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Experimental Investigation of post-installed anchors' behavior under axial tensile force

Deedar A. Hussein
Department of civil Engineering, Erbil technical engineering college, Erbil polytechnic university, Erbil, Kurdistan Region, Iraq., deedar.hussein@epu.edu.iq

Sarkawt Asaad Sarkawt
Department of civil Engineering, Erbil technical engineering college, Erbil polytechnic university, Erbil, Kurdistan Region, Iraq.

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Abstract

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Post installed anchors, Epoxy, grout, average bond stress, pull-out test

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RESEARCH ARTICLE

Experimental Investigation of post-installed anchors' behavior under axial tensile force

Deedar A. Hussein[1], Sarkawt Asaad Hasan[2]

[1] Department of civil Engineering, Erbil technical engineering college, Erbil polytechnic university, Erbil, Kurdistan Region, Iraq.

[2] Department of civil Engineering, Erbil technical engineering college, Erbil polytechnic university, Erbil, Kurdistan Region, Iraq.

***Corresponding author:**
Deedar Arif Hussein
Department of civil Engineering, Erbil technical engineering college, Erbil polytechnic university, Erbil, Kurdistan Region, Iraq.

E-mail:
deedar.hussein@epu.edu.iq

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ABSTRACT

In this research, the ultimate bond capacity of post-installed anchors for adhesives (three brands: *HIT-RE10*, *ROX-GU80* and *DUBELLF1331*) and grouts (*FLO-GROUT2*) has been evaluated experimentally and compared with the reference cast-in-place anchors. In addition, a parametric study has been conducted to assess the effects of the anchor diameter (10, 12, 16 mm), anchor embedded length ($5d_b$,$10d_b$ and $15d_b$) and the cleaning method on the adhesive and grouted anchors.

Among the used three adhesive brands, the anchor adhesive Brand "*HIT-RE10*" had the largest bond capacity. Furthermore, apart from the small embedded length ($5d_b$), the experimental results showed that the ultimate bond capacity of the post installed anchors was higher than the reference cast-in-place anchors. In the same embedded length range (>5db), the average bond stress decreased with the increase in the embedment length. With respect to the effect of the increase in the embedment length and the diameter parameters, the results showed that there is a corresponding increase in the ultimate bond capacity in both the adhesive and the grout anchors.

For the cleaning method parameter in adhesive anchors, the cleaning with air only achieved a higher ultimate bond capacity compared with cleaning using air plus wire brush; however, in grout anchors, the cleaning using air plus wire brush produced the larger capacity. The results also showed that cleaning the holes of the adhesive anchors by washing with water and wire brush produced the highest ultimate bond capacity compared with the other two cleaning method.

Key Words: Post installed anchors, Epoxy, grout, average bond stress, pull-out test

1-INTRODUCTION

Anchors are frequently used to join already cast-in-place concrete elements to newly cast concrete. Anchors can either be cast in fresh concrete (cast-in-place) or inserted into hardened concrete (post installed).

The anchors are used when structural element should be added to an existing framework to ensure structural continuity, which is called retrofitting, or in situations where floors are created in stages, existing buildings need to be extended, or part of the structure is required to be strengthened to resist design forces. post-installed anchors transfer different types of loads such as flexure, shear, axial, and torsional forces, (Awolusi et al., 2019) (Atoyebi et al., 2019).

Both of the load and stress transfer is achieved by preventing relative motion or slippage between the concrete and the rib sides of the inserted anchor bar which called bond strength that it depends on three processes: chemical adhesion; friction; mechanical contact of the bar's ribs with the surrounding concrete (ACI-408R,2003).

Anchors are loaded either by tension, shear, or a combination of them. Depending on the shear transmission through connections, anchors may also be subjected to bending. (Mazılıgüney, 2007).

(Ajamu et al., 2020) examined three different locally available epoxy-based adhesives (HIT 500, Araldite and 4 Minutes) in Nigeria, the largest bond strength found for 10d and 15d embedment length for 12mm bar diameter was 5.52Mpa and 6.80Mpa, respectively. For anchor diameter equal to 16 mm, the bond strength found 5.38Mpa and 6.35Mpa of 16mm bar diameter for the embedment length 10db and 15db, respectively. According to the research findings, the embedment length had a greater influence on the pull-out force than diameters. But Hilti provided the highest bond stress capacity out of the three different types of adhesives that used. when the embedment depth increased from 10db to 15db it leads to bond stress increment in some cases.

(Zeyad et al., 2019) studied the efficiency of various adhesive types as a bonding agent for anchors under pull-out tests. They found that the ultimate capacity of post installed anchors is equal or more than the ultimate capacity of cast-in-place anchors where for the embedded length equal to 10db and 15db without mention any reasons for that behavior.

(Müsevitoğlu et al., 2020) analyzed the behavior of chemical anchors in concrete when subjected to tensile force with several factors, such as concrete compressive strength, reinforcing bar diameters, anchor depths, hole sizes, and hole cleaning. The axial-load-bearing capacity was found to be increased by the anchoring depth, compressive strength, and reinforcing diameter. The specimens cleaned with water were capable of sustaining greater axial loads than those cleaned with air only. The axial-load capacities for the anchors with uncleaned holes were had a lower capacity compared to the other cleaning methods.

In the current study the ultimate bond capacity and average bond stress of post installed anchors for different brands that locally available in Erbil city were studied for anchor diameter 16mm,12mm and 10mm for the embedded length 5db,10db and 15db. Also, the different cleaning methods for adhesive anchors and grouted anchors were discussed for the same anchor dimeter and embedment length.

2- MATERIAL AND METHODS

2.1 Cement

Ordinary Portland Cement produced by Mass Factory had been used for the production of concrete by GOGCA company. The physical and chemical properties of cement are tested and verified according to the specifications of (ASTM - C150).

