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Push–out Test of Timber Concrete Composite Construction

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HIGHLIGHTS

- Push-out specimens for determining the connector capacity in timber concrete composite beams are proposed and tested.
- An equation is proposed to determine the ultimate load of the connector in timber concrete composite construction.
- The proposed equation was applied and gave good results.

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ABSTRACT

In this study, push – out test specimen is proposed to explore the behavior of shear connectors in timber–concrete composite beams. Since there are no standard shapes and dimensions for determining the strength of connectors, push–out specimens such as those used for steel-concrete composite beams are suggested to study the behavior of connectors in timber concrete composite beams. Four specimens are tested. Two of these specimens are with one connector per side. The other two are with two connectors per side. The load and slip are recorded during testing. The results show that the ultimate load per connector ranges from 24.9 kN to 29.4 kN, with an average value of 26.9 kN. An equation is proposed to determine the ultimate load of the connector. Good agreement is achieved between the theoretical and experimental results. An average value of 0.98 is obtained for theoretical to experimental results.

1. Introduction

The connection between the components of any composite structure plays a critical role in determining the behavior and strength of such structure. This connection is usually used in mechanical devices, so-called shear connectors, to resist the interface shear between structural components. The stiffness and strength of a shear connector are the two characteristics required for the design of connection in any composite structure. The push-out test is the conventional test to determine the properties of shear connectors. The various codes for composite construction specify the dimensions, details, and test procedure. However, no standard specimen for push-out tests is still accepted for timber-concrete composite construction, and many studies have been conducted on proposed specimens. Gelfi and Giuriani [1] studied the performance of two types of connections, a smooth Ø 16 mm and a smooth Ø 12 mm bars. They concluded that no considerable improvement in performance could be achieved when inserting the dowels in timber more than five times the bar diameter. Weaver [2] presented the simplest type of shear connector, nail type. They were driven partly in the timber, leaving the top embedded in the concrete. The push-out tests have shown that a nail's penetration into the timber of approximately eleven times the nail´s diameter is required for maximum efficiency of the connector. Using this finding, a full-scale bending test was conducted, and it showed that the strength of the composite floor is largely increased, and the deflection is reduced. Branco et al. [3] carried out push–out test on smooth round nails for specimens made with lightweight concrete and a 2 mm plywood interlayer. Smooth round nails of 3.4 mm diameter and 70 mm total length connected the timber beam to the concrete slabs. One nail was used on each side of the timber beam. Five specimens without and five with interlayer were tested. The concrete cube strength was 31.18 N/mm^2. The maximum load capacity and the slip modulus for nails were measured. The study showed a significant reduction of the maximum slip value when an interlayer with a thickness of 2 mm is used between timber and concrete.

This paper investigates new connectors to resist the horizontal shear and vertical separation between the concrete slab and timber beam of the composite beam. Push–out specimen was proposed to examine this type of connection. The new suggested connector was made from plain steel bars in the form of T by welding two bar pieces. The connectors were driven into pre-drilled holes in timber beams with their heads laid into the concrete slabs. New dimensions and details were also proposed for the push-out test specimens.

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2. Experimental program

2.1 Materials

Locally available materials are used in this investigation. They include cement, natural silica sand, natural gravel, water, timber beam, steel reinforcement, and steel shear connectors.

2.1.1 Cement

Ordinary Portland cement manufactured by the Saudi Arabia factory was used throughout the investigation. The required quantity was brought to the laboratory and stored in a dry place. The physical properties of the cement are presented in Table (1). The setting time test is conducted according to ASTM – C191. [4] The compressive strength is accomplished according to ASTM – C109. [5]

Table 1: Physical properties of cement

Property	Test result	Iraqi StandardsNo. 5 /1968
Setting times:		
- Initial setting time (minutes)	97	More than 45
- Final setting time (minutes)	412	Less than 600
Compressive strength (mortars):		
- 3 days (N/mm2)	17.7	More than 15
- 7 days (N/mm2)	25.0	More than 23

2.1.2 Aggregate

2.1.2.1 Fine aggregate

Natural silica sand from Zubair area in Iraq was used as fine aggregate. Its grading conformed to Iraqi standard 45/1984[6] zone 2, as shown in Figure. (1-a). Some properties of the aggregate are presented in Table (2). The absorption capacity, the specific gravity, and the unit weight of aggregate are carried out according to B.S. 812[7]

