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Experimental Studies On Friction Coefficient Between Concrete Block And Steel Plate Bolted Joints

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***Abstract**: The aim of this study is to determine the friction coefficient (slip coefficient) between steel plate and concrete block interfaces as affected by various parameters using glue and sand between the two elements of friction. In this study, thirty groups of specimen (steel plate -concrete blocks slip) were tested. The materials we used to create this composite model included concrete blocks, steel plate, welded end plates and 8.8 M16 high-strength bolts. The strength of concrete block used is C30 (30 MPa), the concrete block dimension (15*15*37.8 cm). The grades of steel plate Q345. Concrete and steel plate was equipped with four hole bolts, with a diameter φ = 18 mm. The steel plate two surfaces contact with concrete was equipped with V shape grooves, groove depth respectively is 1.0mm and 1.5mm, spacing respectively is 30mm, 40mm and 50mm, Steel plate bolt hole trough set aside, and with steel plate welded joints, screws length 605mm.Steel plate bolt spacing , 3d0 = 54 mm, bolt pitch distance of the edge of plate 2d0 = 36 mm, bolt pitch steel and concrete edge of the contact surface distance, 2d0 = 36 mm. The steel plate thickness t = 14 mm, the test plate width 50 mm., special glue construction work, industrial sand with different diameters, two bolts for pre-tightening force pressure with two steel plates on both sides of the model to apply the pressure force. Friction coefficient, Optimum quantity of glue on the concrete and steel plate surface, optimum quantity of the sand on the concrete surface, optimum groove form for steel plate and failure mode of the specimen were investigated. The overall approach of this experiment was that the coefficient of the friction increase when increasing the amount of glue on the surface of steel plate with no change for other variables. Moreover, when increasing the pressure on both sides of the exhibition model.*

***Keywords:** friction coefficient; bolted joint; steel plate; concrete; sand; structure adhesive JGN-I.*

I. Introduction

Existing concrete structures, failure by sliding in anchor base plate, which used to fix external pre-stressed tendons is one of the catastrophic failures, which depends on the friction conditions in contact area .The mechanical action of anchor base plate with concrete in contact area is mainly by friction between two surfaces and pre-tightening bolts force, which fixed anchor plate on concrete. Thus, friction coefficient between concrete and anchor base plate is very important to prevent the anchor base plate from sliding.

A slip-resistant joint [1] - [10] (also called a friction-type joint) is one that has a low probability of slip at any time during the life of the structure. It is used where any occurrence of a major slip would endanger the serviceability of the structure and therefore has to be avoided. It should be emphasized that the slip-resistant connection is used to meet a serviceability requirement. Thus, in load factor design, the design of a slip-resistant connection is to be carried out under the working loads, not the factored loads; the joint must not slip in service.

In a slip-resistant joint, the external applied load usually acts in a plane perpendicular to the bolt axis. The load is completely transmitted by frictional forces acting on the contact area of the plates* fastened by the bolts. This frictional resistance is dependent on the bolt preload and slips resistance of the faying surfaces. The maximum capacity is assumed to have been reached when the frictional resistance is exceeded and overall slip of the joint occurs that brings the plates into bearing against the bolts.

Slip-resistant joints are often used in connections subjected to stress reversals, severe stress fluctuations, or in any situation wherein slippage of the structure into bearing would produce intolerable geometric changes. In the following sections, the different factors influencing the slip load of a connection are discussed.

Basic Slip Resistance [1] - [10]

The slip load of a simple tension splice, as shown in Fig.1, is given by:

$$P_{slip} = k_s m \sum_{i=1}^{n} T_i \qquad (1)$$

Where: k_s=slip coefficient
m= number of slip planes

$\sum_{i=1}^{n} T_I$=sum of bolts tension

The bolt preloads usually can be assumed to be equal in all bolts. Equation 1therefore reduces to

$$P_{slip} = k_s mnT_i \quad (2)$$

Where: n= represents the number of bolts in the joint.

Equation 2 shows clearly that for a given number of slip planes and bolts, the slip load of the joint depends on the slip coefficient and bolt clamping force. For a given geometry, the slip load of the connection is proportional to the product of the slip coefficient k_s and bolt tension Ti. Both the slip coefficient (k_s), and the clamping force (Ti) show considerable variation from their mean values. The slip coefficient varies from joint to joint and, although a specified minimum preload is usually prescribed, bolt preloads are also known to vary considerably, generally exceeding the prescribed minimum value. These variations in the basic parameters describing the slip load must be taken into account when developing criteria for joint design.

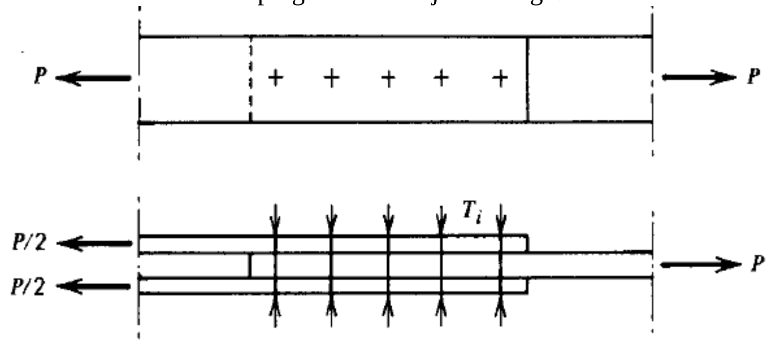


Fig. 1 Symmetric Shear Splice

Evaluation of Slip Characteristics

The slip coefficient k_s corresponding to the surface condition can only be determined experimentally. In the past, slip tests have usually been performed on symmetric butt joints loaded in tension until slip of the connection occurs. The bolt preload, induced by the tightening process, is determined before the test is started. Once the slip load of the connection is known, the slip coefficient can be evaluated from Eq.2.

$$k_s = \frac{P_{slip}}{mnT_i} \quad (3)$$

II. Materials And Methods

Materials: to reach the purpose of this research, an experimental laboratory study was developed using the following materials:

JGN-I- Structure Adhesive: The glue, which used in this experiment, is a new-type glue of structure adhesive JGN-I [11. It can splice with all kinds of sill (concrete, stone material, brick, Rock, etc.) and be used in the structure to strengthen extensively. The properties of this adhesive type are shown in Table 1.