2.2 Fine aggregate

Fine aggregate (Natural sand) was used from (the Aski-Kalak source). The sand the highest particle size was (4.75 mm), the Specific gravity, bulk density equal and fineness modulus to 2.655, 1635 kg/m^3 , and 2.493 respectively. the fine aggregate grading curve is showed in Figure (1). the limits of the (ASTM - C33) standard were also presented below.

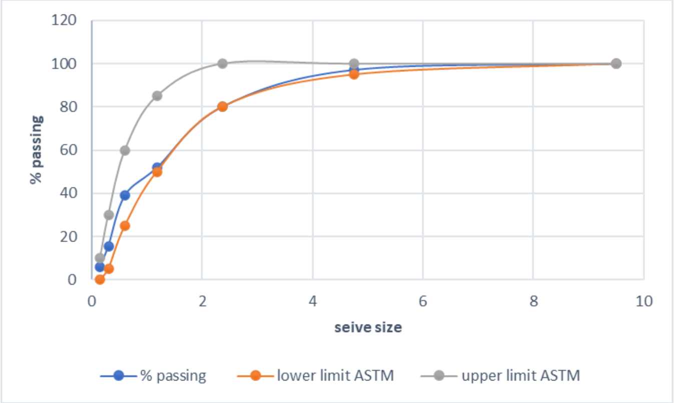

Figure (1) Grading curve of fine aggregate with ASTM limitations

2.3 Coarse aggregate

The crushed aggregate was used with a specific gravity and bulk density equal to 2.678, 1615 kg/m^3, respectively. and gradation of the aggregate detailed in Figure (2).

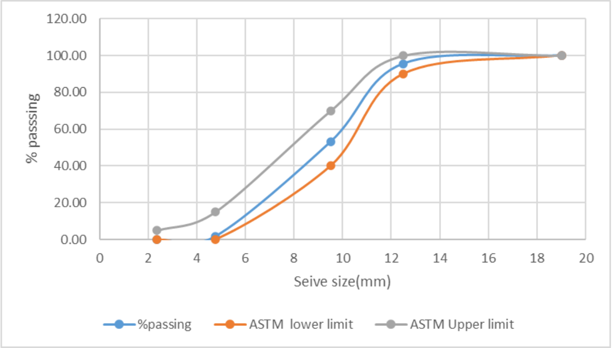

Figure (2) Gradation of the coarse aggregate with ASTM limits

2.4 Water

Tap water was used in the concrete plant for the production of concrete mix as well as curing the concrete and cubes.

2.5 Adhesives

Three different epoxy brands (HIT-RE10, ROX GU80, and DUBELL.F1331) and one non-shrinkage grout (flo-grout2 from DCP brands) have been used in the study, which were locally used in Erbil city on 2022.

Figure (3) Different epoxy brands and Flo-grout 2

2.6 Reinforcement steel bars

Reinforcements are produced by Mass factory that located in Sulaymaniyah. the diameters of the reinforcing bars used in this study are 16 mm, 12 mm, and 10 mm with a drill hole size equal to 20mm,16mm and 14mm, respectively. The tensile properties of these reinforcements are illustrated in the Table (1).

Table (1)Reinforcement properties

Anchor diameter (mm)	*Yield stress (Mpa)*	*Ultimate stress (Mpa)*
10	749	850.96
12	646.7	782.91
16	627.5	734.97

2.7 Sample descriptions:

The experimental program involved casting a concrete slab-on-grade of 4.5 x 6.0 m area and 330 mm thickness, which is larger than the largest used embedded length (15db=240mm) plus two times the larger used anchor diameter (2db=32mm) required by ACII 355.4M-11. Nine cast-in-place reference anchors installed during casting of the concrete slab with various embedment length depth (5db,10db and 15db) for anchor diameter 10mm,12mm and 16mm. After 28 days, 72 anchor holes were drilled, and steel reinforcement bars with diameters of 10 mm, 12 mm, and 16 mm have been installed into the concrete holes using various adhesives and grouts.

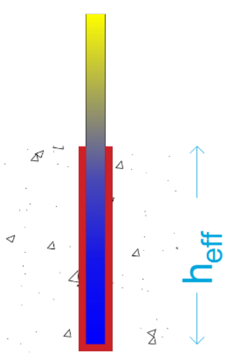

Figure (4) Embedment length details

2.8 Mixing of the concrete, casting and curing procedures:

The experimental program involved casting the concrete slab with concrete cube compressive strength equal to 45.64 MPa at 28 days with a mix proportion 1:2.6:2.87 (Cement: Fine aggregate: Coarse aggregate) and water cement ratio of 0.49; the workability was measured through slump test which was equal to 90mm. The temperature was equal to 20 C^o during pouring the concrete; the concrete slab and control cube samples were cured for 7 days.

Table 2 Mix proportion of the concrete prepared by Gogca company

Quantities(kg/m^3)				
Cement	**Water**	**Super plasticizers ***	**Fine aggregate**	**Coarse aggregate**
336	175	1.5	878	950
*CHRYSO Delta KB, highly water reducer according to technical specification EN934-2 T3.1/T3.2				

Figure (5) casting the concrete slab procedure

2.9 Drilling process :

A vibrating rotary hammer drill was used to the drill holes in the concrete in 14mm,16mm and 20m for the anchor dimater of 10mm,12mm and 16mm, respectively.

2.10 Group descriptions:

2.10.1 Group one: Post installed anchors and cast-in-place anchors

Three different epoxy brands (**HIT-RE10, ROX GU80, and DUBELL.F1331**) locally available in Erbil and one non-shrinkage grout (**FLO-GROUT2**) from DCP brand have been tested for anchor diameters of 10mm ,12mm and 16mm using embedment length of 5db ,10db and 15db.