2.1.2.2 Coarse aggregate

Crushed natural gravel obtained from the Zubair area was used. Its grading satisfies the limits of Iraqi standards 45/1984 for graded gravel with a maximum size of 14 mm, as shown in Figure. (1-b). Some properties of the aggregate are presented in Table (2). The absorption capacity, the specific gravity, and the unit weight of aggregate are carried out according to B.S. 812[7]

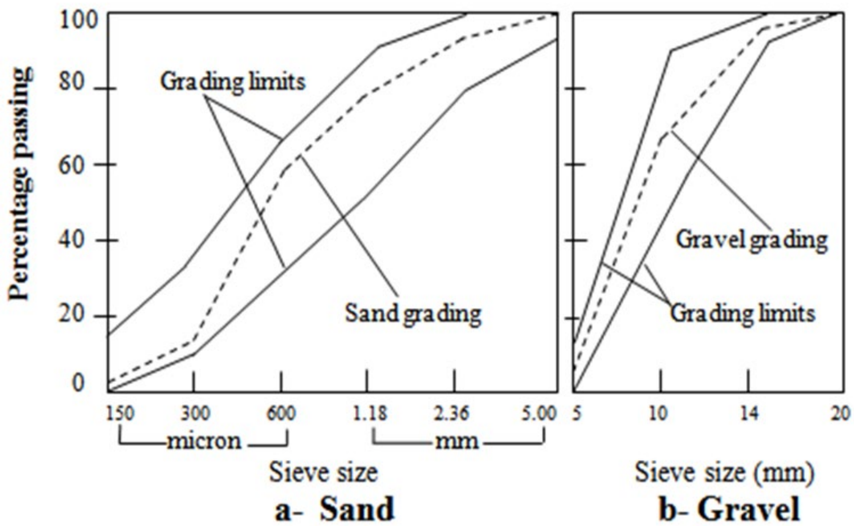

Table 2: Properties of aggregate

Property	Sand	Gravel
Absorption (%)	1.04	0.86
Bulk specific gravity		
- Oven dry	2.45	2.58
- S.S.D.	2.47	2.61
Unit weight (kg/m3)		
- Loose	1631	1467
- Tamped	1766	1577
Clay content (%)	1.25	0.1
Sulphate content (%)	0.42	0.08

2.1.3 Water

Potable water was used in making concrete and curing throughout this work.

2.1.4 Timber Section

Wood composes of about 60 percent cellulose, 28 percent lignin, and minor quantities of other materials. Cellulose forms the framework of the cell wall. Lignin is the cementing material that binds the cells together [8]. The timber beam of cross-sectional dimensions was 93 mm wide x 150 mm in depth. The physical and mechanical properties of timber were measured at the laboratory of structural materials of the Department of Civil Engineering at Basrah University.

2.1.4.1 Physical Properties

More than one property of wood is important to the end product; however, the most important physical properties of used wood are:

a. Moisture Content

It is the amount of water contained in the wood, usually expressed as a percentage of the mass of the oven-dry wood. The test is conducted following ASTM – D 4442. [9] A total number of three specimens taken from the timber beam were tested, and the average value of moisture content is given in Table (3).

b. Specific Gravity

Specific gravity is the weight of any given volume of a substance divided by the weight of an equal volume in water. The specific gravity of wood is generally based on its weight when oven – dry. A total number of three specimens are taken from the timber beam and tested following ASTM – D 2395 – 02. [10] The average value of specific gravity is reported in Table (3).

2.1.4.2 Mechanical Properties

The mechanical properties were obtained from tests of small pieces of wood which do not contain characteristics such as knots, cross-grain, checks, and splits [11]. These specimens may usually be considered “homogeneous”. The measured mechanical properties are:

a. Compressive strength

The ability of wood to resist compressive stresses depends upon the direction of the load concerning the grain of the wood. Wood has much greater strength in compression parallel to the grain than compression perpendicular to the grain. A total number of three specimens are taken from the timber beam and tested following ASTM – D 198 – 84[12]. The average value of compressive strength is in Table (3).

b. Flexural strength

The most important properties obtained from this test are the modulus of elasticity and fiber stresses. This test is done following ASTM –D 198 – 84[12]. The average value of the modulus of elasticity is also given in Table (3).

