Experimental evaluations of load carrying capacity of post installed steel anchors

A Thesis

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By

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DECLARATION

I declare that the Master Thesis: Experimental evaluations of load carrying capacity of post installed steel anchors is my own original work, and hereby I certify that unless stated, all work contained within this thesis is my own independent research and has not been submitted for the award of any other degree at any institution, except where due acknowledgment is made in the text.

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SUPERVISOR CERTIFICATE

This thesis/dissertation has been written under my supervision and has been submitted for the award of the degree of Master in structural engineering with my approval as supervisor.

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DEDICATION

I dedicate my research to Almighty Allah, knowledge, and insight. he has been the source of strength during this whole program.

I dedicate my dissertation work to my family, my friends and my father and my mother who have supported me through the research process.

I also dedicate this dissertation to my supervisor, who has helped me every step of the way. I will always be grateful for everything he did to assist me in creating and finishing my research project.

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In the name of Allah, the Most Gracious and the Most Merciful.

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Finally, I want to thank my wife and all of my friends in the sincerest way.

Abstract:

In this research, the ultimate load capacity of post-installed anchors for three adhesives (three brands: *HIT-RE10*, *ROX-GU80* and *DUBELLF1331*) and grouts (*FLO-GROUT2*) were evaluated experimentally and compared with the reference cast-in-place anchors. A parametric study was conducted to assess the effects of the anchor diameter (10, 12, 16 mm), anchor embedded length ($5d_b$,$10d_b$ and $15d_b$), the cleaning method and drilled hole size on the adhesive and grouted anchors. Also, the effect of the saturation of the concrete on the pullout capacity for adhesive and grouted anchors had been studied.

Among the used three adhesive brands, the anchor adhesive Brand "*HIT-RE10*" appeared to have the largest bond capacity. Furthermore, apart from the small embedded length ($5d_b$), the experimental results showed that the ultimate load 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 embedded length. With respect to the effect of increasing in the embedment length and the diameter parameters, the results showed that there is a corresponding increase in the ultimate load capacity of both the adhesive and the grout anchors.

For the cleaning method parameter in the adhesive anchors, cleaning with Method I (air only) achieved a higher ultimate load capacity compared with cleaning using Method II (air plus wire brush) because wire brush tends to polish the drilled surface; however, in grouted anchors, cleaning using Method I (air plus wire brush) produced the larger capacity than cleaning using Method (II) because wire brush tend to remove dusts that remain in the drilled holes that produce a weaker bond between the grout and the concrete

The results showed also that cleaning holes of the adhesive anchors by Method III (washing with water and wire brush) produced the highest ultimate load capacity compared with the other two cleaning method.

Regarding the adhesive/grout thickness parameter, the ultimate load capacity, a part from the 5db embedment length, increasing adhesive thickness with (+4mm, +8mm and +12mm) resulted in a higher final bonding strength. This behavior was opposite in the grouted anchors, where there was a reduction in the ultimate load capacity with the increase of the grout thickness; this behavior was more pronounced at smaller depth (5db,10db) rather than large depth (15db).

Further, the adhesive anchors installed into wet saturated concrete have larger ultimate load capacity compared with the anchors installed into wet saturated concrete. Both of grouted and adhesive anchors ultimate load capacity increased when the anchors installed in saturated concrete but there was a drop in the ultimate load capacity of grouted anchor if it was installed into wet saturated concrete because it will increase the water / grout ratio. Also grouted anchors installed into dry concrete had lower ultimate load capacity compared to the grouted anchor that installed into saturated concrete.

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CHAPTER ONE

INTRODUCTION

1.1Background

The joining of already-cast-in-place concrete components to new concrete is usually done with anchors. Anchors can either be install in fresh concrete (cast-in-place) or inserted into hardened concrete (post installed).

Understanding the behavior of anchors is essential for selecting the right anchoring for a specific application. This involves knowledge of various anchor failure mechanisms and strengths, as well as load displacement and this calls for understanding of various anchor failure modes, as well as load displacement and characteristics relaxation.

Anchors have a wide range of applications in engineering projects ranging from the oil industry to building extensions or strengthening technique.

When a concrete structure requires the addition of new concrete members to support the loads or to fix an instrument on concrete roof, anchors should be installed in concrete to fix a new member on it.

The challenge addressed there in this study to show how to join fresh and old concrete using bonding materials which include grouts and adhesives that already exist in Erbil’s local marketplace.

There are three different approaches for anchors might use to transmit applied tension loads to the base material. Mechanical interlock, friction, and bonding are the most common load transfer mechanisms as shown in (Fig. 1-1).

a) Mechanical interlock: An anchor and base material transmit loads through a bearing interlock, which is referred to as mechanical interlock. The load transfer mechanism provides a mechanical interlock which is used by headed anchors, anchor channels, screw anchors, and undercut anchors.

b) Friction: Frictions serve as the load transfer mechanism in expansion anchors. The expansion force is produced during installation by the friction between the anchor and the sidewalls of the drilled hole. External tension load and friction force are in an equilibrium state.

c) Bonds: Through chemical interlock, the base material receives the tension force, which is a mix of adhesion or grout with micro-keying. (Eligehausen et al., 2006)

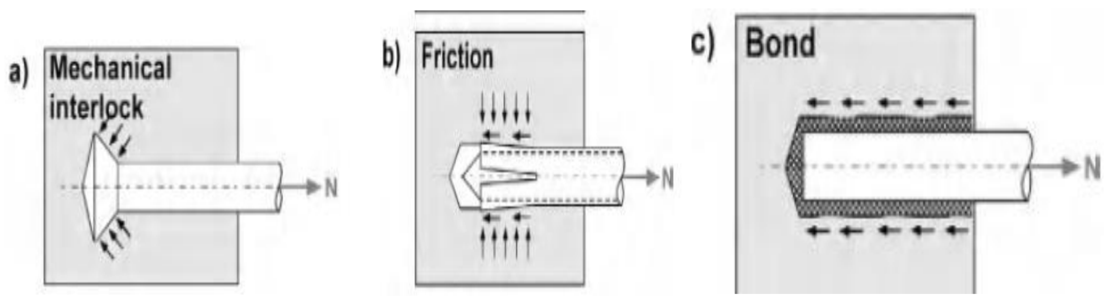


Fig. 1- 1 Anchor load transfer mechanisms (Eligehausen et al., 2006)

1.2Applications of post-installed anchors

Post-installed anchors are typically used in two cases:

A. When a new structural element is attached to an existing structure.

B. When existing members are strengthened.

Below some cases of using anchors in Kurdistan region for different engineering constructions and oil fields such as:

1- Fixing instrument bases or support pipes see (Fig.1-2).

2. Connecting new beams with the existing Reinforced columns (Fig.1-3).

Fig. 1- 2 KAR company equipment Fixing on RC Floors,2020

Fig. 1- 3 Gulan Tower, connecting new steel beams with existing reinforced column ,2014.