Both of the drilling and cleaning of the holes have been done when the concrete was dry. Adhesive anchors installed in dry concrete. However, for the grouted anchors, the concrete was soaked with water for more than 12 hours to provide a saturated surface dry concrete before the installation stage.

2.10.2 Group two: cleaning methods

Three different cleaning methods have been used as detailed below:

i. Method I (Air +Wire brush + Air)
ii. Method II (Air only)
iii. Method III (Wash + Wire brush +Wash).

The drilling, cleaning and installation process were done similar to the group one.

*The grouted anchors should be cured for minimum 3days after installation date.

Table (3) detail of the groups

Group No.	Description	Anchor diameter (mm)	Embedment length	Cleaning methods
G1	Different epoxy brands with grouted anchors and cast-in-place anchors	10	5db	Method I for epoxy And grout
			10db	
			15db	
		12	5db	
			10db	
			15db	
		16	5db	
			10db	
			15db	
G2	Different cleaning method effect on ultimate bond capacity	10	5db	Method (I, II and III) for adhesive anchors and Method (I, II) for grouted anchors
			10db	
			15db	
		12	5db	
			10db	
			15db	
		16	5db	
			10db	
			15fb	

2.11 Preparation and injection the adhesives:

The grouts were mixed with 3.66:1 (water/grout) ratio. The adhesives were injected into to the holes by using the silicon gun packed with the required amounts of the adhesives and then the adhesives were injected into the holes.

2.12 Anchor installations:

The holes were filled with the adhesive or grout with a length equal to 2/3 of the hole length, then the anchors were installed into the holes by twisting the anchors slowly to provide a complete bond between anchor and the adhesive with the concrete.

2.13 Confined Pull-out test:

The pull-out tests have been done after 14days, and 28 days from the installation of the adhesive and grouts, respectively.

Pullout tests have been done using a calibrated hydraulic hollow jack with a 220 KN capacity as shown in the Figure (6); the base plate had been provided between the hydraulic jack and the concrete to provide a confined concrete test setup avoiding the occurrence of the cone failure. the dimensions of the plate were determined as per ACI355.4 (2020). The anchors are loaded till the maximum load is reached.

The taken base plate dimensions were equal to:

- Width of the plate =300mm (min should be 100mm)
- Thickness of the plate =16mm (t_{plate} = 16 mm ≥ db =16mm)
- Hole diameter in the center of the plate = 25mm(1.5db(24mm) -2.0db(32mm))

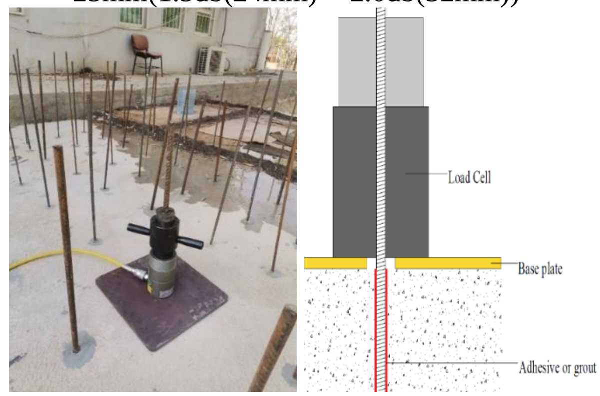

Figure (6) Pullout test configuration

A. Grout B. Adhesive

Figure (7) Bond failure for grouted and adhesive anchors

3- RESULTS AND DISCUSSION

3.1 Ultimate bond capacity

The results of the current study (Table 4 and 5 and Figure 8 to 10) show that the ultimate bond capacity of the post installed anchors (adhesive and grouted) is larger than the ultimate bond capacity of the reference cast-in-place anchors within the embedment length of 10db to 15db. This in agreement with results of (Zeyad et al., 2019) who reported that when the embedment length of post installed anchor is more than 10db, the ultimate bond capacity is equal or more than ultimate bond capacity of cast-in-place anchors .However, the ultimate bond capacity of post installed anchors were less than cast-in-place's ultimate bond capacity in low embedment length (5db). But, (Haidar et al., 2020) stated that anchors ultimate capacity of cast-in-place is more than post installed anchor capacity for anchor diameter of 12mm and 16mm with the embedded length 100mm and 150mm.

The authors of the current paper attribute the larger ultimate bond capacity in the post installed anchors (compared of the reference cast-in-place anchors with the same embedded length and anchor diameter) to having greater bond area at the failure plane (between the adhesive and the concrete) compared with the bond area between the anchor and the concrete in the cast-in-place anchors.

For the small embedment length (5db), the ultimate bond capacity of cast-in-place anchors was found to be more than the ultimate bond capacity of the post installed anchors in the current study. This is in agreement with the results of (Christopher Gamache) who reported that the Concrete's near-surface performance for anchoring is less consistent compared to its interior attributing. This behavior is attributed to the larger concentration of concrete paste in the top layer of the concrete, shrinkage cracks, and contact to environmental factors. Christopher stated also that Comparing the anchors installed in the formed side of the concrete to those installed on the unformed side, there was a capacity reduction around 30%. Typically, there is also more aggregate concentration on the formed side of the concrete member.

Furthers, the current study results showed that the ultimate bond capacity increased with the increase in the embedment length and the anchor diameter. This confirmed the results of (Müsevitoğlu et al., 2020), (Haidar et al., 2020) (Zeyad and Shihada, 2014.).

The details of the above observed behavior of the anchor are presented below for each anchor diameter,

I. Φ10mm

The anchors with the embedment length of 5db (50mm) had an ultimate bond capacity of 80%,72%,48% and 41.6% of the cast-in-place anchors ultimate bond capacity for HIT-RE10, ROX-GU80, DUBELL.F1331 and Grout, respectively.