Table 1. Mechanical properties of JGN-I Structure Adhesive

Performance indicator		Performance index (Class A glue)	Technical parameters
Appearance	Sub-Group A: off-white paste; B sub: black viscous material	——	——
Weight ratio	A: B = 3:1	——	——
Mixed density	1.7 ± 0.1 g/cm³		
Colloidal properties	Tensile strength / MPa	≥30	≥30
	Tensile elastic modulus / MPa	≥3500	≥3600
	Flexural strength / MPa	≥45	≥45
	Compressive strength / MPa	≥65	≥65
	Elongation / %	≥1.3	≥1.5
Bonding properties	Steel - steel shear strength / MPa	≥15	≥18
	Steel - steel tensile strength / MPa	≥33	33
	With concrete tensile bond strength/ MPa	≥2.5, for concrete cohesive failure.	
Solid content		≥99	≥99

Note: Table 1.Material properties for the highway bridge strengthening design specification (JTG/T J22-2008) [11] .1. This product should store in a cool, dry and ventilated in the garage; 2. Shelf life: 12 months; 3. the tool cannot be put off on A and B group, have clean or abandon been used; 4. this product is non-poisonous, while touching the skin carelessly, can polish with the acetone first, then wash with water.

Sand: The details of sand used in this experiment described as following: Sieve no. and mesh size of sand shown in Table 2.

Table 2. Sieve no. and mesh size of sand

Sand Type	Sieve No.	Mesh size (μm)	Sand Type	Sieve No	Mesh size (μm)
Coarse sand	8	3500-2000	Fine sand	80	250-160
	12	2000-1300		100	160-125
	16	1300-1000		120	125-105
	20	1000-800		150	105-85
	24	800-530		180	85-75
Medium sand	30	630-500		200	75-65
	34	500-450		240	65-45
	36	450-400		280	45-35
	40	400-360		320	35-25
	46	360-310			
	60	310-250			

Coarse Sand

For the coarse sand, sand sieve No.(A) and the amount (B) two factors, each factor is to consider two levels, respectively, A1: sieve No.16; A2: sieve No.24; B1=0.2g/cm^2; B2=0.1g/cm^2; by using orthogonal design method ,four tests carried out .

Medium Sand

For the medium sand, sand sieve No. (A) and the amount (B) two factors, each factor is to consider three levels, namely, A1: sieve No.34; A2: sieve No.40; A3: sieve No.60; B1=0.109g/cm^2; B2=0.073g/cm^2 ; B3 =0.045g/cm^2; by using orthogonal design method, nine tests carried out.

Fine Sand

For the fine sand, sand sieve No.(A) and the amount (B) two factors, several factors are considered mesh two levels, usage factors into two levels, namely, A1: sieve No.100; A2: sieve No.150; B1=0.45g/cm^2; B2=0.23g/cm^2; by using orthogonal design method ,four tests carried out .

Steel Plate:

The properties of steel plate we used in this test specimens shown in Table 3.

Table 3. Steel plate Properties

Plate thickness (mm)	Yield strength (Mpa)	Modulus of elasticity (Gpa)
14	345	206

Precast Concrete Block

This experimental concretes block test specimens uses an old bridge common concretes C30.

Test Specimens Design:

Steel - concrete friction coefficient test specimens design, including concrete blocks, steel plate, welded end plates and 8.8 M16 high-strength bolts, Test specimen setup and test specimen vertical section shown in Figure 2.& Figure 3 respectively. The strength of concrete block used is C30 (30 MPa), the concrete block dimension (15*15*37.8 cm). The grades of steel plate Q345. Concrete and steel plate was equipped with four hole bolts, with a diameter φ = 18 mm. The steel plate two surfaces contact with concrete was equipped with V shape grooves, groove depth respectively is 1.0mm and 1.5mm, spacing respectively is 30mm, 40mm and 50mm, Test steel plate grooves design shown in Figure 4. Steel plate bolt hole trough set aside, and with steel plate welded joints, screws length 605mm.Steel plate bolt spacing , 3d0 = 54 mm, bolt pitch distance of the edge of plate 2d0 = 36 mm, bolt pitch steel and concrete edge of the contact surface distance, 2d0 = 36 mm. The steel plate thickness t = 14 mm, the test plate width 50 mm, Tests Steel Plate Contact Area Dimension shown in Figure 5.

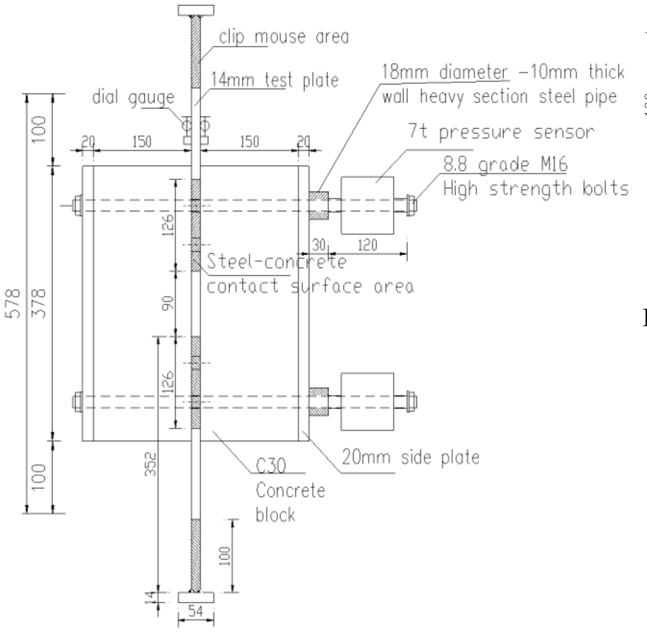


Figure 2. Test specimen setup (Dimension in millimeters)

