلوك هذا النوع من الروابط في منشأت حديد-كونكريت-حديد السندويجية.

Notations

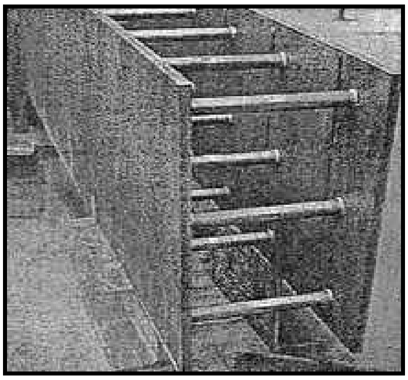
The major symbols used in this paper are listed below; these and others are defined as they first appear. When duplication occurs, the used notation is clarified within the text.

a, b :Constants.
BSP :Bi-steel plate.
D :Diameter of connectors.
DSC :Double-skin composite.
Ec :Secant modulus of concrete.
fu :Ultimate tensile strength of connectors.
$f'c$:Characteristic cylinder compressive strength of concrete.
hs :Height of stud (thickness of concrete layer).
Q :Connector force.
Qu :Ultimate load of connector.
SCSS :Steel-concrete-steel sandwich.
Tu :Ultimate tensile force of connector.
u_{ab} :Relative movement between layers.
γ :Slip interface.
α :Constant.

1. Introduction

Bi-steel plate (BSP), steel-concrete-steel sandwich (SCSS) construction, or double-skin composite (DSC) construction is a relatively new and innovative form of construction consisting of a layer of plain concrete, sandwiched between two layers of relatively thin steel plates, connected to the concrete by shear connectors [1, 2, and 3].

Different types of connectors have been used in composite construction such as rigid, bond, flexible, composite and friction grip connectors. The connectors are attached to the steel part either by welding like the headed stud (which is commonly used in practice) or by tightening like the stud with threaded ends penetrating through the concrete and the steel parts and tightened by bolts (which is used in this study). Figure (1) shows some connection techniques used in sandwich construction.

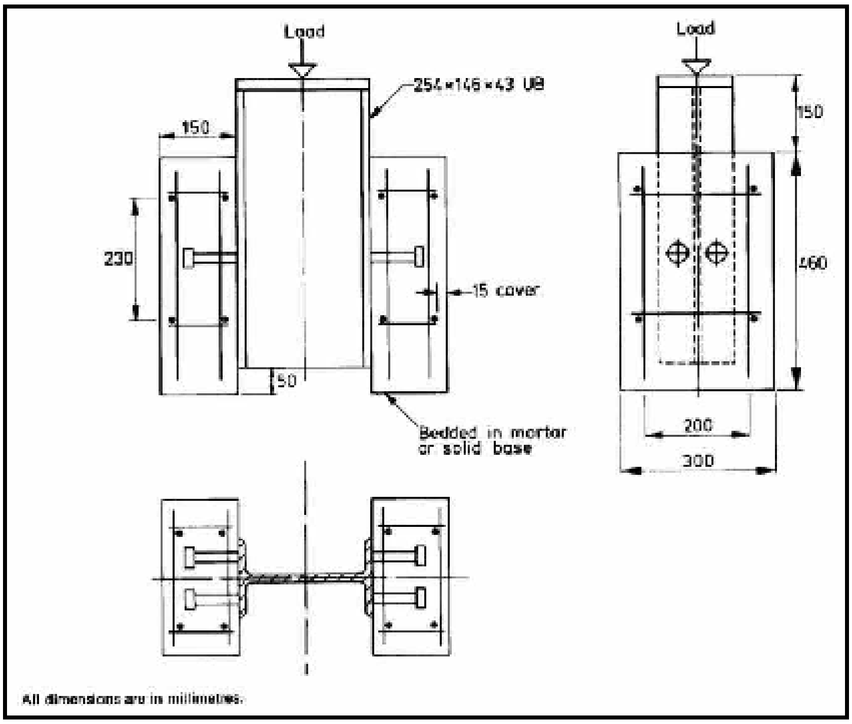


(A)

(B)

Figure (1): Steel-concrete-steel sandwich construction; (A): Welding technique [4, 5]; (B): Threaded stud and nut technique (used in this study).