The ultimate bond capacity was equal to 114.28%,78.57%,89.28% and 100% of the cast-in-place anchors ultimate bond capacity for HIT-RE10, ROX-GU80, DUBELL.F1331 and Grout, respectively where the embedment length was equal to 10db (100mm).

For anchors installed with an embedment length of 15db (50mm), the ultimate bond capacity was 114.48%,101.35%,101.35% and 100% of cast-in-place ultimate bond capacity anchors for HIT-RE10, ROX-GU80, DUBELL.F1331, and Grout, respectively.

II. Φ12mm

Firstly, the ultimate bond strength achieved 130.76% ,80.76%,69.23% and 60% of the cast-in-place anchors ultimate bond capacity for epoxy brands HIT-RE10, ROX-GU80, DUBELL.F1331 and Grout, respectively in the case of embedment length of 5db(60mm).

Secondly, for the Anchors installed with an embedment length of 10db(120mm), the ultimate bond capacity was 140%,100%,100% and 130% of the cast-in-place ultimate bond capacity anchors for HIT-RE10, ROX-GU80, DUBELL.F1331, and Grout, respectively.

Finally, the anchors installed with the embedment length of 15db(180mm) had an ultimate bond strength equal to 80%,72%,48% and 41.6% of the cast-in-place anchors ultimate bond capacity for HIT-RE10, ROX-GU80, DUBELL.F1331 and Grout, respectively.

III. Φ16mm

The ultimate bond capacity for the anchors installed by HIT-RE10, ROX-GU80, DUBELL.F1331 and Grout was 135%,157.14%,71.42% and 110.71% of the cast-in-place anchors ultimate bond capacity for HIT-RE10, ROX-GU80, DUBELL.F1331 and Grout, respectively for the embedded length 5db(80mm).

The ultimate bond capacity reached 116.36%, 98.18%, 90.90% and 110.90% of the cast-in-place anchors ultimate bond capacity for HIT-RE10, ROX-GU80, DUBELL.F1331 and Grout, respectively, when the embedment length equal to 10db(160mm).

For the Anchors installed with an embedded length of 15db(240mm), the ultimate bond capacity was 112.5%,93.75%,112.5% and 103.12% of the cast-in-place ultimate bond capacity anchors for HIT-RE10, ROX-GU80, DUBELL.F1331, and Grout, respectively.

Table (4) Ultimate bond capacity of Post installed anchors (Grouted and Adhesive) and Cast-in-place

Anchor diameter (mm)	Embedment length	Ultimate bond capacity (KN)				
		Cast-in-place (Reference)	HIT-RE10	ROX GU80	DUBELL.F1331	Grout (Flo-grout2)
10	5db	40	32	28.8	19.2	16.64
	10db	44.8	51.2	35.2	40	44.8
	15db	47.36	52.8	48	48	47.36
12	5db	41.6	54.4	33.6	28.8	24.96
	10db	48	67.2	48	48	62.4
	15db	51.2	70.4	56	64	65.6
16	5db	44.8	60.48	70.4	32	49.6
	10db	88	102.4	86.4	80	97.6
	15db	102.4	115.2	96	115.5	105.6

Table (5) Relative strength compared to cast-in-place anchors

Anchor diameter (mm)	Embedment Length	Ultimate bond capacity (%)				
		Cast-in-place(Reference)	HIT-RE10(%)	ROXGU80(%)	DUBELL.F1331(%)	Grout(Flow-grout2)(%)
10	5db	100	80.00	72.00	48.00	41.60
	10db	100	114.28	78.57	89.28	100.00
	15db	100	111.48	101.35	101.35	100.00
12	5db	100	130.76	80.76	69.23	60.00
	10db	100	140.00	100.00	100.00	130.00
	15db	100	137.50	109.37	125.00	128.12
16	5db	100	135.00	157.14	71.42	110.71
	10db	100	116.36	98.18	90.90	110.90
	15db	100	112.5	93.75	112.5	103.12

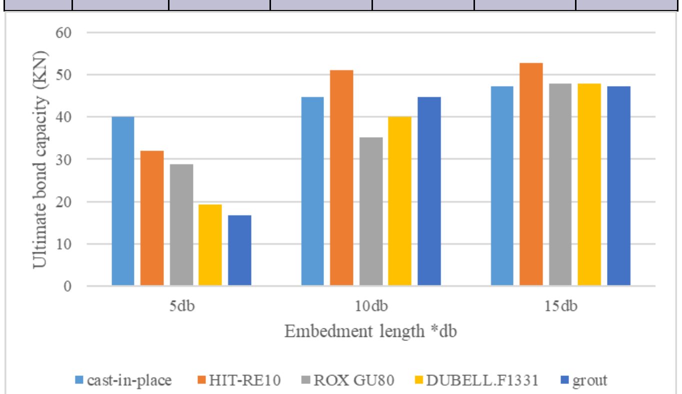

Figure (8) Comparison of the ultimate bond capacity of epoxy brands, grout and cast-in-place with different embedment length for Φ=10mm

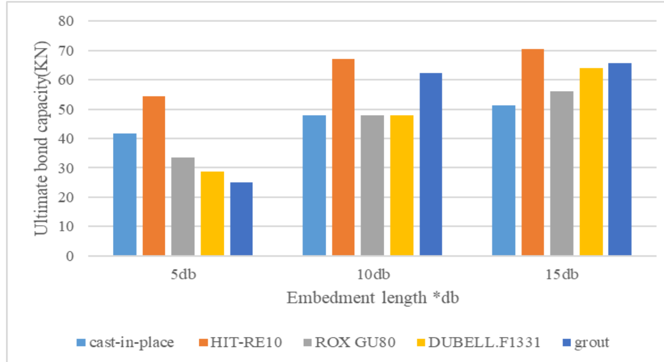

Figure (9) Comparison of the ultimate bond capacity of epoxy brands, grout and cast-in-place with different embedment length for Φ=12mm