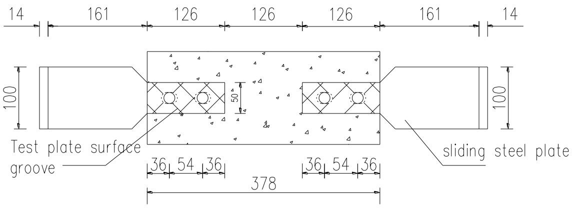


Figure 3. Test specimen vertical section (Dimension in millimeters)

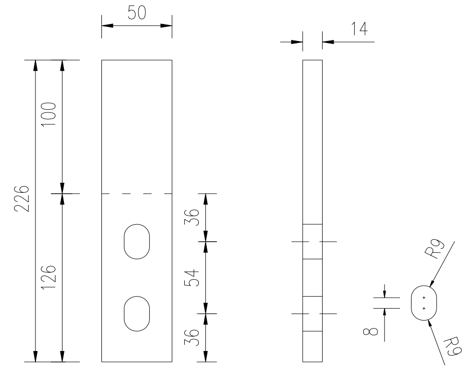


Figure 5. Test Steel Plate Contact Area Dimension (Unit: mm)

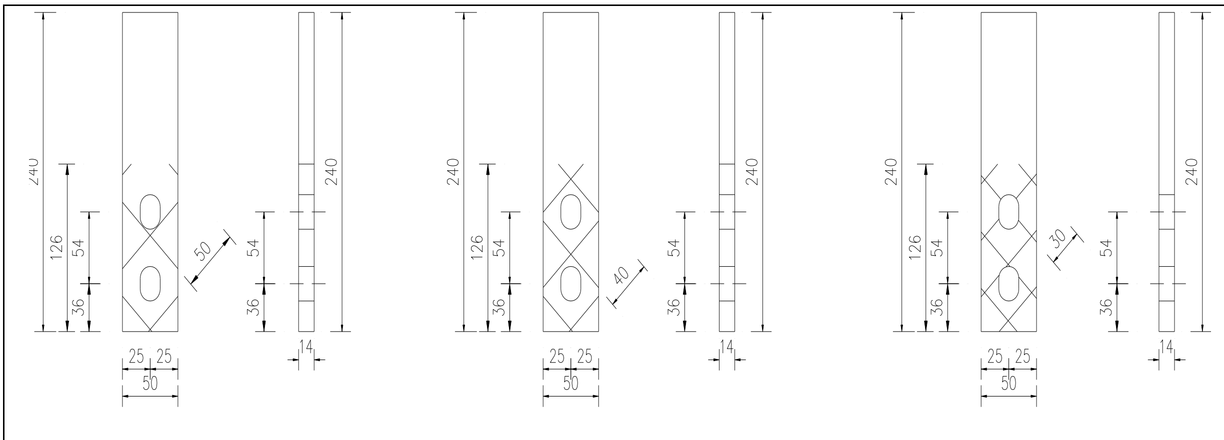


Figure 4. Test steel plate grooves design.

Test Instruments:

The main equipment and tools that have been used in this experiment can be summarized in the following: Tensile testing machine, displacement meter (micrometer), magnetic blanket supports, pressure sensors, static strain collection gauge, Torque Twist.

Test Contents

In this study, experiments were divided into six parts, five based on various factors to obtain the optimum value for the friction coefficient corresponding to the sliding force, that is resisted by these factors, Part V is the worst of the factors affecting the coefficient of friction, for a comparison between the best case to get the optimum friction coefficient, which is obtained from the other four parts, all these parts have been clarified as follows: Different trenches size on the steel plate with a fixed amount of sand and glue on the concrete block and steel plate surface using sand sieve size (16), and with pre tightening bolt force (average value 3 tons) (G1, G2, G3, G4 &G5) .Data and variables that were used in this case to represent the relationship between the displacement and sliding force of the model designed for this test is explained in Table 4.

Table 4. Test data for (G1 ~ G5) Different grooves size on the steel plate surfaces.

Classifications	Spe. No.	sand		Glue amount （g/cm^2）		Bolt preload (t)	Imposed Concrete pressure (Single rod / t)	Groove pitch (mm)	Groove Depth (mm)	Trench area / contact surface area (%)
		Sieve size average Diameter (mm)	Amount （g/cm^2)	concrete	plate					
Steel Plate without grooves	G1	16(1.15)	0.2	0.064	0.064	4.07	3.15	——	——	——
Different forms of grooves	G2	16 (1.15)	0.2	0.064	0.064	4.48	2.99	30	1.0	18.1
	G3	16 (1.15)	0.2	0.064	0.064	5.00	3.10	30	1.5	27.2
	G4	16 (1.15)	0.2	0.064	0.064	4.52	2.94	40	1.0	15.4
	G5	16 (1.15)	0.2	0.064	0.064	2.80	3.01	50	1.5	14.5

Different amounts of sand and glue on the surface of steel plate and concrete block with different diameters of sand, a sand passing through the sieve's Size (16, 24, 36, 46, 60, 100 and 150),steel plate with optimum groove surface form on a steel plate (spacing 30 mm, depth 1.5 mm) which gave the optimum value for the friction coefficient, with pre tightening bolt force (average value 3 tons) (G6, G7 ,G8 ,G9 , G10 ,G11 ,G12 ,G13 ,G14 ,G15 ,G15 ,G17 ,G18 ,G19 ,G20 ,G21). Data and variables that were used in this case to represent the relationship between the displacement and sliding force of the model designed for this test is explained in Table 5.