Table 3: Physical & Mechanical properties of timber

Property	Moisture content %	Specific gravity	Compression perpendicular to grains (tangential) N/mm² $x10^{-3}$	Compression perpendicular to grains (radial) N/mm² $x10^{-3}$	Compression parallel to grains N/mm² $x10^{-3}$	Modulus of elasticity N/mm² $x10^{-3}$
Test results	2.95	0.83	11.8	12.1	70.6	21.8

2.1.5 Steel Reinforcement

Steel mesh of 5 mm diameter deformed bars was used to reinforce the concrete slab against temperature and shrinkage. The spacing between bars was 100 mm in both directions. One layer of steel mesh was used for each concrete slab. Three tensile test specimens of reinforcing bars were tested, and the properties of steel are presented in Table (4). The test is conducted following B.S. 4449[13].

2.1.6 Shear Connectors

To resist the longitudinal shear at the interface between the concrete slab and timber beam and prevent vertical separation, plain steel rebars of 12 mm diameter were used as shear connectors. These connectors were fabricated in the workshops of the College of Engineering, University of Basrah. The connector was fabricated from two pieces of a bar, one of length 140 mm to form the shank and the other of length 60 mm to form the head of the connector. The two pieces were connected, by welding, in the form of T, Figure. (2). Three specimens of length 800 mm were used to find their properties in tension, Table (4). The test is conducted in accordance with B.S. 4449[13].

Table 4: Physical properties of steels

Item	Actual diameter mm	Cross sectional area mm2	Yield strength N/mm2	Yield strain %	Modulus of elasticity N/mm2	Ultimate strength N/mm2	Average elongation %
5 mm Steel mesh	5	19.6	590	0.003491	196×10^3	670	23
12 mm undeformed bars (connector)	12	113	369	0.001942	190×10^3	455	14

2.2 Concrete mix

The same concrete mix was used throughout this investigation. The mix proportions of the ingredients by dry weights were [1 cement: 1 sand: 2 gravel], and the water-cement ratio (w/c) was 0.45 to give a cube compressive strength of about 35 N/mm² at the age of 28 days and slump of about 70mm. Mixing was carried out according to B.S.1881 [14]. A tilting drum mixer was used.

2.3 Fabrication of Specimens

The properties of a shear connector should be found from tests on composite beams, but in practice, a special specimen is used. Most of the data on connectors have been obtained from "push–out" tests for steel-concrete composite construction. However, there is no standard method for conducting the push-out test for timber concrete composite construction. Therefore, push–out specimens such as those used for steel-concrete composite construction are suggested to study the behavior of connectors in timber concrete composite construction, Figure. (2). Typically four specimens (S1, S2, S3, and S4) were tested; the first two specimens were with one shear connector installed on each side of the timber beam (Specimen S1 and S4), and the other two specimens were with two connectors on each side of the timber beam (Specimen S3 and S4). The concrete slabs were 420 mm in width, 650 mm in length, and 80 mm in thickness. They were reinforced with a minimum reinforcement. One layer of steel mesh of 5 mm diameter deformed bars and 100 mm spacing was erected in the middle of the thickness of the concrete slab. The timber beam was 93 mm, 150 mm in cross-sectional dimensions, and 650 mm in length. The two components, timber, and concrete, were connected to a 150 mm length offset, as shown in Figure. (2). To fasten the connector in the timber beam, a hole of 10 mm diameter was drilled into the timber beam, and then the connector was driven into the hole by hammering. The length of the connector in timber was 100 mm. To cast the two slabs so that they are in a horizontal position, the first slab was cast, Figure. (3), and then, after 48 hours from casting, the specimen was lifted and turned over to prepare for the second casting, Figure. (4).

2.4 Test procedure

The tests were conducted in the Construction Materials laboratory at the college of engineering – university of Basrah. The universal testing machine with 50 tons was used to apply the load to the specimens. Tests were usually conducted 28 days after casting of the concrete slab. Loads were applied in equal increments and maintained constant at each load level while the vertical slip between the slabs and timber beam was measured. The dial gauges were positioned to measure the slip at the interface of timber and concrete of shear connectors, Figure (5). The load was applied to one end of the timber beam while a piece of steel angle section was fastened on the other end by screws through holes in the angle. Two dial gauges were installed on both ends of the angle section. The average value of these dial gauges readings was considered the occurred slip. Two other dial gauges on each concrete slab were installed to measure the uplift (separation) between timber and concrete. The same procedure was repeated for all four specimens. Finally, the specimens were loaded to ultimate load without unloading.