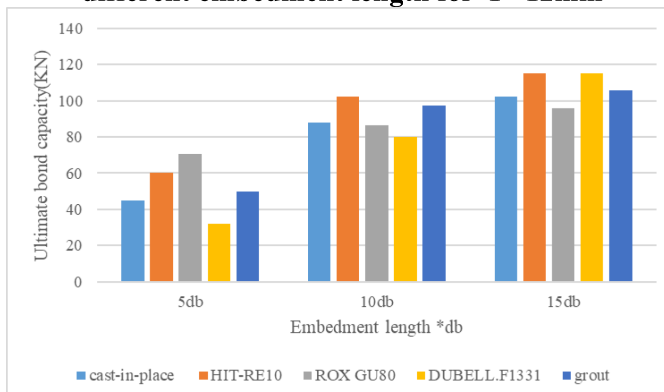

Figure (10) Comparison of the ultimate bond capacity of epoxy brands, grout and cast-in-place with different embedment length for Φ=16mm

3.2 Average bond stress

The results of the current study (Table 6 and Figure 11 to 15) show that the average bond stress decreases with the increase in the embedment length for all anchor types when the embedment length increased from 10db to 15db. This is in agreement with the results obtained by(Müsevitoğlu et al., 2020), (Luke, 1984).

However, (Atoyebi et al., 2019) found that increase in the embedment depth leads to an increase in average bond stress for some brands which they tested (12mm and 16mm) anchor diameter for three epoxy brands (Araldite, 4minutes and Hilti) with the embedment length equal to (10db and 15db). Atoyebi et al found that the average bond stress increased for Araldite epoxy brand when embedment length increased from 10db to 15db for both diameters.

However, the current study, there was no clear trend for average bond stress compared to 10db and 15db in low embedment length (5db) because the quality of the concrete is not similar to the quality of sub layer as it was affected by drilling process and the percentage of the paste in top layer is more than sub layer.

Further detailed results are listed in the following sections.

3.2.1 Cast-in-place

The average bond stress reached 25.47 Mpa ,14.26 Mpa and 10.05 Mpa of 10 mm anchor diameter for the embedment length 5db (50mm), 10db (100mm) and 15db (150mm), respectively. When the anchor diameter of 12mm was used, the average bond stress had been found to be 18.40Mpa ,10.61Mpa and 7.54Mpa for the embedment length of 5db (60mm) ,10db (120 mm) and 15db (180mm), respectively. When the anchor diameter was equal to 16mm, the average bond stress recorded to be 11.14 Mpa ,10.94 Mpa and 8.49 Mpa when the embedment length equal to 5db (80mm), 10db (160mm) and 15db (240mm), respectively.

3.2.2 HIT-RE10

When the embedment length was equal to 5db, the post installed anchors using HIT-RE10 epoxy brands with a diameter 10mm ,12mm and 16mm had an average bond stress of 20.38 Mpa and 24.06 Mpa and 15.04 Mpa, respectively. The average bond stress started to decrease for all diameters (10mm,12mm and 16mm) for the embedment length equal to 10db compared to 5db which found to be 16.30Mpa ,14.86Mpa and 12.73Mpa respectively. For the embedment length equal to 15db, the average bond stress was equal to 11.21Mpa, 10.38Mpa and 9.55Mpa for the diameter 10mm,12mm and 16 mm, respectively.

3.2.3 ROX-GU80

The anchors installed using ROX-GU80 epoxy brands with the embedment length equal to 5db had an average bond stress of 18.34Mpa,14.86Mpa and 17.51Mpa for anchors diameters equal to 10mm,12mm and 16mm, respectively. But when the embedment length of 10db was used for the diameters equal to 10mm, 12mm and 16mm recorded a lower average bond stress of 11.21Mpa ,10.61Mpa and 10.74Mpa, respectively. When the embedment length increased to 15db, the average bond stress were equal to 10.19Mpa, 8.25Mpa and 7.96Mpa for diameter 10mm,12mm and 16mm, respectively.

3.2.4 DUBELL.F1331

When the anchors installed with DUBEL.F1331 epoxy brands, the average bond stress achieved 12.22 Mpa,12.73Mpa and 10.19Mpa for the embedment length of 5db (50mm), 10db (100mm) and 15db (150mm) for the diameter equal to 10mm, respectively. But when 12mm anchor diameter was used, the average bond stress was equal to 12.73Mpa, 10.61Mpa and 9.43Mpa for the embedment length equal to 5db (60mm), 10db(120mm) and 15db(180mm), respectively. For the 16 mm anchor diameters, the average bond stress found to be 7.96Mpa, 9.95Mpa and 9.55Mpa for the embedment length equal to 5db(80mm) 10db (160mm) and 15db(240mm), respectively.

3.2.5 Grout (FLO-GROUT2)

For the grouted anchors, the average bond stress for anchor diameter 10mm for the embedment length 5db(50mm) ,10db(100mm) and 15db(150mm) were found to be equal to 10.59Mpa and 14.26Mpa and 10.05Mpa, respectively. When the diameter 12mm has been used, the average bond stress was equal to 11.04Mpa and 13.80Mpa and 9.67Mpa for the anchor depth 5db(60mm) ,10db(120mm) and 15db(180mm), respectively. When 16 mm anchor diameter installed with grouts, the average bond stress was equal to 12.34Mpa, 12.14Mpa and 8.75Mpa for the embedment length 5db(80mm), 10db(160mm) and 15db(240mm), respectively.