Most of the data on connectors have been obtained from various types of push-out tests. The standard push-out test (as shown in Figure (2)) and the other commonly used types of push-out test consist usually of two concrete slabs and one in-between steel beam of I-section. These types are used to simulate the behaviour of stud in composite concrete slab-steel (I-section) beam [6], but in SCSS construction the matter is different since the beam or the slab consists of two steel plates and one concrete layer in-between [7]. Thus the aim of this study is to suggest a modification on the standard test by using two steel parts to sandwich a layer of concrete to simulate more properly the behaviour of stud in steel-concrete-steel sandwich construction.



NOTE: Reinforcement should be of 10 mm diameter mild steel bars.

Figure (2): Push–out test on shear connectors (redrawn from Reference (6)).

Yam and Chapman [8] presented a study for the inelastic behaviour of simply supported composite beams, based on Newmark's model. A nonlinear behaviour is assumed for the shear connectors, which is presented in the following exponential form:

$$Q = a \cdot \left(1 - e^{-b \cdot \gamma}\right) \quad \textbf{... (1)}$$

in which, (a) and (b) are constants of idealized load/slip function of a shear connector, (γ) is the slip at interface, (Q) is the shear load on a shear connector. By choosing two points from the experimental curve so that the slip in the second point (γ_2) is twice its value (γ_1) at the first point then the constants can be defined as:

$$a = \frac{Q_1^2}{2 \cdot Q_1 - Q_2} \quad \textbf{... (2)}$$

$$b = \frac{1}{\gamma_1} \log_e \left(\frac{Q_1}{Q_2 - Q_1} \right) \quad \textbf{... (3)}$$

in which, subscripts (1 and 2) represent the points on the experimental load – slip curve for the provided shear connector. Figure (3) shows a typical load-slip relationship (exponential formula).

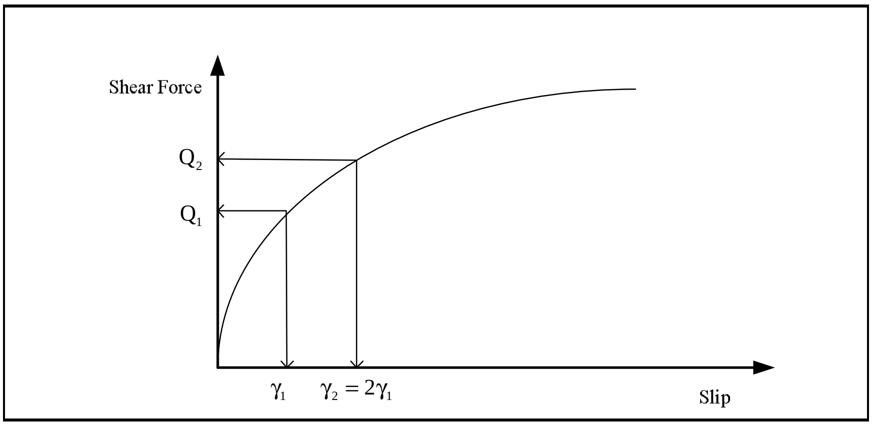


Figure (3): Typical load-slip relationship from the standard push-out test.

Al–Amery and Roberts [9] proposed a theoretical model for the analysis of composite beams with partial interaction. In this model, the load-slip curve for the connectors is presented in a modified form with respect to the exponential function of Yam and Chapman, as follows: $Q = Q_u \cdot \{1 - \exp(-\alpha . u_{ab})\}$

...(4)

in which, (Q_u) is the ultimate shear strength of a connector and (α) is a constant, which can be determined from test results. For example:

$$\alpha = \frac{1}{\bar{u}_{ab}} \cdot \ln\left(\frac{Q_u}{Q_u - \bar{Q}}\right) \quad \textbf{... (5)}$$

in which, ($\bar{u}_{ab}$) is the slip corresponding to a load ($\bar{Q}$).