Table 5. Test data for (G6 ~ G21) Different amounts of sand and glue on the steel plate and concrete block surfaces with different sand sieve size

Categories	Specimen No.	Sand amount		Glue amount （g/cm^2）		Bolt preload (t)	Imposed Concrete pressure (Single rod / t)
		Sieve size average Diameter (mm)	Amount （g/cm^2）	Concrete	Steel		
Coarse sand	G3	16 (1.15 mm)	0.2	0.064	0.064	5.00	3.10
	G6	16 (1.15 mm)	0.1	0.064	0.064	4.72	3.01
	G7	24 (0.665 mm)	0.2	0.064	0.064	5.43	3.09
	G8	24 (0.665 mm)	0.1	0.064	0.064	5.09	3.01
Medium Sand	G9	36 (0.425 mm)	0.109	0.033	0.02	4.88	3.11
	G10	36 (0.425 mm)	0.073	0.033	0.02	5.20	2.98
	G11	36 (0.425 mm)	0.045	0.033	0.02	5.10	3.11
	G12	46 (0.335 mm)	0.109	0.033	0.02	5.12	3.07
	G13	46 (0.335 mm)	0.073	0.033	0.02	4.95	3.10
	G14	46 (0.335 mm)	0.045	0.033	0.02	5.03	3.09
	G15	60 (0.28 mm)	0.109	0.033	0.02	5.26	3.12
	G16	60 (0.28 mm)	0.073	0.033	0.02	5.11	3.12
	G17	60 (0.28 mm)	0.045	0.033	0.02	4.99	3.10
Fine sand	G18	100 (0.1425 mm)	0.045	0.016	0.015	5.00	3.04
	G19	100 (0.1425 mm)	0.023	0.016	0.016	5.17	3.05
	G20	150 (0.095 mm)	0.045	0.019	0.016	5.10	3.06
	G21	150 (0.095 mm)	0.023	0.014	0.012	5.11	3.05

Different amounts of glue on the surface of steel plate with the optimum amount of glue and sand on the surface of concrete, optimum form of grooves on the surface of steel plate which gave the optimum value for the friction coefficient (G12) and with pre tightening bolts force (average value 3 tons) (G22, G23, G12 ,G24 ,G25).Data and variables that were used in this case to represent the relationship between the displacement and sliding force of the model designed for this test is explained in Table 6.

Table 6. Test data for (G27 ~ G31) Different amount of glue on the steel plate surfaces case

Categories	Specimen No.	Sand		Amount of Glue （g/cm^2）		Bolt preload (t)	Imposed Concrete pressure (Single rod/ t)
		Sieve size-average Diameter(mm)	Amount （g/cm^2）	Concrete	Steel		
0.6g	G22	46(0.335 mm)	0.109	0.0327	0.0109	5.05	3.11
0.8g	G23	46(0.335 mm)	0.109	0.0327	0.0145	5.06	3.13
1.0g	G12	46(0.335 mm)	0.109	0.0327	0.0182	5.12	3.07
1.2g	G24	46(0.335 mm)	0.109	0.0327	0.0218	5.14	3.12
1.4g	G25	46(0.335 mm)	0.109	0.0327	0.0254	4.90	3.11

Different pre tightening bolts force (0.7 P, 0.9 P 1.0 P and 1.1 P), with optimum amounts of glue on the surface of steel plate, an optimum amount of glue and sand on the surface of concrete and with optimum form of grooves on the surface of steel plate, which gave the optimum value for the friction coefficient (G26, G12, G27, G28).Data and variables that were used in this case to represent the relationship between the displacement and sliding force of the model designed for this test is explained in Table 7.

Table 7. Test data for (G32 ~ G34) Different pre tightening bolts force case.

Categories	Specimen No.	Sand amount		Glue amount （kg/m^2）		Bolt preload (t)	Imposed Concrete pressure (Single pole / t)
		Sieve size average Diameter (mm)	Amount （g/cm^2）	concrete	Steel		
0.7P	G26	46 (0.335 mm)	0.109	0.0327	0.0182	4.21	2.21
0.9P	G27	46 (0.335 mm)	0.109	0.0327	0.0182	4.15	2.86
1.0P	G12	46 (0.335 mm)	0.109	0.0327	0.0182	5.12	3.13
1.1P	G28	46 (0.335 mm)	0.109	0.0327	0.0182	4.53	3.41

No glue on the surface of steel plate with an optimum amount of glue and sand on the surface of concrete with optimum form of grooves on the surface of steel plate and with optimum pre tightening bolt force (1.0 P) , which gave the optimum value for the friction coefficient (G29).
No glue on the surface of steel plate and concrete, no sand on the concrete surface with an optimum form of grooves on the surface of steel plate and with optimum pre tightening bolt force (1.0P), which gave the optimum value for the friction coefficient (G30).Data and variables that were used in this case to represent the relationship between the displacement and sliding force of the model designed for this test is explained in Table 8.

Table 8. Test data for (G35 ~ G36) a) in case of no glue on the steel plate surface. b) In case of no glue on the steel plate surface, no glue and sand on the concrete block surface

Categories	Spe. No.	Sand amount		Glue amount （g/cm^2）		Bolt preload (t)	Imposed Concrete pressure (Single pole / t)
		Sieve size Average Diameter (mm)	Amount (g/cm^2）	concrete	steel		
Concrete with sand &glue, steel without sand & glue	G29	46	0.109	0.0327	No glue	——	3.13
No sand, no glue	G30	No sand		No glue		——	3.10

Test specimens Assembly Processes: Test pieces assembly processed according to the following:

1) Concrete blocks were cast for compression strength equal to the strength of Old Bridge Concrete C30 standard compressive strength for pre-cast concrete block test, the strength of concrete is required to achieve the design strength of concrete C30., with dimensions 15 * 15 * 37.8 cm, and holes on the concrete with dimensions and diameters according to design specifications and test model, then tested the compression strength of concrete, the average strength of the cubes equal 30 MPa.

2) Prepared test sliding steel plate according to design specifications required for the preparing of the test model. Then were prepared groove forms with dimensions as shown in the figure, and make holes on the steel plate with dimensions and diameters based on design specifications for a test model.

3) Sensor pressure and tensile test machine were calibrated.

4) After the end of the preparatory work, a compilation of the model that was used in the experiment, and to collect the required model do the following:

5) Polished surface of concrete block and steel plate by electric polishing machine until the surface of each became a level and smooth

6) The area of steel plate, concrete contact surface was recognized, by drawing on concrete surface.

7) the surface of each steel plate and concrete was cleaned with acetone by using cotton from impurities , dirt, oils and any other impurities, and then left to dry.

8) Glue on the required contact area on the surface of concrete block and steel plate was coated according to the amount required for each specimen model. sured that the glue within the grooves on the surface of steel plate

9) Sand over the glue on the surface of concrete block was scattered by using the sieve size and the amount of sand required by the design requirements.