Table (6) Average bond stress of cast-in-place, adhesive brands and grouted anchors

Anchor diameter (mm)	Embedment length	Average bond stress (Mpa)#				
		Cast-in-place	HIT-RE10	ROXGU80	DUBELLF1331	Grout (Flo-grout2)
10	5db	25.47	20.38	18.34	12.22	10.59
	10db	14.26	16.30	11.21	12.73	14.26
	15db	10.05	11.21	10.19	10.19	10.05
12	5db	18.40	24.06	14.86	12.73	11.04
	10db	10.61	14.86	10.61	10.61	13.80
	15db	7.54	10.38	8.25	9.43	9.67
16	5db	11.14	15.04	17.51	7.96	12.34
	10db	10.94	12.73	10.74	9.95	12.14
	15db	8.49	9.55	7.96	9.55	8.75

Average bond stress calculated through the equation

$$Average\ bond\ stress\ (Mpa) = \frac{P}{\pi * D * H_{eff}}$$

Where;

P=the ultimate load (N)

D=Anchor diameter (mm)

H_{eff}=Embedment length (mm)

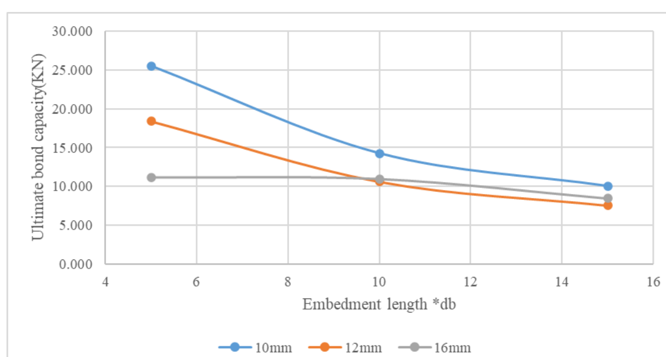

Figure (11) Relationship between average bond stress vs embedment length for cast-in-place anchors

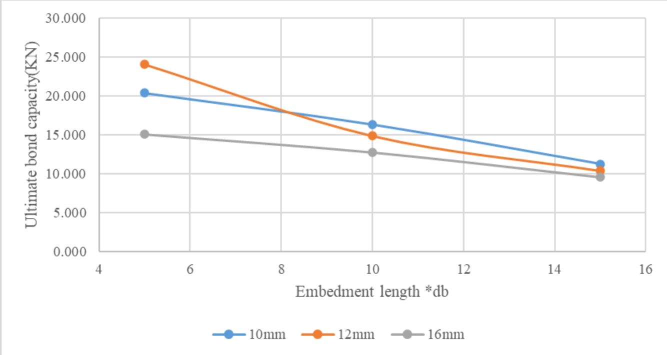

Figure (12) Relationship between average bond stress vs embedment length for HILTI-RE10 Epoxy brand

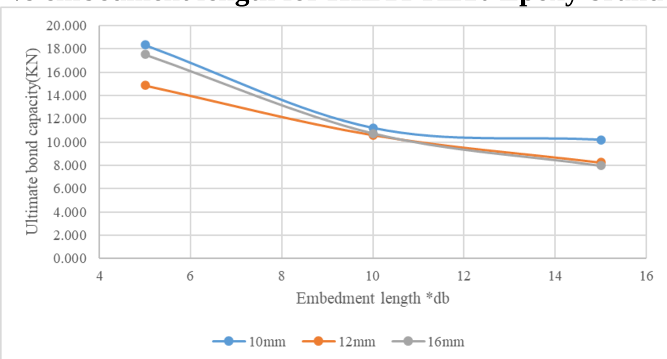

Figure (13) Relationship between average bond stress vs embedment length for ROX-GU80 Epoxy

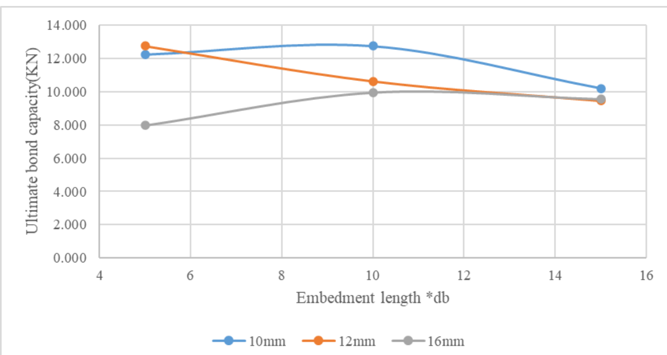

Figure (14) Relationship between average bond stress vs embedment length for DUBELL.F1331 Epoxy

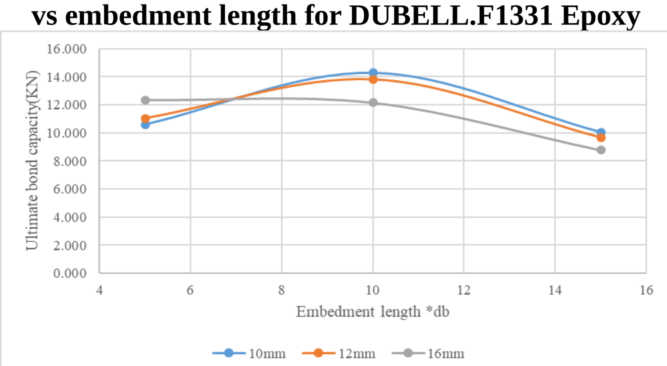

Figure (15) Relationship between average bond stress in grouted anchors vs embedment length for grouted anchors

3.3 Group two: cleaning methods

3.3.1 Adhesives

The results of the current study (Table 7 and Figure 16 to 18) showed that the cleaning methods had a notable influence on the ultimate bond capacity; drilled holes cleaned using method I (Air +Wire brush +Air) had an ultimate bond capacity less than holes cleaned by Method II(Air only). This is because the wire brush tends to polish the drilled hole surface that reduce the capability of adhesive to create a mechanical interlock with the sides of the hole ;this results are in agreements with the results of (Luke, 1984), (Cook et al., 1998).