Back analysis of numerous test results has indicated that the characteristic shear resistance (Qu) can be either determined from push shear tests or taken conservatively as the lesser of [2]:

$$Q_u = 0.8 \quad f_u \quad \pi \quad d^2 / 4 \quad \textbf{... (6)}$$

$$Q_u = 0.8 \quad T_u \quad \textbf{...(7)}$$

$$Q_u = 0.29 \quad \alpha \quad d^2 \quad (f'c \quad E_c)^{0.5} \quad \textbf{... (8)}$$

$$\alpha = 0.2 \quad (h_s / d + 1) \text{ for } 3 \le h_s / d \le 4 \quad \textbf{...(9)}$$

$$\alpha = 1.0 \text{ for } h_s / d \ge 4 \quad \textbf{...(10)}$$

where d, h_s and $f_u \le 500 \quad N/mm^2$ are the shank diameter, overall height and ultimate tensile strength of the stud, and $f'c$ and E_c are the characteristic cylinder strength and the secant modulus of the concrete.

2. Details of Test Specimens and Instrumentations

The suggested push-out test consists of two columns of rectangular hollow section (100*100*6) mm and one concrete slab of dimensions (450*300*100) mm (as shown in Figure (4)). The connector which is used in this test is a stud threaded along the whole length. This stud is embedded in the concrete layer and projected through the steel columns (details of connection as well as other dimensions and details are shown in Figure (5)).

The load is applied on the concrete with a steel plate as a capping to distribute the applied force on the concrete part. Under each steel column a piece of wood is used also to distribute the transmitted force from the concrete to the steel columns through the connectors and prevent relative movement at the base of the columns. The total applied load is measured by a loading machine and the relative movement (slip) between concrete and steel is measured at each connector as well as at the base of the concrete by using dial gages. Five dial gages are used and the averages of these readings are taken to construct the load-slip relationship. It is worthy to mention that the test is stopped when one of the connectors at any location is fractured.

Figure (4): Modified push-out test.

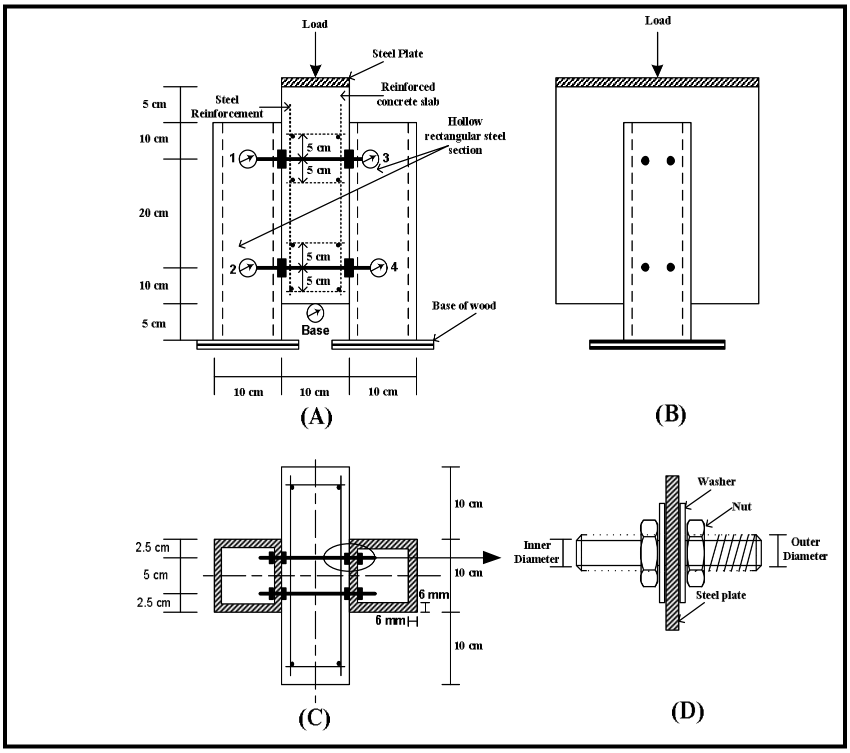


Figure (5): Dimensions and details of modified push-out test; (A): Front view; (B): Side view; (C): Top view; (D): Details of connection (magnified picture).