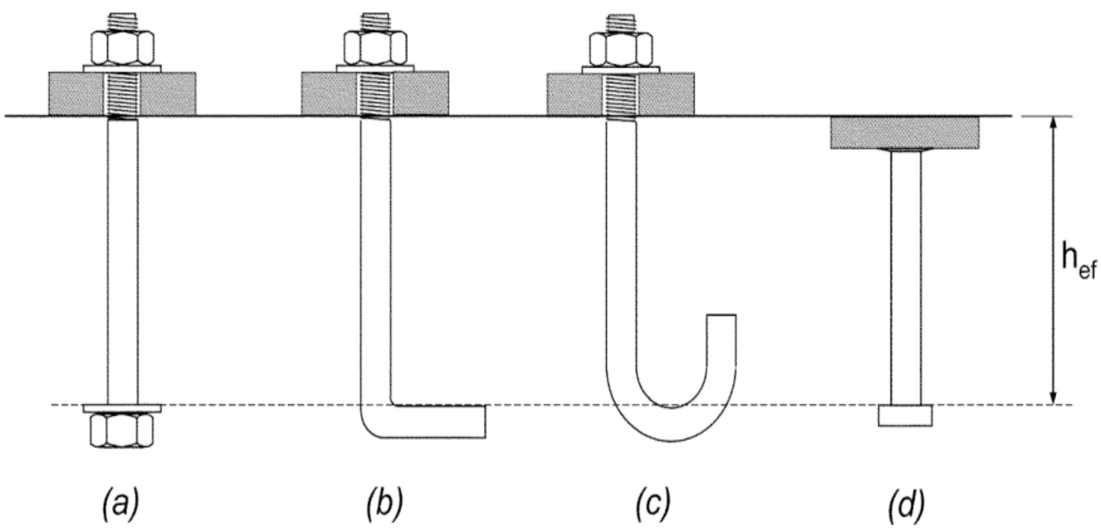
1.3 Types of anchors:

1.3.1 Cast-in-place anchors:

Cast-in-place anchors are the most basic kind of the anchors. As the name indicates, these anchors are poured into freshly-poured concrete before it hardens. The most common design is a standard anchor bolt with the hexagonal head (hex head bolt), In addition, there are also hooked L bolts and J bolts as shown in (Fig.1-5).

Cast-in-place anchors can be used in a wide range of applications. Furthermore, they are difficult to cast. When the force need long embedded length and great tensile strength, cast-in-place anchors are suggested (Level, 2017).

Moreover, the benefit of cast-in-place systems is that the position of predicted external loads is known and may be accommodated in the reinforced concrete member's design by correctly placed reinforcement. The drawback of these systems is the additional layout and planning required, as well as the possibility of incorrect placement (Eligehausen et al., 2006).



(a) Hex head bolt with washer
(b) L-bolt with washer
(c) J-bolt with washer
(d) Welded headed stud

Fig. 1- 4 Types of the cast-in-place anchor

1.3.2 Post-installed anchors

1.3.2.1: Bonded anchors

Bonded installed anchors are installed into the hardened concrete member by drilling holes through it and inserting the reinforcement with the adhesives or the grouts. There are several uses for bonded-installed anchors, including the connection of fresh concrete to existing reinforced concrete components and allowing forces to transfer through joints, as well as reinforcing existing structures with extra straight anchors (Randl, 2011) .

Transmission of the stress and load between the concrete and anchors is related to the link between the anchors and the concrete that located around the anchors. This transmission is produced by the resistance to the relative motion or slippage between the face of the placed anchor and the concrete. Bond stress is a term used to describe the resistance to slippage. Three actions determine the bond stress between the anchors and the surrounding concrete: Chemical adhesion, friction, and mechanical contact between the anchor's ribs and the concrete around ribs are all factors to be considered (ACI 408R-03 , 2003).

1.3.2.2 Mechanical anchors

Mechanical anchors are anchors (Fig. 1-5) Mechanical anchor That mechanically attach themselves in the base material, achieved holding values by friction and movement inside the mechanical anchor. These anchors are made up of many pieces that may move independently and cause expansion of the mechanical anchor. Also, it is extended and then inserted into the hole in the base material. This creates friction and holds power by applying pressure on the hole's wall. Mechanical anchors are designed to be inserted in the hole in the base material and remain in it.

Fig. 1- 5Mechanical anchor

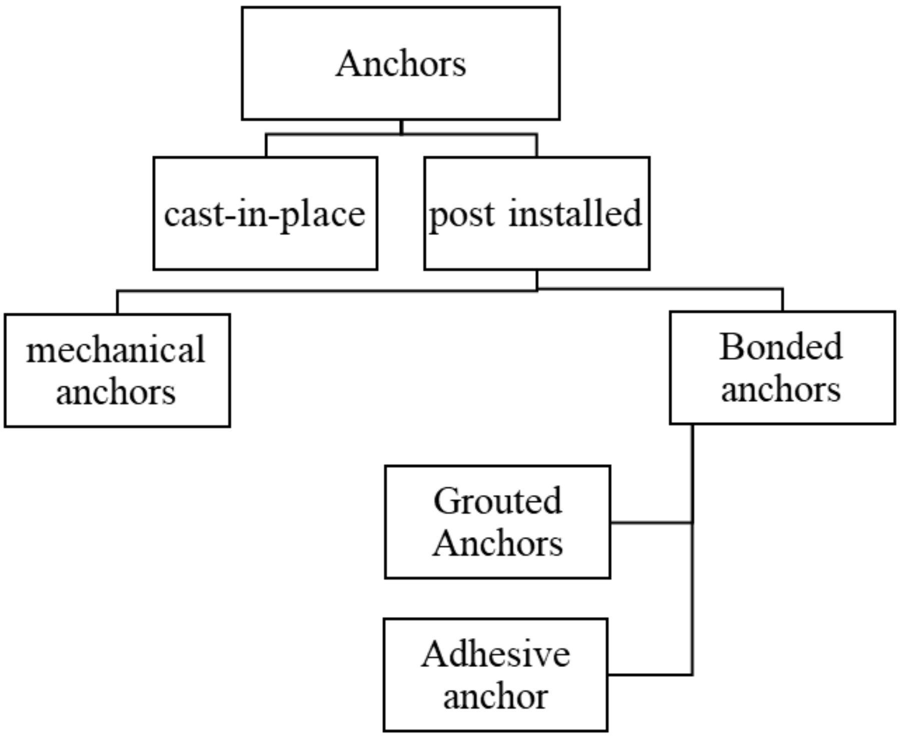


Fig. 1- 6 Classification of anchors

1.4 Failure Mechanisms

1.4.1 Post installed anchors

The Common failure conditions that occur in post-installed anchors are summarized as below:

A- Steel failure

When the strength of both the chemical adhesive and grouts and the concrete is high, and the tensile strength of the bond between the steel and the concrete is more than the tensile strength of steel, this kind of failure occurs (see Fig. 1-7. a).