Also, the drilled holes cleaned by method III(Wash +Wire brush +Wash) had an ultimate bond capacity more than previous two cleaning methods because it removes the dust that produced during the drilling process that makes a creation better bond between adhesive and concrete, which confirm to the results obtained by(Müsevitoğlu et al., 2020).

Detailed results are shown in the following paragraphs;

I. Φ10mm

For 10mm diameter adhesive anchors, the ultimate bond capacity increased by 13.33% ,29.09% and 2.67% for the anchor holes cleaned by method II for the embedded length 5db(50mm) ,10db(100mm) and 15db(150mm), respectively if compared to anchors holes cleaned by method I. Also, the ultimate bond capacity increased by 16.67%,31.82% and 4.67% for the holes that cleaned by Method III when the embedment length equal to 5db(50mm) ,10db(100mm) and 15db(150mm), respectively.

II. Φ12mm

When the anchor diameter was equal to 12mm, the ultimate bond capacity increased by 52.38%,2.00% and 21.17% for the holes cleaned by method II compared to the holes cleaned by method I for the embedment length equal to 5db(60mm),10db(120mm) and 15db(180mm), respectively.

Where the anchor holes cleaned by method II, the ultimate bond capacity increased by 57.14%,134.67% and 45.14% for the embedment length equal to 5db(60mm), 10db(120mm) and 15db(180mm), respectively.

III.Φ16mm

When the anchor diameter 16mm used with the embedment length equal to 5db(80mm), 10db(180mm) and 15db(240mm), the ultimate bond capacity increased by 2.27%,24.07% and 12.23%, respectively, when the drilled hole cleaned with method II with respect of holes cleaned by method I.

When anchor holes cleaned by method III, the ultimate bond capacity of anchors increased by 13.64%, 31.48%, 35.00% for the embedded length 5db(80mm), 10db(180mm) and 15db(240mm) respectively compared to holes cleaned by method I.

Table (7) Ultimate bond capacity of adhesive anchors with various cleaning methods

Anchor diameter (mm)	Embedment length	Ultimate bond capacity (KN)			Relative ultimate bond capacity (%)	
		Method I (Air only+ Wire brush +Air) (Reference)	Method II (Air only)	Method III (Wash only +Wire brush+Wash only)	Method II	Method III
10	5db	28.8	32.64	33.6	113.33	116.67
	10db	35.2	45.44	46.4	129.09	131.82
	150	48	49.28	50.24	102.67	104.67
12	5db	33.6	51.2	52.8	152.38	157.14
	10db	48	48.96	64.64	102.00	134.67
	15db	56	68.16	81.28	121.17	145.14
16	5db	70.4	72	80	102.27	113.64
	10db	86.4	107.2	113.6	124.07	131.48
	15db	96	107.84	129.6	112.33	135.00

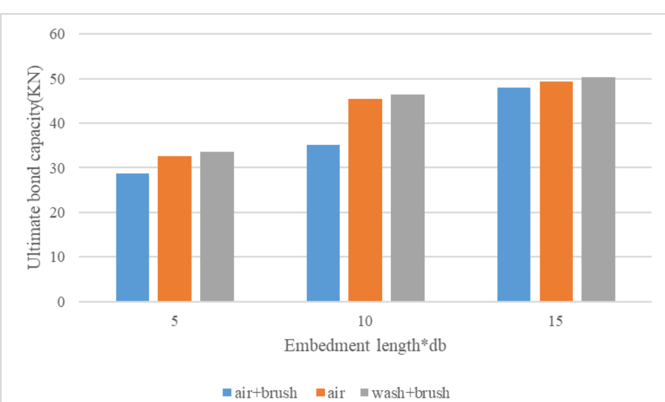

Figure (16)Ultimate bond capacity for adhesive anchor diameter equal to 10mm with different cleaning methods

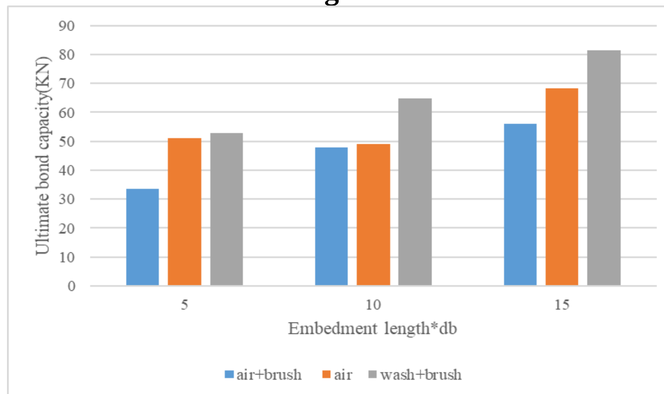

Figure (17) Ultimate bond capacity for adhesive anchor diameter equal to 12mm with different cleaning methods

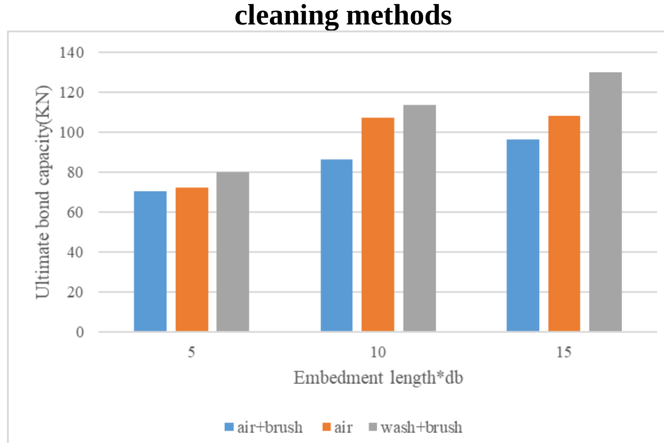

Figure (18) Ultimate bond capacity for adhesive anchor diameter equal to 16mm with different cleaning methods

3.3.2 Grouted anchors (Flo-grout2)

According to the current study results (Table 7 and Figures 19 to 21), the ultimate bond capacity decreased for the grouted anchors when the drilled hole cleaned by method II (Air only) compared with the method I (Air +Wire brush +Air) because there are some dusts that produced in the holes during drilling operations, which caused a weak bond between the grout and concrete interface.