3.Results and Discussion

The concrete used to manufacture the test beams is designed to have a cylinder compressive strength between (30-40) MPa at age of (28) days. The cement which is used in the mixture of concrete is ordinary Portland cement (Spline) made in Lebanon and the sand is (Al-Akhaidher) with fineness modulus (2.8), while the gravel is crushed and having maximum size equal to (14) mm. The proportion of mixture (by weight) is (1) cement: (1.7) sand: (2) gravel with water cement ratio equal to (0.45). At least three cylinders (15*30) cm are made from each batch used to manufacture the test push-out sample. These cylinders and the push-out sample were cured under the same conditions. The sample and the cylinders were left in water up to 28 day and they were tested at the same time after approximately 45 day in air beyond the end of curing. The average cylinder compressive strength is (43) MPa. A threaded stud is used as a connector with specifications and details as given in Table (1).

Equation (7) gives values of (Qu) greater than that of the push-out test (the factor which is used in this equation (0.8) gives values for (Qu) greater than the push-out test) thus it is required to find another factor by dividing (Qu/Tu) and taking the least value to be in the save side. For this study this factor must be less than or equal to (0.65).

Table (1): Specifications and Test Results of Stud-Average Values.

Name of Stud	Measured Diameter (mm)		Tu (kN) From Tensile test	Qu (kN) From Push-Out Test	Qu/Tu From Test	Qu (kN) From Equation (7)	Qu (kN) From Equation (8)	Max. Measured Slip (mm)
	Inner	Outer						
A	10	11.8	48.67	36.75	0.755	38.94	46.5	3.97
B	6.2	7.2	18.33	12	0.655	14.66	17.3	1.89
C	5	5.75	12	8.5	0.71	9.6	11	1.11

The inner diameter is used in all calculations in the relations except equation (8) which depends on the outer diameter. Three of push-out tests for each diameter are made, and five dial gauge readings are taken for each test and the average values of these readings are plotted as shown in Figures (6), (7) and (8). The relation given by Yam and Chapman (the exponential equation) still gives good simulation for the load-slip relation but there the constants (a and b) is varying from test to another test. Figures (9) and (10) represent the effect of the parameter under this study (diameter of stud) on the connector ultimate force and maximum measured slip. Figure (11) shows pictures of the connector region after failure.

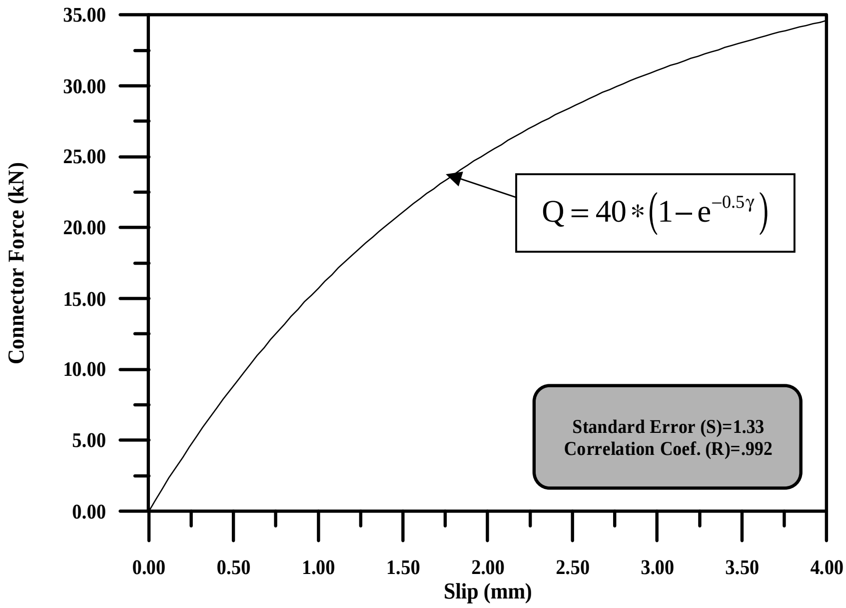


Figure (6): Load-slip relationship of stud (A).