B- Concrete cone Breakout

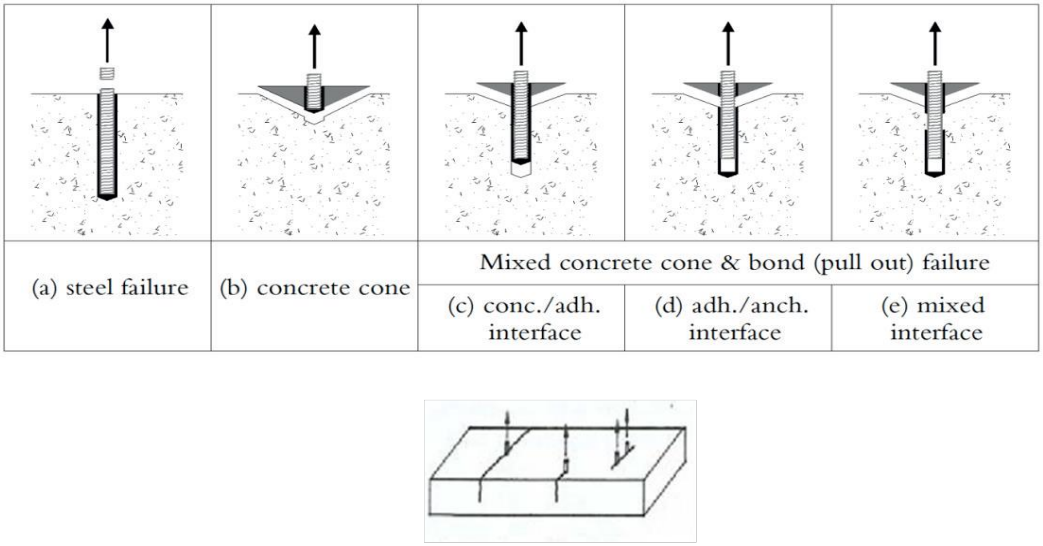
The anchoring causes the concrete to fail conically because the tensile stresses produced in the concrete higher than the concrete's tensile strength under axial tension load. As a result, complete conical failure occurs close to the concrete's surface in the shallowly installed anchor holes. Anchor strength declines as concrete strength declines, and the cone height rises (see Fig.1-7. b).

C- Pull-Through Failure or pullout

When the anchors are withdrawn from the concrete mass which it is inserted, this kind of collapse happens. As the adhesion stress of chemical anchors exceeds the adhesion strength, it begins to pull out from concrete. Low adhesion strength or uncontrolled situations during anchoring placement cause this type of failure. It might be due to the chemical's inability to achieve maximum adhesion strength (see Fig. 1-7 c,d,e).

D- Concrete Splitting

When the base component is shallow or the anchor samples are near to the edge sections, concrete splitting happens. When the applied tension force is increased, the capillary cracks extend to the edge, causing the concrete surface to split (see Fig. 1-7.f).



(f). Concrete Splitting

Fig. 1- 7 Mode of failures of adhesive anchors transferee tension loads (Cook et al., 1998)

1.5 Bond behavior (Cast-in-place anchors)

The anchors must transfer forces effectively and reliably to the concrete for the optimal design in the reinforced concrete, as shown in (Fig. 1-8), The loads are transferred from the anchors to the concrete around the anchors by:

1. Chemical bonding of the anchors to the concrete.
2. Frictional forces caused by roughness of the contact, forces transverse to the bar surface, and relative slippage between the concrete surrounding the anchors and the anchors themselves.
3. The mechanical anchoring or bearing of the ribs on the surface of the concrete.(ACI 403, 2003)

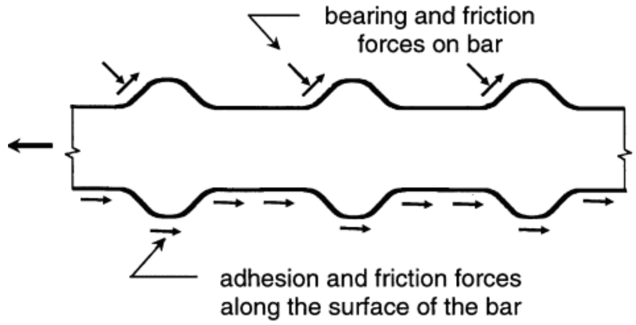


Fig. 1- 8 Mechanism for transferring bond force (ACI 408R-03)

Most of the loads are transferred either by bearing or friction after the initial slip of the anchors. However, deformations(ribs) between the concrete and the anchors contribute significant role in load transfer.

Anchors are also affected by friction, with slip-induced, friction occurring from transverse stresses at the surface of bars generated by slight changes in anchors shape.

Surface adhesion is reduced when a deformed anchor bar moves in relation to the surrounding concrete, while bearing forces on the ribs and friction forces on the ribs of the bar are generated.

The friction forces are increased by compressive bearing forces on the ribs. As slip increases, friction on the barrel of the reinforcing bar decreases, leaving forces at the contact faces between the ribs and the concrete around the bars as the primary force transmission mechanism (ACI403, 2003).

Compressive and shear stresses on the concrete contact surfaces equalize the pressures on the anchor's surface, resulting in tensile stresses that might cause cracking in planes perpendicular and parallel to the bars, as illustrated in Fig. 1-9.

The cracks were shown in Fig. 1-9 cause the formation of a conical failure surface for tensioned bars that project from concrete. otherwise, they have just a minor role in anchoring and reinforcement development.

Transverse cracks were formed, as presented in Fig. 1-9-b, when the cover of the concrete or the space between bars is too small, resulting in splitting cracks, as illustrated in Fig.1-9-c. If the concrete cover, the bar spacing, or transverse reinforcement are adequate to avoid or prevent a splitting failure, the system would fail by shearing along a surface at the top of the ribs around the bars, resulting in a pullout failure, as illustrated in Fig.1-9-d.

Cracked concrete in a location adjacent to the bearing surfaces of some of the deformations is frequent for both splitting and pullout failures. If the reinforcement is adequately anchored to the concrete, the stress in the anchors may reach yield point. Bond failures have been documented in tests at bar stresses up to the tensile strength of the steel.

Bond resistance is regulated by the following simple qualitative descriptions:

1. The concrete's mechanical properties (related to the tensile and bearing strength).
2. Quantity of the concrete surrounding the anchors (as determined by the concrete cover and bar spacing).
3. the presence of confinement in the form of transverse reinforcement, which can delay and control the growth of the cracks.
4. The anchors surface condition.
5. the bar's geometry (height of the deformation , spacing, breadth, and face angle)(Bond, 2003) .

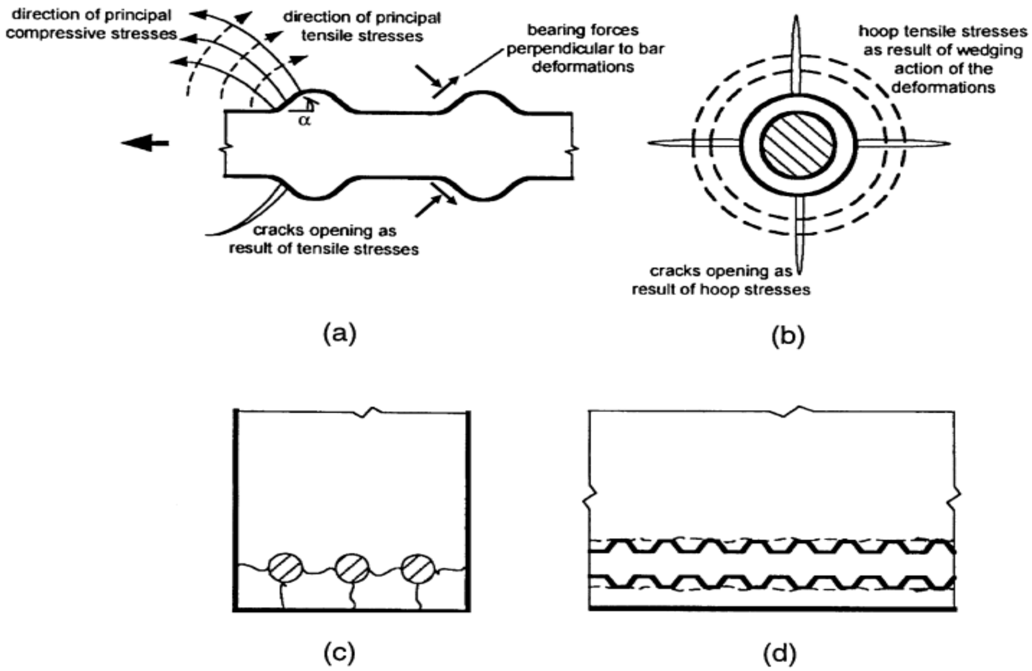


Fig. 1- 9 Cracking and damage mechanism in bonds (ACI 408R-03)

(a) Side view of the deformed bar with deformation face angle indicating development of the crack.