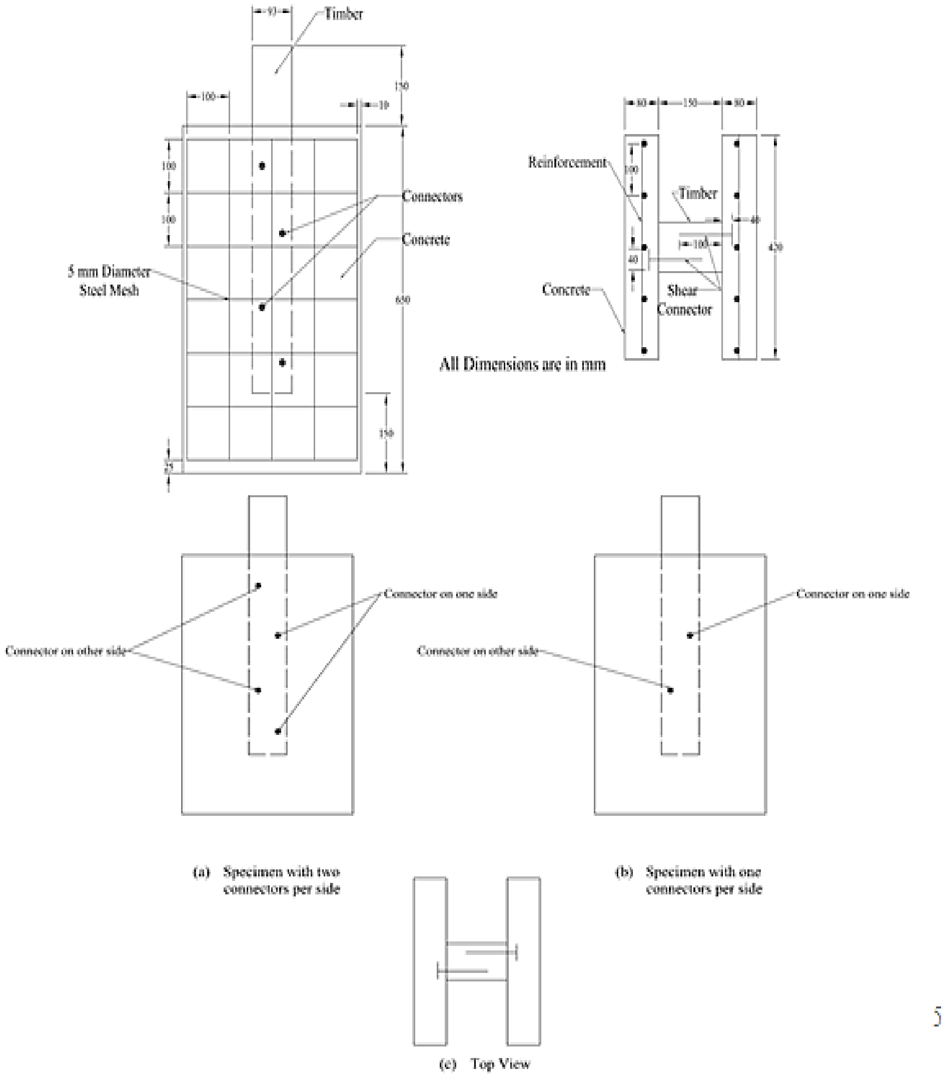

Figure 1: Push – out specimens details

Figure 2: The casting of the first slab for push-out specimens

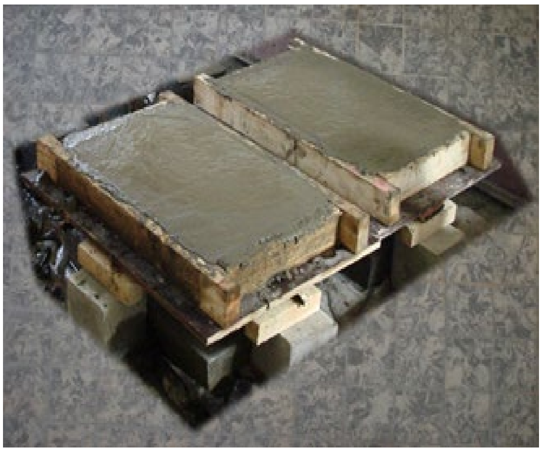

Figure 3: The casting of the second slab for push-out specimens

Figure 4: Push-out test arrangement

3. Results and Discussions

3.1 Behavior of Specimens

Figures (6) to (9) illustrate the failure mode of specimens in push-out tests. All specimens were loaded to the ultimate load, Pu. The load was applied in increments. The cracks appeared in the concrete slab when the load reached approximately 0.5 Pu. The cracks started in the middle third of the length of the concrete slab. When the load reached the ultimate load, one or both slabs separated from the timber beam. This has occurred at large slips. After failure, the measured uplift between the concrete slab and timber beam was more than 1.5 cm for all specimens.