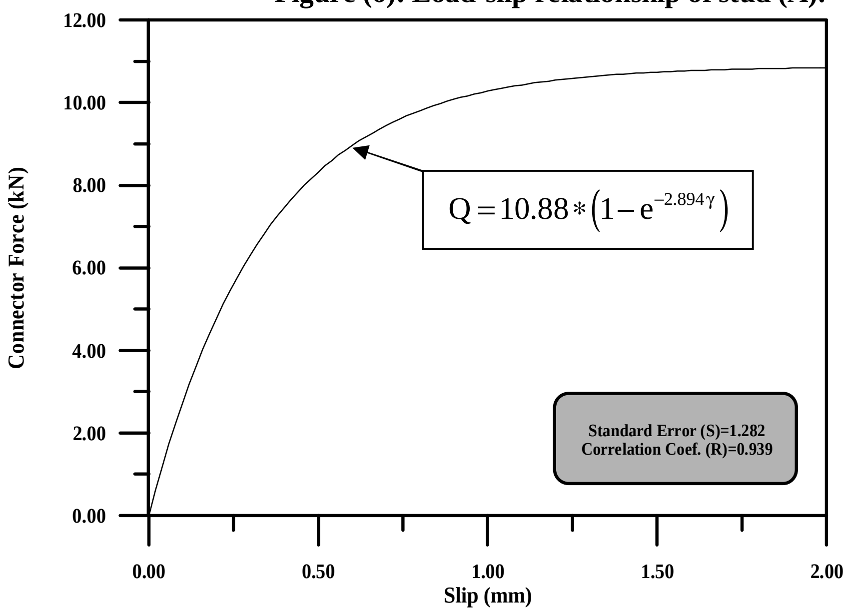


Figure (7): Load-slip relationship of stud (B).

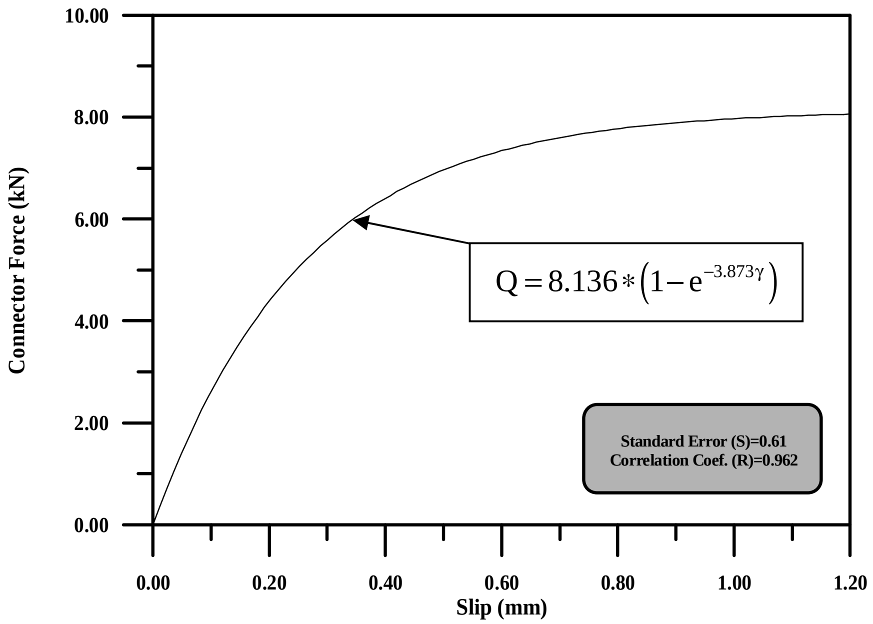


Figure (8): Load-slip relationship of stud (C).