(b) A fracture is created in the side view of a deformed bar with deformation of the face angle.

(b) Splitting cracks in the end view extend parallel to the reinforcement.

(c) The member's end view, revealing splitting fractures between the reinforcement and through the concrete cover.

(d) Member side view exhibiting shear fracture and/or local concrete crushing due to the pullout of the reinforcement.

1.6 Loading of anchors

Loading of anchors involves a good comprehension of the physical processes that occur during the procedure of setting and loading in construction materials, particularly in the concrete (Li et al., 2005).

Anchors are subjected to loads in tension and shear, or a combination of tension and shear, via connection to the embedded anchor (Fig. 1-10). Anchors might bend as a result of shear transmission through connections. Pipelines, bridges, railway barriers, and machine foundations are all subject to dynamic loading. Anchorage systems may be affected by fatigue and seismic loads (Mazılıgüney, 2007)

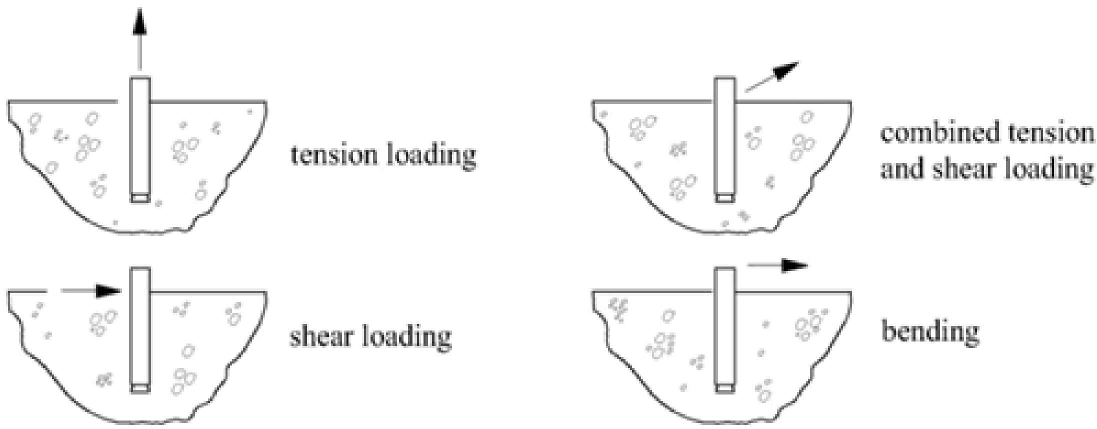


Fig. 1- 10 Possible loading types of anchors

1.7 Hypothesis

1. The relation between the pull-out capacity of chemical anchors and the embedment length is predicted to be not linear.
2. Drilled hole that filled with water, it reduces the capacity of adhesive and grouted anchors.
3. Higher capacity of chemical anchors can be achieved by cleaning the drilled hole with water.
4. The capacity of anchors decreases, when the drilled hole sizes increase a for the same diameter and embedded length.

1.8Aim of the research

The following points are of the research's aims:

1. Evaluate the performance of epoxy brands and grouts available at local Erbil markets in 2022.
2. Study the tendency of the increase in the pullout capacity of adhesive and grouted anchors with the increase in the embedment length.
3. Study of the effect of the cleaning method of post installed chemical and grout on the ultimate load capacity of anchors.
4. Study of the effect of drilled hole sizes (base material thickness) on the capacity of post installed anchors (adhesives and grouted).
5. Evaluate the capacity of the post installed anchors with the reference cast-in-place anchors.
6. Evaluate the effect of the saturation of the concrete on the ultimate load capacity.

1.9 Research Methodology:

The following tasks would be carried out in order to achieve the goals of this research:

1. Review past studies on post-installed anchors and the techniques that were used.

2. Conducting an experimental study in the following steps:

- Construction a concrete slab without reinforcing steel bars and nine anchors cast-in-place with 3 different diameters (10mm,12mm and 16mm) with a (5db,10db and 15db) for each steel bar diameter.

- Installing the anchors by using the adhesives and grouts.

- Perform a pullout test for each anchor.

3. Compare the samples of post-installed rebar to the control samples.

1.10 Layout of thesis

The research is divided to the following chapters:

- Chapter one (Introduction): This chapter contains an overview on the cast-in-place and post-installed anchors. Additionally, it provides an explanation of the significance, objectives, and methods of the research and the layout of the thesis.
- Chapter two (Literature review): This chapter reviews previous researches on the anchors and the factors that effect on the ultimate load capacity.
- Chapter three (Experimental work): Explains the procedures used to achieve the goals of the experimental results of the research.
- Chapter four (Results and discussion): In this chapter, the conducted tests are presented, discussed and compared with the previous findings
- Chapter five (Conclusion and recommendations): The main conclusions and recommendations from the research are presented in this chapter.

CHAPTER TWO

LITRATURE REVIEW

2.1Introduction

The anchors ultimate load capacity is influenced by a variety of factors. This chapter review the post-installed rebar anchors in past studies, as well as the parameters that influence the post-installed rebar connections.

2.2Anchor Performance Affecting factors:

The performance and behavior of bonded anchors are influenced by a variety of parameters (Cook, 1993,Eligehausen et al., 2006 ,Cook and Konz, 2001 ,Yilmaz et al., 2013 and El Menoufy and Soudki, 2014).

They are classified into four primary categories:

1. Installation considerations include hole orientation, drilling machine type, moisture content in the hole, installation temperature, embedment length, and diameter of anchor.
2. Service factors include temperature change throughout the period of the life of the structure, exposure to severe temperatures, moisture conditions, freeze-thaw cycles, and exposure to physical and chemical hazards.
3. Adhesive properties include the kind of adhesive material used, how it was inserted, and the adhesive's initial and ultimate strengths.
4. The qualities of concrete are influenced by a number of variables, including its strength, age, kind, percentage of humidity, and cracking.

The following sections the literature review of the parameters affecting the ultimate load capacity of the anchors:

2.2.1 Anchor diameter:

The anchor diameter has influence on the pull-out load, For the larger diameter bars, The bond strength or pull-out load have larger anchor contact surface area with the grout or adhesive (Tayeh et al., 2019, Müsevitoğlu et al., 2020, Haidar et al., 2020 , Zeyad and Shihada, n.d. and Ajamu et al., 2020) .

However, González et al., 2018 stated that the anchor diameter had little effect on ultimate capacity of anchors, but it has a considerable impact on displacement during service loads.

Mazılıgüney, 2007 indicated that for chemically bonded post-installed anchors in low-strength reinforced concretes, anchor diameters are the most significant parameter for tensile behavior.

In grouted anchors, the larger diameters have a larger surface area at the steel/grout interface, and need more loads per unit length of the anchors to perform that failure mode, but also it requires more force to create a steel-only failure. The failure mode experienced at the steel/grout interface bond failure can be changed from grout/steel interface bond to grout/concrete interface bond by increasing the anchor diameter without changing the hole diameter. This increases the force that require to cause failure at grout/concrete interface (Zamora et al., 2003).