Figure 5: Failure of push-out specimens by the separation between timber and concrete

Figure 6: Failure of push-out specimens by crushing of the concrete area surrounding the connector

Figure 7: The longitudinal flaw in the timber beam after the failure of the push-out specimen

Figure 8: Bending of connectors after failure in push-out test

The failure of specimens is characterized by two modes. In the first, the connectors were pulled out from the hole in the timber beam and remained embedded in the concrete slab. Also, a longitudinal flaw in the timber beam occurred along the full length of the beam, as shown in Figure (8). This mode of failure was observed in specimens (S2 and S3). In the other mode, the concrete failed in the region of the shear connectors, Figure (7). This is because of the concentration of stresses in the area surrounding the connector. Both modes of failure were observed in specimens (S1 and S4).

The behavior of specimens reveals that the number of connectors per specimen does not affect the mode of failure. Specimens S2 and S3 fail by the same mode, although specimens S2 have two connectors while S3 has four. The same finding may be stated for specimens S1 and S4.

3.2 Strength of Connector

In addition to Ref. [15], the current research results are used to propose an equation to determine the strength of dowel-type connectors for timber concrete composite beams.

To express the equation, a form resembling that for the design of timber of Eurocode EN 1995 [16] is used. The analysis of the results indicates that the capacity of one connector may be expressed by;

$$F_{v,Rk} = 2\sqrt{\beta}\,\sqrt{M_{y,Rk}\,.\,d.\,l_t.\,\gamma^2} \qquad (1)$$

where, $F_{v,Rk}$ = ultimate strength of one dowel (N)

d = diameter of dowel (mm)

$M_{y,Rk}$ = yield moment of the dowel, which is given by EC5, equation 8.30

= $180\ d^{2.6}$ (N.mm)

l_t = length of dowel embedded in timber component.

$\gamma = \frac{10}{d}$

$\beta = \frac{f_{h,k}}{f_c'}$

$f_{h,k}$ = embedment strength of timber which is given by EC5, equation 8.32

= $0.082\rho_k\,(1 - 0.01d)$ (N/mm^2)

ρ_k = density of timber (kg/m^3)

f_c' = concrete cylinder compressive strength (N/mm^2)

Equation (1) is used to calculate the dowel strength for push-out specimens with properties as shown in Table (5). The strength of one dowel is obtained as the ultimate load recorded by the testing machine divided by the number of dowels in the push-out specimen. The results of this equation are summarized in Table (6). The average ratio of theoretical to experimental results is 0.98, which indicates a good agreement.

As shown in Table (5), the experimental results for ultimate connectors load illustrate that the number of connectors per specimen seems to not influence connector load. The average connector load from the results of specimens S1 and S2 is 26.6 kN, while it is 27.1 kN for specimens S3 and S4. The average connector load capacity for the four specimens is 26.9 kN.

Table 5: Properties of Push-Out Test specimens

Specimen No.		Connector Diameter (mm)	Length of Connector in Wood (mm)	Concrete Cylinder Compressive Strength (N/mm2) f'_c	Ultimate Connector Load (Experimental) $(F_{v,Rk})_E$ kN
S_1	Current Research	12	100	30	27.3
S_2		12	100	30	25.9
S_3		12	100	30	24.9
S_4		12	100	30	29.4
8A	Ref. (15)	8	80	25	23.6
8B		8	80	25	23.4
10A		10	100	25	30.3
10B		10	100	25	29.7
12.5A		12.5	125	25	32.5
12.5B		12.5	125	25	34.8

Table 6: Results of equation (1)

Specimen No.		Wood Resistance $f_{h,k}$ (N/mm2)	$\beta = \frac{f_{h,k}}{f'_c}$	Plastic Moment of Connector $M_{y,Rk}$(N.mm)	Connector Capacity $(F_{v,Rk})_T$(kN)	$\frac{(F_{v,Rk})_T}{(F_{v,Rk})_E}$
S_1	Current Research	59.9	2	115118	27.7	1.01
S_2		59.9	2	115118	27.7	1.07
S_3		59.9	2	115118	27.7	1.11
S_4		59.9	2	115118	27.7	0.94
8A	Ref. (15)	65.14	2.6	40115	20.4	0.86
8B		65.14	2.6	40115	20.4	0.87
10A		63.73	2.55	71659	27.0	0.89
10B		63.73	2.55	71659	27.0	0.91
12.5A		61.96	2.48	128008	35.0	1.09
12.5B		61.96	2.48	128008	35.0	1.02
Average						0.98

3.3 Load–slip relationship

As mentioned earlier, four specimens were tested. Two of those specimens had one connector per side (S1 and S2), and the other two had two connectors per side (S3 and S4).