10) Pushed sand scattered over the glue by using a heavy weight to fix the sand on the glue, and then raise the block weight.

11) The specimen model assembled by placing the sliding steel plate over an area of specific adhesion on the surface of concrete, assembly attention to ensure that the two test plate has been in the same axis line, and with the axis parallel to concrete blocks, then connected them by two bolts with a high strength and pressure model applied by forcefully pressuring side by connecting bolts using the steel plates from both sides to distribute the pressure force on the model of the specimen evenly. The pressure force applied by the design specifications.

(Remove bond nails after 24 hours from the assembled model).

Structural adhesive curing time according to the requirements of steel - concrete assembly required curing at room temperature for 72h only before the tension test.

Loading Process:

After the completion of the assembled model ,used in the experiment as mentioned in test specimen assembly processes and after leaving the specimen for 72 hours immediately before tensile testing , according to the specific design requirements, when using the glue as an adhesive .and to prevent cracking of concrete blocks, that may be occurred during the test according to tension force , concrete is compressed vertically by applied pressure force greater than the force ,which expected to crack the concrete ,this applied force by using a compression mechanism set up of steel plates to the top and bottom of each concrete block and the force applied by using screws, then the actual test began by put the specimens which want to be tested in a tensile test machine , the vertical center line of the specimen exactly on center of tensile machine , then were processed dial gage at a certain point on the upper steel plate to measure the displacement when applied force loading in progress . Then the loading progress phase started, a phase gradually began to carry an initial load value 5 kN and after that gradually increased the load with the same value of the initial load until the slide happened, in the case of the displacement value have been big increased with the gradually load value of 5 kN, used another gradually load 2 kN, in every loading phase was recording the displacement value and corresponding applied load until sliding occurs. There are indications of a slide when the load progressed: (1) tensile test machine, load needle indicator came back. (2) Dial gauge reading increased rapidly.

Data processing: To determined the friction coefficient between the steel plate and concrete block depending on the applied tensile force that made the steel plate sliding and pressure applied to the specimen test , and from the results of previous tests of the different groups', friction coefficient can be obtained from the Eq.1 showned before as following:

Friction coefficient measured: $$k_s = \frac{P_{slip}}{m \cdot \sum_{i=1}^{n} T_i} \quad (4)$$

where， P_{slip} : tests measured sliding load (KN);

m: the number of contact surfaces, taking $m = 2$;

T_i: bolt pre tightening up force actual value (KN), (takes three significant digits);

n : test specimen one side bolt number, take n = 1.

III. Results

The result's details of the different groups have been explained according to the following:

a) In the case of steel plate equipped with different trenches size (30 – 1.0 mm), (30-1.5mm), (40-1.0 mm), (50 – 1.5 mm) width, depth respectively. Friction coefficient values corresponding to the sliding force and a slip failure Feature for groups 1, 2, 3, 4 and 5 by using equation. No.1 is determined as shown in Table 9. Moreover, the relationship between the displacement and the sliding force curve is shown in figure 6. Then explained the relationship between the friction coefficient and trenches on the surface of steel plate as shown in figure 7.

Table 9. Test results for (G1 ~ G5) Different trenches size on the steel plate surfaces with a fixed amount of sand and glue on the concrete block and steel plate surface.

Specimen No.	Maximum displacement (mm)	Sliding load (kN)	Friction coefficient measured	A slip failure Feature
1	0.006	36	0.571	Concrete did not crack, upper plate was sliding.
G2	0.019	45	0.752	Concrete did not crack; lower plate was sliding.
G3	0.028	61	0.986	Concrete did not crack, upper plate sliding. There were clear slip marks.
G4	0.028	56	0.952	Concrete did not crack, lower plate sliding.
G5	0.026	46	0.765	1) K19-1 Concrete appears a 7cm-long small surface cracks, crack closure upon unloading; 2) Upper plate was sliding.

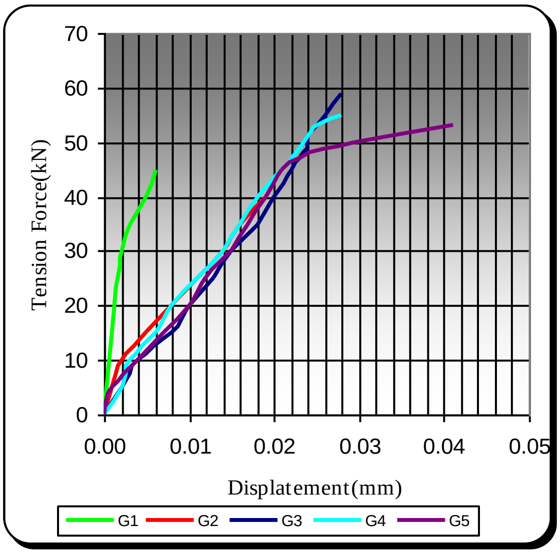


Figure 6. Displacement vs. Tension force Curve for (G1, G2 .G3 .G4 ,G5)

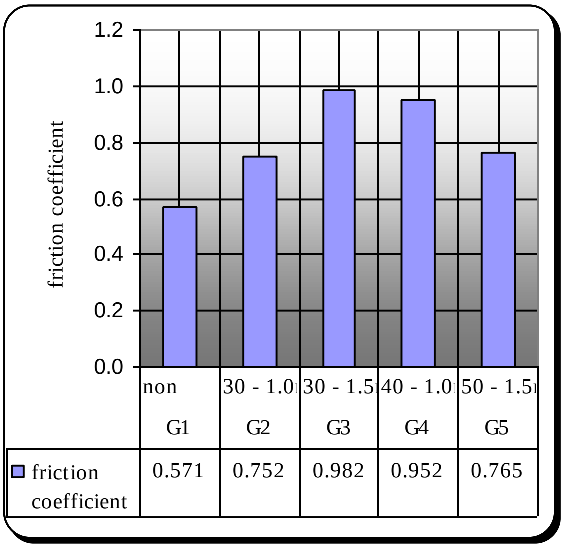


Figure 7. Groove forms vs. Friction Coefficient chart

b) In the case of steel plate equipped with optimum trenches from, which gave the largest value for the friction coefficient(G3) with different amounts of sand and glue on the surface of steel plate, concrete, and with pre tightening bolt force (P) (average value 3 tons). Friction coefficient values corresponding to the sliding force and a slip failure Feature for groups (3, 6, 7, 8,9,10,11,12,13,14,15,16,17,18,19,20 and 21) by using equation. No.1 is determined as shown in Table 10. Moreover, the relationship between the displacement and the sliding force curve are shown in figure 8. (a, b, c) for coarse sand, medium sand and fine sand respectively. Then the relationship between the friction coefficient and amounts of sand and glue on the steel plate and concrete is determined as shown in figure 9.