2.2.2 Concrete Strength

When the ultimate capacity of the anchors is determined by concrete parameters, the tensile characteristics of the concrete has an influence on the failure modes of the anchors. Although the tensile and compressive strength of concrete related to each other but the impact of grain size, type, and particle distribution in aggregates can affect the tensile and compressive strength relationship**.** The anchors ultimate capacity also varies with the slump, the height of the concrete drop, and the degree of vibration during placing all influence on the concrete segregation (Mazılıgüney, 2007).

(González et al., 2018) compared the effect of common vibrated concrete with self-compacting concrete on the strength of post-installed bonded anchors. They found that the compressive strength of the self-compact concrete block was higher than the compressive strength of the conventional concrete block. The anchors capacity was better for the anchors installed with adhesive in conventional concrete than anchors installed in self-compacting concrete. This is due to the conventional concrete's have greater aggregate content percentage, which results in a wider bonding surface between the filler material and aggregate.

Cook et al., 1998 found that for the majority of products for concrete mixes with compressive strengths ranging from 20 MPa to 60 MPa, the effect of concrete strength on the ultimate capacity of adhesive anchors is low.

The bond strength of the cast-in-place and post-installed rebars has been demonstrated by (Eligehausen et al., 2001) based on the compressive strength of the concrete (Fig. 2-1). They observed that whereas the bond strength of post-installed anchors rose when the compressive strength increased from 20 MPa to 40MPa, the bond strength of cast-in-place anchors also increased as the compressive strength of concrete increased.

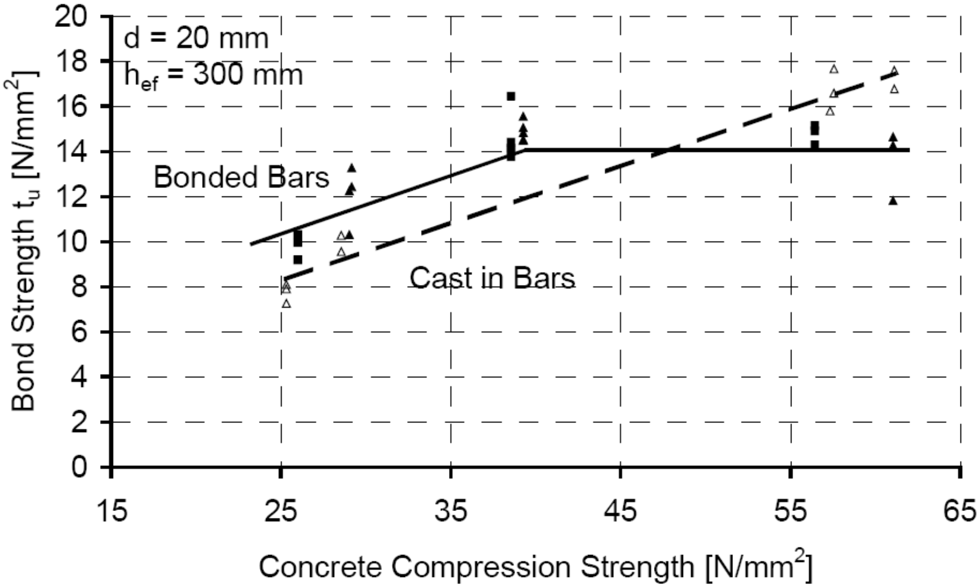


Fig. 2- 1 Influence of concrete compressive strength (Eligehausen et al., 2001)

(Yilmaz et al., 2013) investigated the load-deflection behavior of the adhesive and grouted anchors installed in the concrete with normal compressive strength (30 MPa) and high compressive strength (60 MPa), concluding that the capacity of anchors improved with the increase in the concrete compressive strength, however, this increase was not uniform across the different types of anchors with variable embedment lengths. The concrete compressive strength seemed to be more efficient at shallow embedment depths since cone breakout of the concrete was the main failure mode for shallow anchors.

2.2.3 Strength of the steel

The type of the steel used in anchoring is mostly determined by the anchorage's purpose that require in joining old and new concrete sections. Threaded rebars are the most often utilized steel type for chemically bonded post-installed anchors. (McVay et al., 1996 and Cook, 1993)

The tensile strength of the anchors must be lower than the strength of the embedded portion of the steel to accomplish steel failure mode. When tensile failure of the steel is the desired failure mode, as the steel tensile strength rises, the ultimate strength also increased. Threaded rebars have higher bond strengths than unthreaded rebars, particularly where bond failure is the approved required failure type. Threaded rebars (or ribbed bars) considerably increase the bond performance under earthquake circumstances, according to (Çolak, 2001)**.**

The nominal tensile capacity of the anchor can be computed as the product of the anchor's appropriate cross sectional area times the anchor's minimum yield strength According to (Klingner and Mendonca, 1982)**.**

2.2.4 Embedment depth

The anchors transfer the applied loads to the surrounding concrete via the overall depth with in the concrete which is known as effective embedment depth. The effective embedment depth in tension applications is typically equal to the depth of the concrete failure surface. Cast-in-place of headed anchor bolts and studs are used to achieve an efficient embedment depth which measured from the bearing contact surface of the head (Mazılıgüney, 2007).

According to (Unterweger and Bergmeister, 1998), the effective embedment depth of chemically bonded anchors is about ten times greater than the diameter of the threaded rod or reinforcing bar.

(Gesoglu et al., 2005) indicated that the anchor's pullout capability was found to be most critically affected by the embedment depth. The capacity of anchors rose practically linearly with the embedment depth when the characteristics of the anchor and the concrete remained unaltered.

The ultimate capacity of anchors increases non linearly as the embedment length of anchors increases, according to (Çolak, 2001).Another notable feature had been noted for bonded lengths over 75 mm, where the tension capacity begins to vary from linearity. For longer bonded lengths, the linear bond stress distribution is incorrect.

In grouted anchors, a deeper embedment depth should increase the capacity of grouted anchors that experienced by grout/concrete and grout/steel interface bond failures according to uniform bond stress models(Conard, 1969).

2.2.5 Edge Distance

The failure cone of the anchor will intersect with the edge if it is installed or placed close enough to the concrete edge, which will lower the failure load. The failure mode will be the edge cone failure. As a result, the edge distance of the anchor should be enough to avoid the edge cone from failing.

2.2.6 Anchor Spacing

If the anchors of an anchor group are installed too close to another one, the failure cones of the individual anchors will overlap and result in a combined failure cone. For full anchor capacity, when the acceptable failure mode is concrete cone failure, an overlapping of the failure cones might be occurred when the actual spacing is smaller than the critical spacing (Gesoğlu, 1995)

Anchor spacing is less important when the failure mechanism is bond failure or combined cone-bond failure, hence lower anchor spacing can be used.

2.2.7 Cleaning methods:

Drilling dust might have an influence on the bond strength on chemical and grouted anchors. This parameter evaluated with ACI 355.4 (2011) standards, which referred for applying 50% of the manufacturer's suggested cleaning effort. All cleaning techniques, such as brushing and blowing, were covered by this clarification, but only 50% of the effort is required.

If the manufacturer specified six blowing and brushing operations, three blowing and brushing activities are used to assess hole cleaning sensitivity.

Long-term performance was not observed to be affected by hole cleaning more than short-term performance. In short-term testing, 50% clean holes only provided 81 % of the capacity of 100% cleaned holes (Cook et al., 2013).