The variation of measured slip with the total load on the specimen is plotted in Figures. (10) and (11). Figure (10) gives the average relationship for specimens S1 and S2 and Figure. (11) for specimens S3 and S4. The load slip relationship for one connector is shown in Figure. (12). This figure is drawn as the average of the four tested push–out specimens. All three figures illustrate that connectors' load–slip relationship is nonlinear. A curve fitting for the experimental results in the form of is,

$$Q = a\,(1 - e^{-bS}) \tag{2}$$

Also, where Q = load on one connector (kN), S is the slip a, and b are constants in each figure.

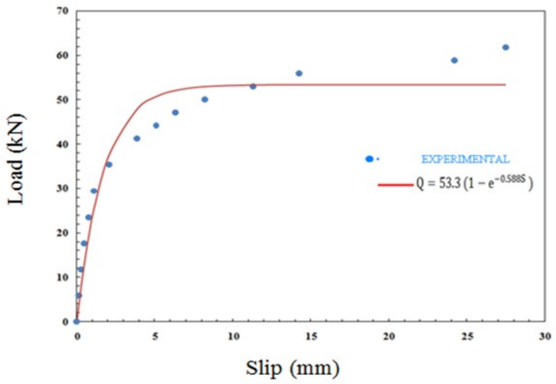

Figure 9: Total load - slip curve for push-out test (Average of specimens S1 and S2)

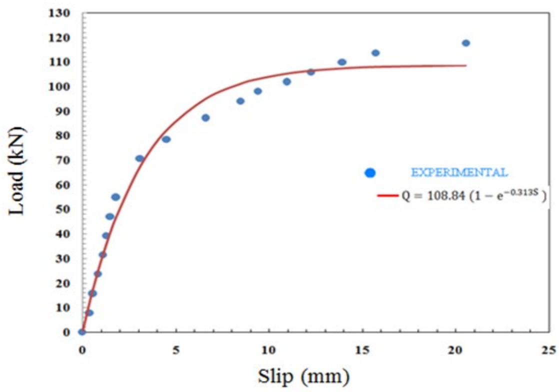

Figure 10: Total load - slip curve for push-out test (Average of specimens S3 and S4)

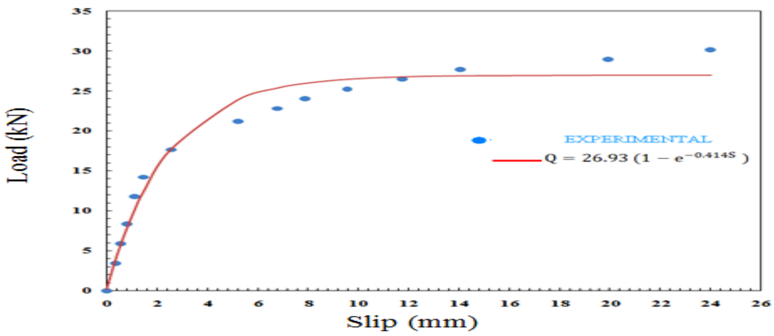

Figure 11: Load-slip curve per one connector for push-out test (Average of all specimens)

4. Conclusions

Push-out specimens for determining the connector capacity in timber concrete composite beams are proposed and tested. A new type of connector is also offered. The connector is made of a plain steel bar in the form of a T by welding two bar pieces. The failure of specimens occurred in two modes. In the first, the connectors were pulled out from the hole in the timber beam and remained embedded in the concrete slab. Also, a longitudinal flaw in the timber beam occurred along the full length of the beam. In the other mode, the concrete failed in the region of the shear connectors with the pull out of connectors from the timber beam. The cracks in concrete slabs appeared when the load reached half the ultimate load, and they started at the middle third of the length of the concrete slab. When the load reaches the ultimate load, one or both slabs are separated from the timber beam. After failure, the measured uplift between the concrete slab and timber beam was more than 15 mm for all specimens. The number of shear connectors per specimen appeared to not affect the connector's behavior or strength. An equation is proposed to determine the ultimate load of the connector in timber concrete composite construction. This equation was applied and gave good results. The average value of load capacity for the connector, from the results of the four tested specimens, is 26.9 kN. In contrast, the value given by the suggested equation is 27.7 kN with a percentage error of 3%.

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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