Table 10. The Test results for (G3, G6 ~ G21) Different amounts of sand and glue on the steel plate and concrete

Specimen No.	Maximum displacement (mm)	Sliding load (kN)	Friction coefficient measured	A slip failure Feature
G3	0.028	61	0.986	Upper plate was sliding, there were clear marks.
G6	0.026	51	0.846	Both upper and lower plates were sliding, with clear slip traces.
G7	0.022	39	0.632	Upper and lower steel plates were sliding on the right side of the plate.
G8	0.020	41	0.681	Upper and lower steel plates were sliding, the right side of the upper plate, the left side of the lower plate。
G9	0.025	55	0.885	Both upper and lower plates were sliding, upper, the left side of the plate; lower both sides of the plate.
G10	0.021	39	0.655	Lower plate was sliding.
G11	0.014	27	0.434	Lower plate was sliding.
G12	0.028	54	0.880	Both upper and lower plate sliding, no concrete cracking
G13	0.032	62	0.999	Lower plate was sliding.
G14	0.019	41	0.664	Upper plate was sliding.
G15	0.024	42	0.674	Upper plate was sliding.
G16	0.021	34	0.544	Both upper and lower steel plates were sliding.
G17	0.013	30	0.485	Upper plate was sliding. There was clear marks'.
G18	0.017	38	0.624	Lower plate was sliding.
G19	0.014	33	0.541	Lower plate was sliding.
G20	0.020	41	0.670	Lower plate was sliding.
G21	0.026	36	0.591	Lower plate was sliding.

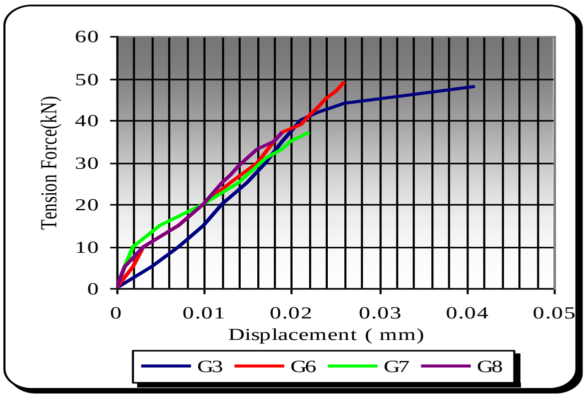


Figure 8.a. Displacement vs. Tension force Curve for Coarse sand (G3 ,G6 .G7 .G8)

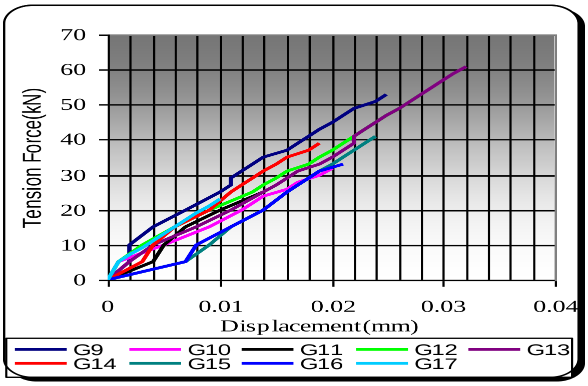


Figure 8.b. Displacement vs. Tension force Curve for Medium sand (G9, G10 .G11 .G8)

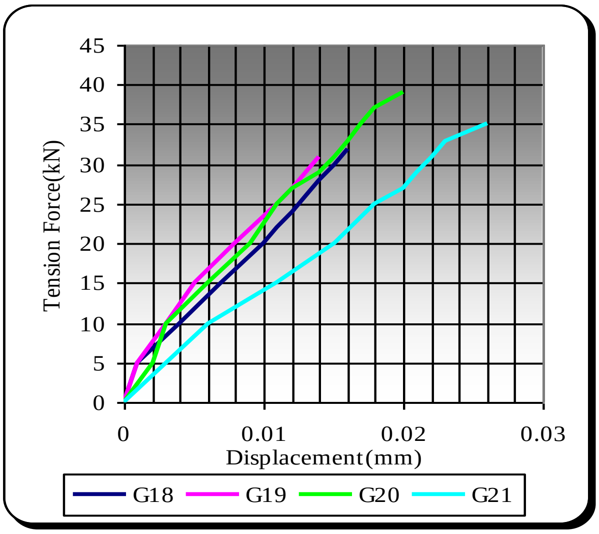
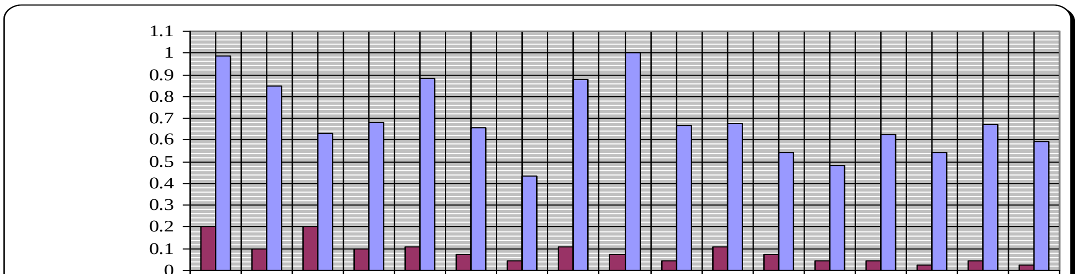


Figure 8.c. Displacement vs. Tension force Curve for Fine sand (G18 ,G19 .G20 .G21)