(Luke, 1984,Cook et al., 1998) reported that cleaning the drilled holes via wire brush tends to polish drilled surface that reduce the capability of adhesive to create a mechanical interlock with the sides of the hole.

(Müsevitoğlu et al., 2020)found that when the drilled holes that cleaned by washing with brushes had an ultimate capacity more than previous cleaning methods because it removes the dust that produced during the drilling process that makes a creation better bond between adhesive and concrete.

Cementitious and polymer grouted anchors bonding strength affected by hole cleaning. There is a lack of research on the influence of hole cleaning on grouted anchors(Zamora et al., 2003) .

2.2.8 Hole orientation

The majority of adhesives tend to fall downward, making it difficult to fill upward holes with adhesives. Horizontal holes are less sensitive, although they can still develop gaps between the adhesive and the concrete or anchors. These voids decrease anchor ultimate load capacity greatly. This is an important characteristic that ACI 355.4 (2011) requires ACI certified employees to install adhesive anchors in horizontal to upward applications.

(Cook et al., 2013) investigated this parameter and found that horizontal installation had a 0.93 influence ratio (which is equal to the long-term performance by comparing a baseline creep test and a creep test subjected to a specific parameter) while vertical installation had a 0.86 influence ratio.

Qualification tests for adhesive anchors should to be utilized between horizonal and vertical constructions are also included in ACI 355.4 (2011). This parameter should not influence anchor performance if the item passes this test and is installed by an experienced technician.

According to (Cook and Burtz, 2003) cementitious grouts are particularly challenging to place overhead Because of the sag of the grout material. Cementitious and polymer grouted anchors should not be utilized in overhead applications.

2.2.9 Drilled hole size:

The drilled hole size refers to the distance between the drill bit and the anchor diameter.

(Cook et al., 2013) cited two studies on chemical anchors with contradictory findings. In research with testing adhesive anchors with the 1.2db to 1.8db hole diameter range, it was shown that thinner adhesive bond line thickness increased creep resistance, but additional tests in the larger 1.2db to 4.1db hole diameter range showed that bond lines had no effect on resistance.

(Müsevitoğlu et al., 2020) studied the effect of the thickness of adhesive material for the anchor diameter 16 mm and 20 mm for the embedded length 5db,10db and 15db with a drilled hole size (+4mm, +6mm and +8mm) . They found that the increase in the drilled hole size did not significantly improve the anchoring capacity.

(Gesoglu et al., 2005) studied this parameter effect on the ultimate load capacity for the embedded length equal of 250mm with anchor diameter 20mm. The drilled hole prepared with three different sizes (24mm, 28mm and 32mm). They found that the drill diameter had no effect on the results.

(Haidar et al., 2020) tested the adhesive capacity for anchor diameter12mm and 16mm with drilled hole size (14mm,16mm) and (18mm,20mm), respectively, for the embedment length equal to 100mm and 150mm, they found that this parameter which has a slight effect on the pull-out capacity, where the average ultimate capacity increased recorded for the two types of epoxies was 6 %.

Bond line thickness has an impact on both headed and non-headed grouted anchors when it fails by concrete interface failure modes (Zamora et al., 2003).

Increased bond line thickness may also lead to grout failure. Same with adhesives, the bond line thickness may have an impact on the creep resistance of grouted anchors(Cook et al., 2013).

As the anchor diameter is increased without changing the hole diameter, the failure mode shifts from the grout-steel interface bond to the grout-concrete interface bond(Zamora et al., 2003).

2.2.10 Moisture at installation stage:

Cook and Konz (2001) found that the dampness of the hole had a substantial impact on bond strength in two ways:

1. Moisture can obstruct the chemical reaction between the hardener and the resin, preventing adhesives from penetrating the concrete pores and reducing mechanical interlock.
2. The moisture has the potential to construct a physical barrier between the adhesives and the concrete, it is affecting the adhesive's chemical interaction.

(Cook et al., 2013) stated that moist holes only have 82 % of the capacity of dry holes. The samples subjected to water by making three inches of water on top of the concrete for eight days.

In moist holes, cementitious grouted anchors are commonly installed, whereas polymer grouted anchors are installed in dry holes. Moisture has been shown to have a negative impact on polymer grouted anchors capacity (Cook and Burtz, 2003).

Cementitious grouted anchors should be installed with moist holes to permit for optimal cement hydration during curing. Since dry hardened concrete draws moisture away and does not allow for full hydration of the grout, installing cementitious grouted anchors in a dry hole might result in decreased bond strength. Installing cementitious grouted anchors in a damp hole might increase the water/cement ratio and decrease the grout's strength (Cook et al., 1998).

(Blanchette, 2012) stated that there was a reduction in the ultimate load capacity when anchor is installed into wet saturated concrete because it is related to dry cleaning methods or wet cleaning methods. Cleaning of the dry drilled hole is requiring less effort than cleaning wet drilled hole because some dusts remain at drilled hole that produced during drilling process in a wet saturated concrete.

2.2.11 Hole drilling methods

Various drill bits produce different results concrete surface roughness. Compare to a core drill bit with a diamond tip, a carbide-tipped drill bit leaves a rougher surface and increases the capacity of the anchors. (Cook et al., 2013) investigated this parameter and found that the chemical anchor capacity of the hammer-drilled holes (Fig. 2-2) was 73% more than that of the diamond core drilled holes.

A) Diamond drill bit B) Carbide drill bit

Fig. 2- 2 Drill bits types

Cementitious grouts transfer loads through mechanical interlock and friction from the anchors to the base concrete (Zamora et al., 2003)**.** (Cook and Burtz, 2003) found that there was a slight (3%) increase in hammer drilled hole capacity compared to diamond core drilled holes for one test series, but there is a reduction in hammer drilled hole capacity (17%) compared to core drilled holes for another test series.

2.3 Uniform Bond Stress

In adhesive anchor systems, the primary mechanism for transmitting load seems to be a uniform bond stress model (Fig-2.3). This bond stress model is appropriate for adhesive anchor systems with holes that are no larger than 1.5 times the anchor diameters and an embedding ratio no greater than 20db (Cook et al., 1998).

But, According to (Cook et al., 1998), For embedment depths, it is possible to assume a constant bond stress over the depth and a bond strength that is independent of the depth between 4.5db to 25db . According to (LANG, 1979) Bond stress declines for embedment depths more than 9db .

$$N = \tau * \pi * d * h_{eff} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 2.1$$

N = bond pullout capacity of one anchor in tension for uncracked concrete

τ = controlling a uniform bond stress between the concrete and adhesive or the steel anchor and adhesive

d = anchor diameter

h_{eff} = effective depth of the anchors

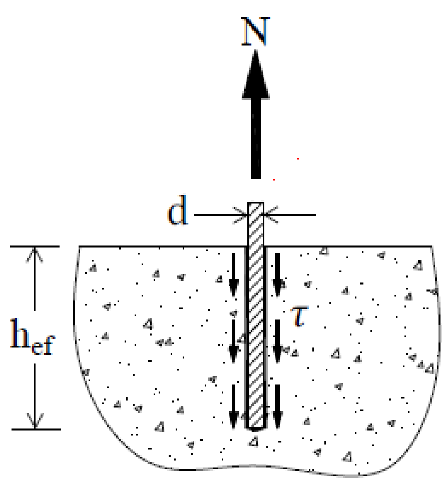


Fig. 2- 3 Uniform Bond Stress Model

(Müsevitoğlu et al., 2020) analyzed the behavior of chemical anchors in concrete when subjected to a tensile force for anchor diameter equal to 16mm and 20mm for the embedment length equal to 5db,10db and 15db for two different concrete compressive strength (Fig-2.4). In normal concrete compressive strength, it has been noted that average bond stress decreased where embedded length increased from 10db to 15db for anchor diameter 20mm but there was a slight increase for anchor diameter 16mm where the embedded length increased from 10db to 15db.