Detailed results are shown in the following paragraphs;

I. Φ10mm

If the anchor holes were cleaned by method II, The ultimate bond capacity decreased to 96.15% ,66.21% and 91.89 % of anchor holes that cleaned by method I of 10mm anchor diameter for the embedment length 5db(50mm),10db(100mm) and 15db(150mm), respectively.

II. Φ12mm

When the anchor diameter 12mm was used, the ultimate bond capacity achieved 125.64% ,91.28% and 92.68% of the ultimate bond capacity that cleaned by method I for the embedment length 5db(60mm) ,10db(120mm) and 15db(180mm), respectively.

III. Φ16mm

When the anchor diameter was equal to 16mm, the ultimate bond capacity reduced to 66.45% ,69.5% and 81.21% of the ultimate bond capacity of anchors that cleaned by method I when the embedment length equal to 5db(80mm), 10db(160mm) and 15db(240mm), respectively.

Table (7) Ultimate bond capacity of grouted anchors with various cleaning methods

Anchor diameter (mm)	Embedment length	Ultimate bond capacity (KN)		Ratio= Method II/Method I (%)
		Method I (Air+ Brush)	Method II (Air)	
10	5db	16.64	16	96.15
	10db	44.8	31.36	66.21
	15db	47.36	43.52	91.89
12	5db	24.96	31.36	125.64
	10db	62.4	56.96	91.28
	15db	65.6	60.8	92.68
16	5db	49.6	32.96	66.45
	10db	97.6	67.84	69.50
	15db	105.6	85.76	81.21

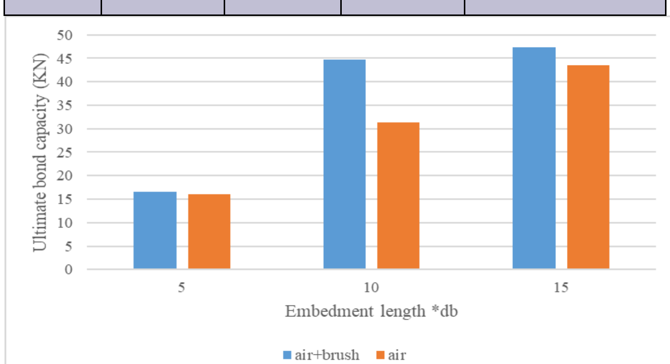

Figure (19) Ultimate bond capacity for grouted anchor bar diameter =10mm with different cleaning methods

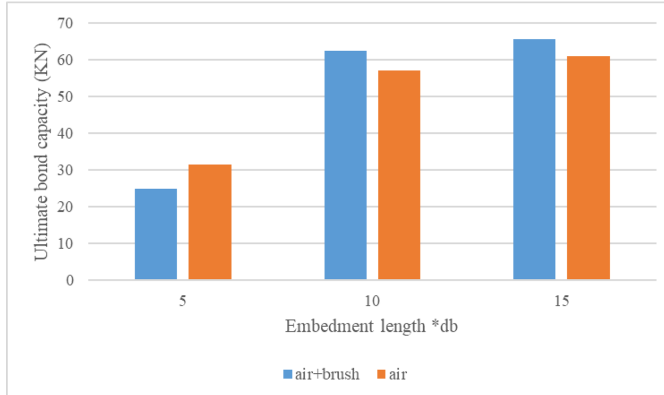

Figure (20) Ultimate bond capacity for grouted anchor bar diameter =12mm with different cleaning methods

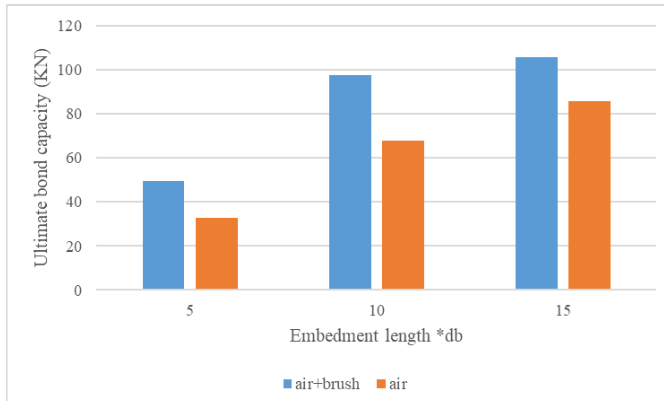

Figure (21) Ultimate bond capacity for grouted anchor bar diameter =16mm with different cleaning methods

4- CONCLUSION

The following conclusions could be drawn from the current study:

1. Among the three studied adhesive brands (*HIT-RE10*, *ROX-GU80* and *DUBELLF1331*), the brand HIT-RE10" achieved the largest ultimate bond capacity.
2. In both the grouted anchors and adhesive anchors, as the embedment length and the bar diameter increased, the ultimate bond capacity increased. The embedded length parameter is appeared to be more effective than the anchor diameter.
3. In both the grouted anchors and adhesive anchors, apart from the small embedment length ($5d_b$), the average bond stress for both the adhesive and grouted anchors decreased with the increase of the embedment length.
4. In adhesive anchors, the cleaning method had a notable effect on the ultimate bond capacity, where the cleaning method III (wash +wire brush +wash) produced the largest ultimate bond

capacity, followed by method I (air +Wire brush +air) then method II (air only)

5. In grouted anchors, the cleaning method using air with wire brush had the higher bond strength compared with those cleaned by air only.

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