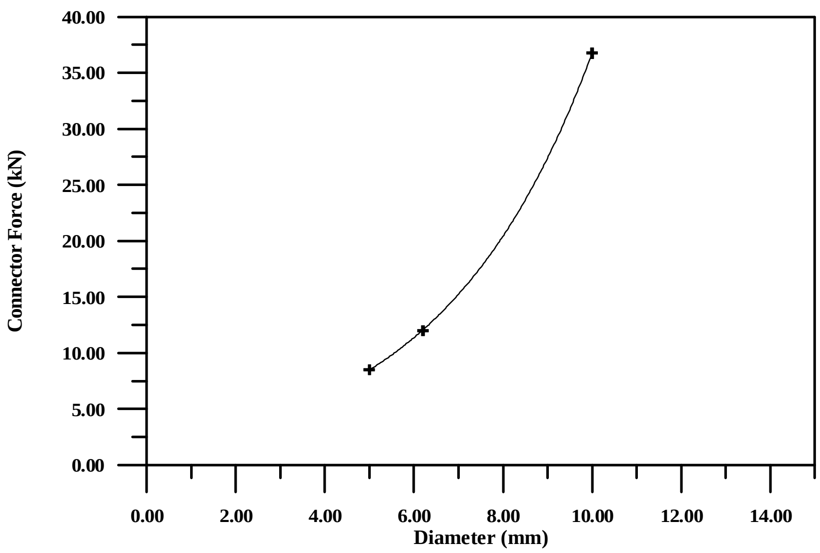


Figure (9): Variation of connector force with the diameter of stud.

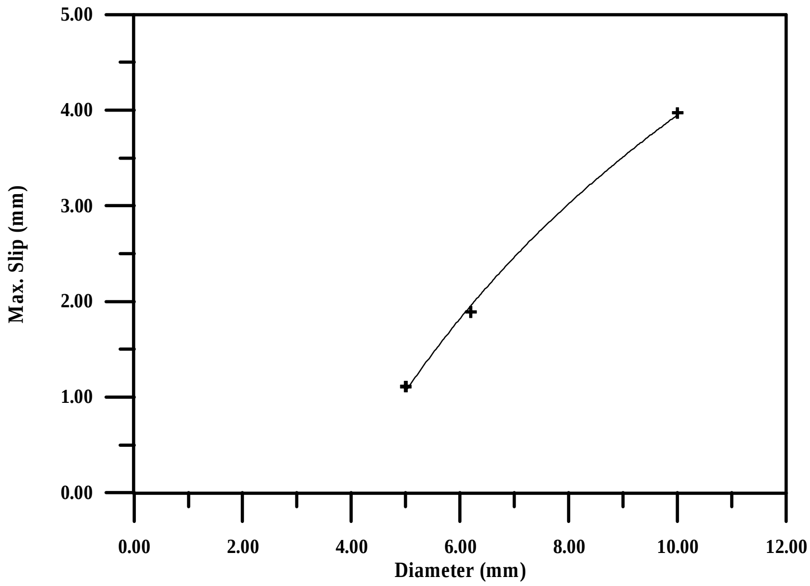


Figure (10): Variation of maximum slip with the diameter of stud.

(A)

(B)

Figure (11): Types of failure; (A): Local failure (Crushing of concrete surface around the connector; (B): Control failure (fracturing of the connector by direct shear).

4. Conclusions

From the suggested test, described in this study, and depending on the type of failure at these tests for varying diameter, it can be concluded that shear failure in the connector is the control failure, while at concrete, only local failure is noticed (crushing of concrete surface around the connector which only affects the slip value by increasing the value of slip).

The split failure of concrete slab is unlikely to occur in such test. The split failure of concrete occurs only when the concrete has low compressive strength (it will be described in the next research) or when the stud has a diameter or strength greater than those covered in this study.

Pull-out of stud is also unlikely to occur since the stud is threaded along the whole length and fastened by nuts at each steel column.

Equations (6 or 7), which estimate the connector ultimate force (controlled equation in this study), require using a reduction factor equal to (0.65) instead of (0.8) used in the previous studies [(2)] (to be more in the safe side).

For future work, it is recommended to study the effect of using a stud without threads and nuts but welded directly to the steel parts and to make comparison between these two cases. It is also recommended to study the effect of compressive strength of concrete, effect of impact loading, fatigue loading or fire on the behaviour of the connectors.

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