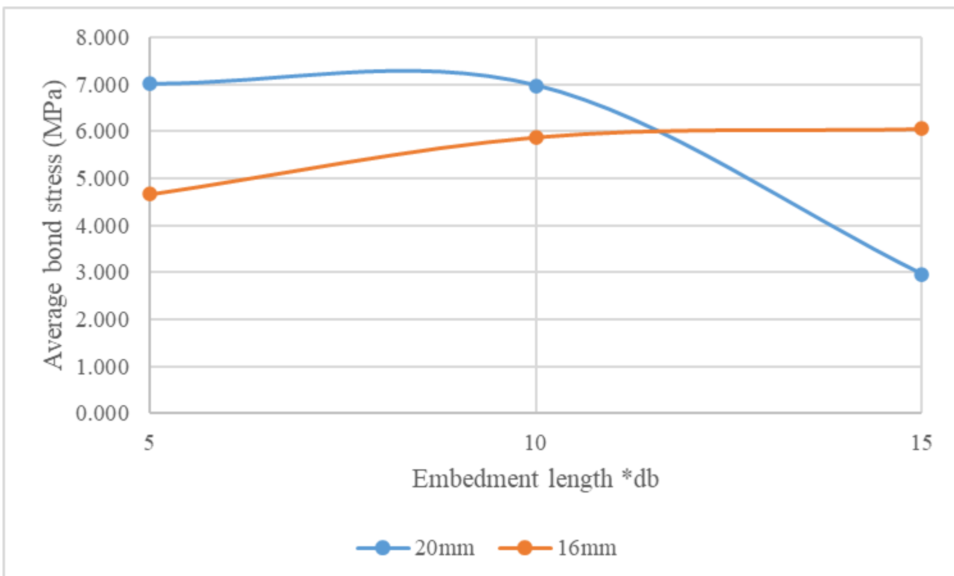
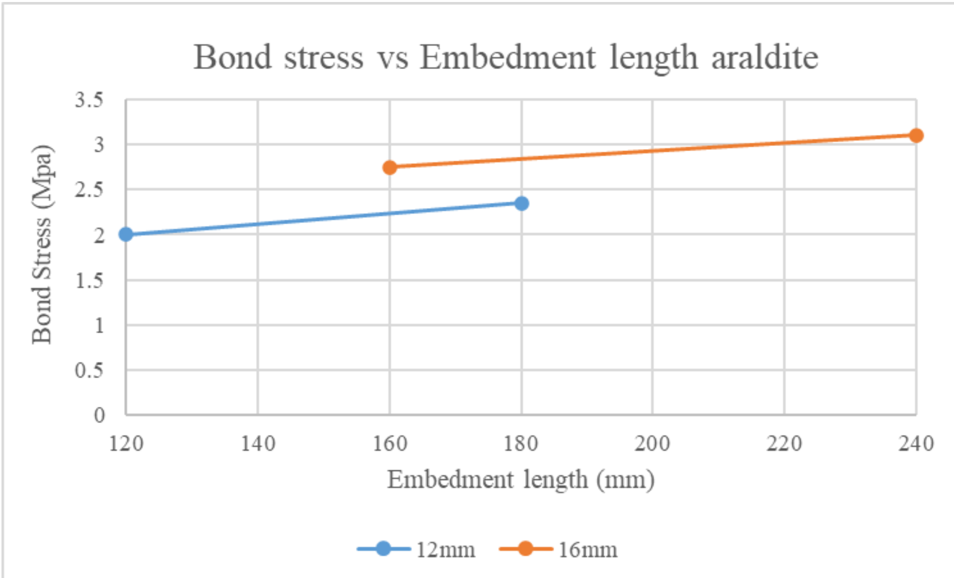


Fig. 2- 4 Relationship between the average bond stress and embedment depth for adhesive anchors (Müsevitoğlu et al., 2020)

However, (Ajamu et al., 2020) stated that the increase in the embedment depth leads to an increase in the average bond stress for some brands (Fig.2-5) .They tested (12mm and 16mm) the anchor diameter for three epoxy brands (Araldite, 4minutes and Hilti) with the embedment length equal to (10db and 15db), they found that the average bond stress increased for Araldite epoxy brand when embedment length increased from 10db to 15db for 12mm anchor diameter.

Cementitious and polymer grouted anchors bonding strength could be affected by hole cleaning. There is a lack of research on the impact of hole cleaning on grouted anchors(Zamora et al., 2003) .