	G3	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17	G18	G19	G20	G21
sand amount	0.2	0.1	0.2	0.1	0.109	0.073	0.045	0.109	0.073	0.045	0.109	0.073	0.045	0.045	0.023	0.045	0.023
friction coefficent	0.986	0.846	0.632	0.681	0.885	0.655	0.434	0.88	0.999	0.664	0.674	0.544	0.485	0.624	0.541	0.67	0.591

Figure 9. Sand amount vs. Friction Coefficient chart

c) In the case of different amounts of glue on the surface of steel plate with the optimum amount of glue and sand on the surface of concrete , optimum form of grooves on the surface of steel plate and with optimum pre tightening bolts force(average value 3 tons), which gave the optimum value for the friction coefficient (G12) . Friction coefficient values corresponding to the sliding force and a slip failure Feature was determined as shown in Table 11. for groups 12, 22, 23, 24 and 25 by using equation. No.1. Moreover, the relationship between the displacement and the sliding force curve was drawn as shown in figure 10. Then the relationship between the friction coefficient and amounts of glue on the steel plate is determined as shown in figure 11.

Table 11. The Test results for (G22 ~ G25, G12) Different amount of glue on the steel plate surfaces

Specimen No.	Maximum displacement (mm)	Sliding load (Kn)	Friction coefficient measured	A slip failure Feature
G22	2.833	45	0.723	Upper plate sliding, there were obvious slip marks.
G23	0.031	52	0.832	Lower plate sliding, there were obvious slip marks.
G12	0.028	54	0.880	The upper and lower steel plates were sliding, with clear sliding marks.
G24	3.462	55	0.882	Lower plate was sliding
G25	0.037	76	1.222	Two plates were not slid-ing。

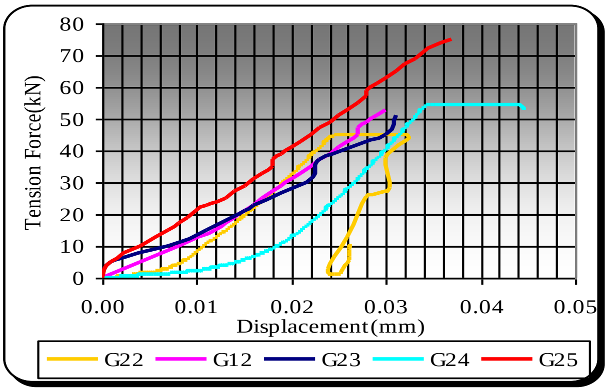


Figure 10. Displacement vs. Tension force Curve for (G22, G12 .G23 .G24 , G25)

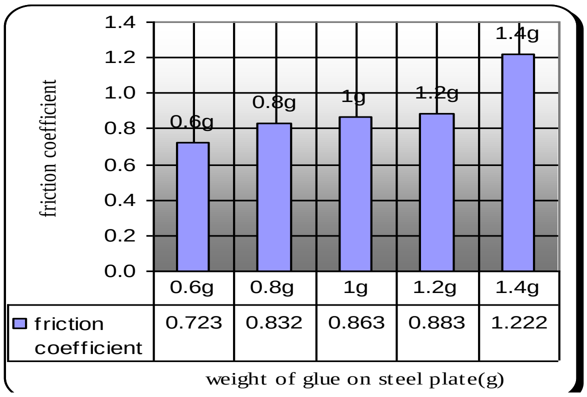


Figure 11. Weight of glue on steel plate vs. Friction Coefficient chart

d) In the case of different pre tightening bolts force (0.7 P, 0.9 P 1.0 P and 1.1 P), with optimum amounts of glue on the surface of steel plate, optimum amount of glue and sand on the surface of concrete and with optimum form of grooves on the surface of steel plate, which gave the optimum value for the friction coefficient (G12). Friction coefficient values corresponding to the sliding force and a slip failure Feature was determined as shown in Table 12. for groups 12, 26, 27 and 28 by using equation. No.1. Moreover, the relationship between the displacement and the sliding force curve was drawn as shown in figure 12. Then the relationship between the friction coefficient and amounts of glue on the steel plate is determined as shown in figure 13.

Table 12. Test results for (G26 ~ G28, G12) Different value of the pressure side view on both sides of concrete block (different bolt preload).

Specimen No.	Maximum displacement (mm)	Sliding load (kN)	Friction coefficient measured	A slip failure Feature
G26	2.841	43	0.949	Lower plate sliding, there was an obvious slip marks.
G27	3.01	44	0.765	Upper plate sliding, there was an obvious slip marks.。
G12	0.030	54	0.863	The upper and lower steel plates were sliding, with a clear sliding marks.
G28	3.014	57	0.836	Upper plate was sliding

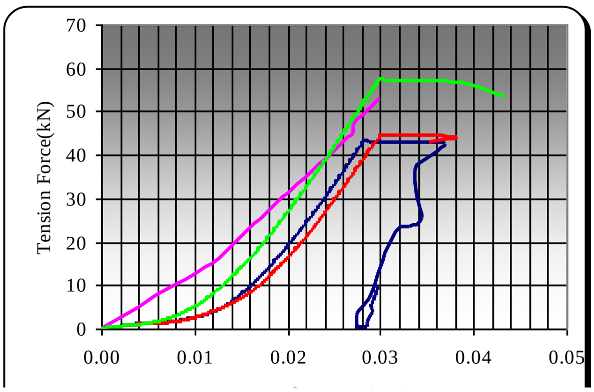


Figure 12. Displacement vs. Tension force Curve for (G29, G30)

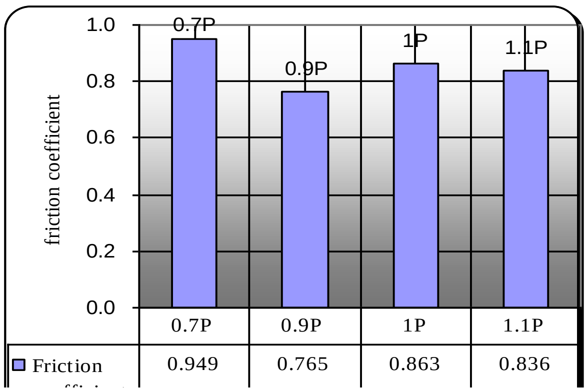


Figure 13. Bolt Preload vs. Friction Coefficient chart

e) In the case of no glue on the surface of steel plate with an optimum amount of glue and sand on the surface of concrete with optimum form of grooves on the surface of steel plate and with optimum pre tightening bolt force (1.0 P) , which gave the optimum value for the friction coefficient (G29).
f) In the case of no glue on the surface of steel plate and concrete, no sand on the concrete surface with optimum form of grooves on the surface of steel plate and with optimum pre tightening bolt force (1.0 P) , which gave the optimum value for the friction coefficient (G30).

Friction coefficient values corresponding to the sliding force and a slip failure Feature was determined as shown in Table 13. for groups 29 and 30 by using equation. No.1. Moreover, the relationship between the displacement and the sliding force curve was drawn as shown in figure 14.

Table 13. The Test results for (G35 ~ G36) a) There is no glue on the steel plate surface with a glue and sand on the concrete block surface; b) There is no glue on the steel plate surface and no glue and sand on the concrete block surface.

Specimen No	maximum displacement (mm)	Sliding load (kN)	Friction coefficient measured	A slip failure Feature
G29	2.893	26	0.413	Lower plate was sliding。
G30	1.373	10.34	0.164	The upper and lower steel plates were sliding.

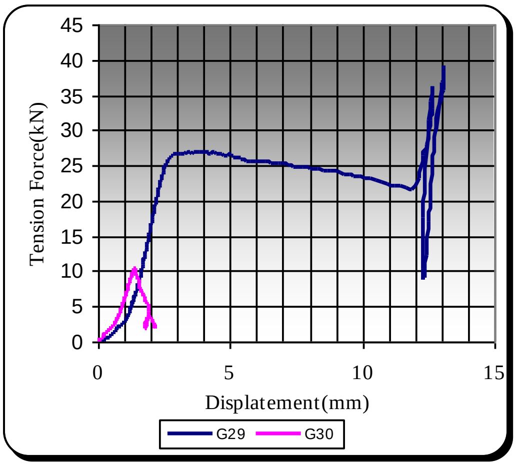


Figure 14. Displacement vs. Tension force for (G29, G30)

Note: For groups(1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,23,25),used dial type hydraulic Universal Testing Machine. For groups (22, 24, 26, 27, 28, 29, 30), used Micro-Computer Control Electro-hydraulic servo Universal Testing Machine.

IV. Discussion

The results of experiments that were carried out for different groups according to different variables can be summarized as follows:

1) In the case of steel plate with different groove forms, it is found that the maximum optimal friction coefficient value corresponding to the maximum sliding force when a sliding steel plate with a groove form 1.5 * 30 mm, depth , width ,respectively . Friction coefficient is 0.993(G3).

2) In the case of different amounts of sand and glue on the surface of steel plate and concrete with an optimum groove size on the steel plate ,which described in case 1, the average pre tightening bolts force value 3 tons , found that the maximum optimal friction coefficient value is 0. 880, when the amount of glue on the concrete and steel plate equal 0.033 g/cm^2, 0. 02 g/cm^{2,} respectively and the amount of sand (sieve no. 46) on the concrete surface equal 0.109 g/cm^2 (G 12), because in this group, there are no cracks in the concrete. Moreover, upper and lower steel plate was sliding with clear sliding marks, as indicated in the slip failure Feature shown in the Table (10).

3) In the case of different amounts of glue on the steel plate surface(0.6g , 0.8g , 1.0g 1.2g and 1.4g) with an optimum groove size on the steel plate , the amount of glue on the concrete surface equal 0. 033 g/cm^2 , the amount of sand(sieve no. 46) on the concrete surface equal 0.109 g/cm^2 and the average pre tightening bolts force value 3 tons , which obtained from case 2, it is found that the maximum optimal friction coefficient value is 0. 880, when the amount of glue on the steel plate surface equal 1.0g (0.02 g/cm^2) (G12), because in this

group, there are no cracks in the concrete. Moreover, upper and lower steel plate was sliding with clear sliding marks, as indicated in the slip failure Feature shown in the Table (11).

4) In the case of different pre-tightening bolt force (0.7 P, 0.9 P, 1.0 P, and 1.1 P) with an optimum groove size on the steel plate, the amount of glue on the concrete and steel plate equal 0. 033 g/cm^2 , the amount of sand(sieve no.46) on the concrete surface equal 0.109 g/cm^2, which obtained from case 3, it is found that the maximum optimal friction coefficient value is 0.880, when the pre-tightening bolts force value equal 1.0 P (3 tons) (G12),because in this group, there are no cracks in the concrete. Moreover, upper and lower steel plate was sliding with clear sliding marks, as indicated in the slip failure Feature shown in the Table (12).

5) In the case of no glue on the surface of steel with an optimum groove size on the steel plate, the amount of glue on the concrete and steel plate equal 0. 033 g/cm^{2,} the amount of sand (sieve no.46) on the concrete surface equal 0.109 g/cm^2 and with optimum pre-tightening bolt force 1.0 P (3 tons), which obtained from case 4, it is found that the maximum optimal friction coefficient value is 0.413. Finally, when there have no glue and sand in concrete and steel plate with optimum pre-tightening bolts force 1.0 P (3 tons), found that the maximum optimal friction coefficient value is 0.164.

V. Conclusion

From the result presented in this paper, the following conclusion can be drawn.

According to the test data's for this test specimen model, it is found that, the optimum maximum friction coefficient is 0. 880. The optimum amount of glue on the concrete and steel surface is 0. 033g/cm^2, 0.02 g/cm^2, respectively. The optimum amount and sieve no. of sand is 0. 109g/cm^2, 46 respectively ., the optimum steel plate groove size is 1.5 mm, 30 mm depth, width respectively , the optimum pre-tightening bolts' force is 3. 0 tons. The friction coefficient increased with increased of the amount of glue on the steel plate surface. The minimum friction coefficient is 0.164.

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