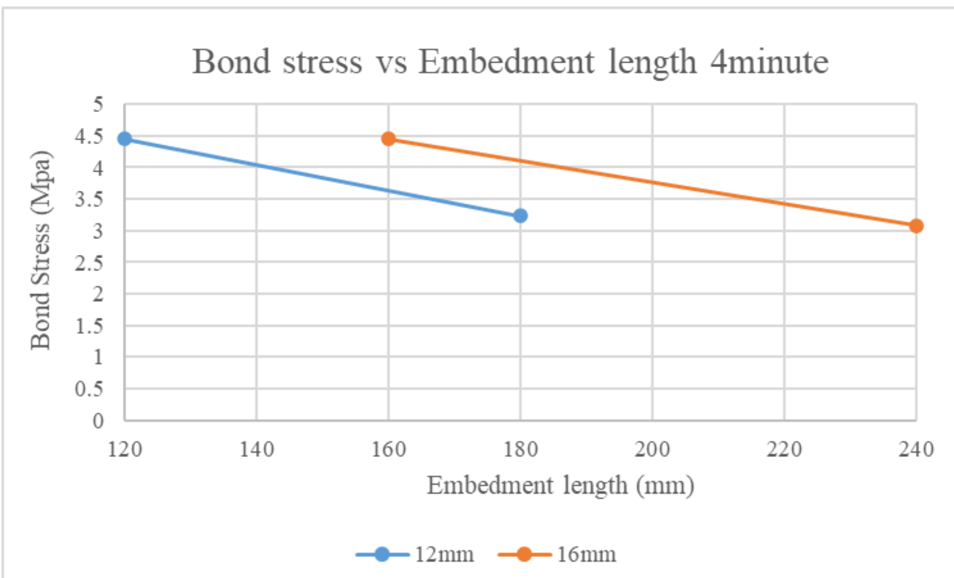
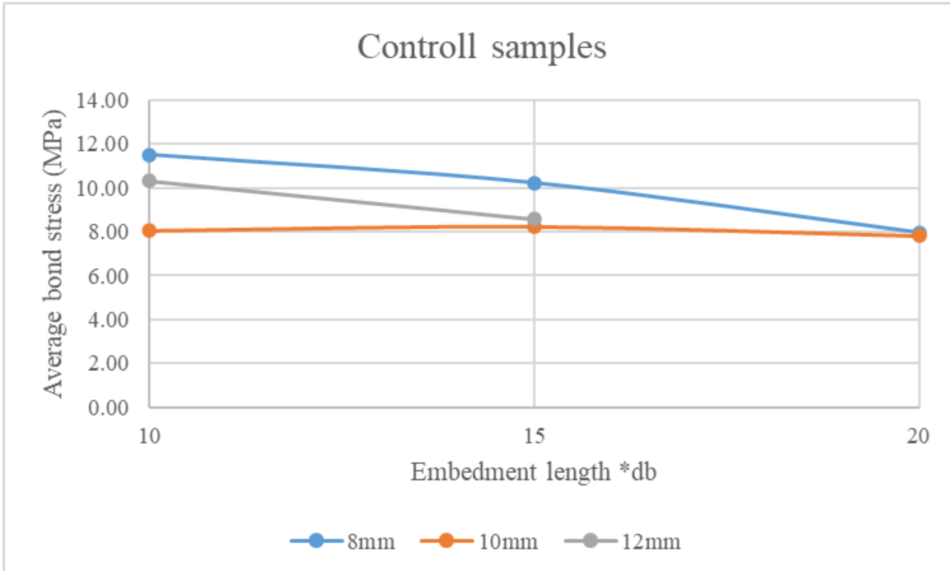
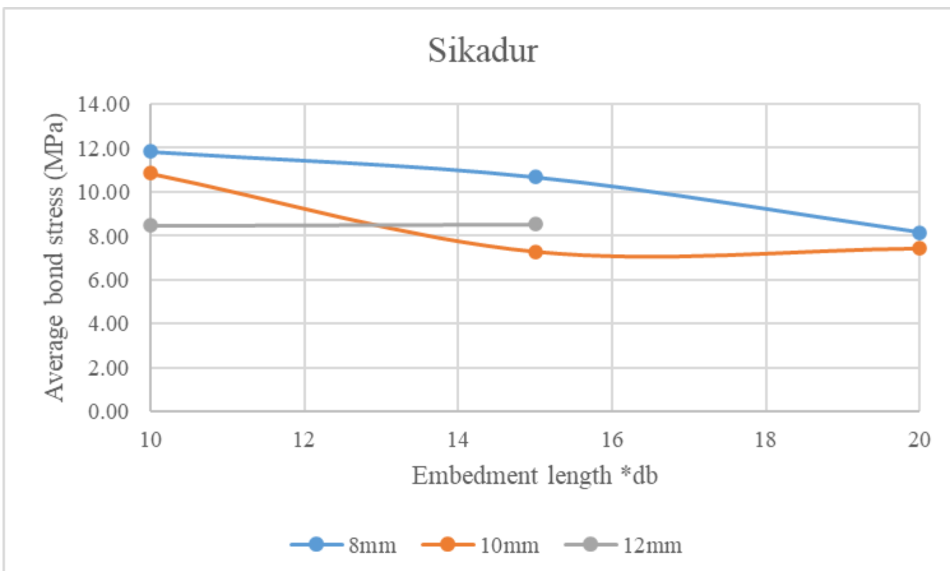
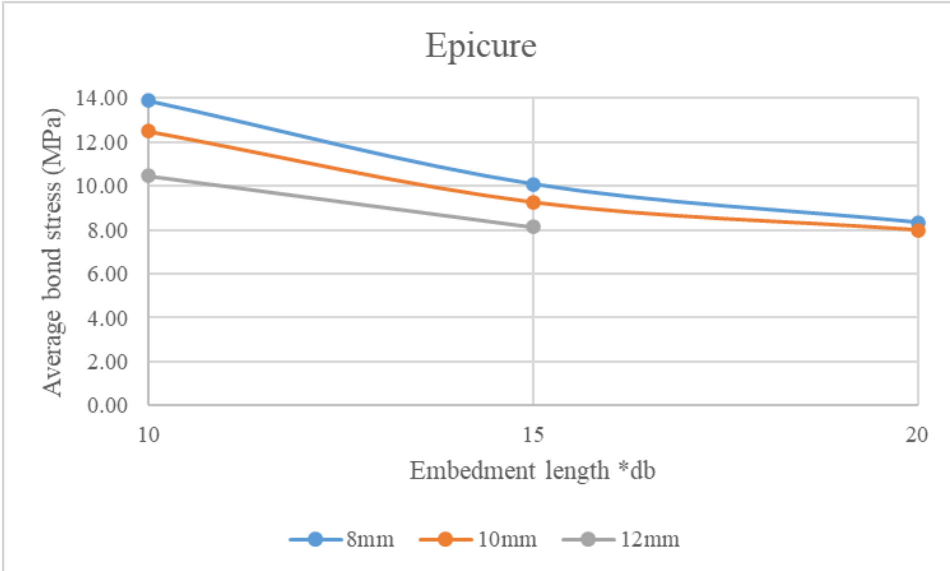


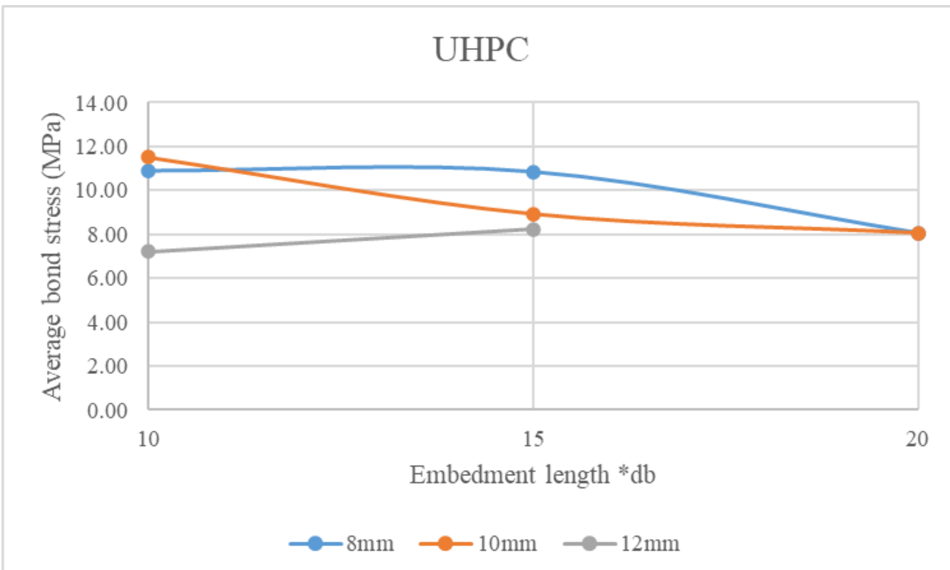
Fig. 2- 5 Relationship between average bond stress and embedment depth with different brands of adhesives (Ajamu et al., 2020)

(Zeyad and Shihada ,2014) investigated the efficiency of various kinds of adhesives used in post-installation rebar connections as a bonding agent between anchors and the concrete as shown in (Fig. 2-6). They tested anchor diameter of 8mm, 10mm, and12 mm were used. While the embedding lengths for 8 mm and 10 mm diameter bars were equal to 10db, 15db, and 20db, and 10db and 15db for 12 mm bars. They found that average bond stress decreased where the embedded length increased from 10db to 15db for the used adhesive brands, control samples, mortars.


Controll samples
Average bond stress (MPa)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
10
15
20
Embedment length *db
8mm
10mm
12mm


Sikadur
Average bond stress (MPa)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
10
12
14
16
18
20
Embedment length *db
8mm
10mm
12mm


Epicure
Average bond stress (MPa)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
10
15
20
Embedment length *db
8mm
10mm
12mm


UHPC
Average bond stress (MPa)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
10
15
20
Embedment length *db
8mm
10mm
12mm

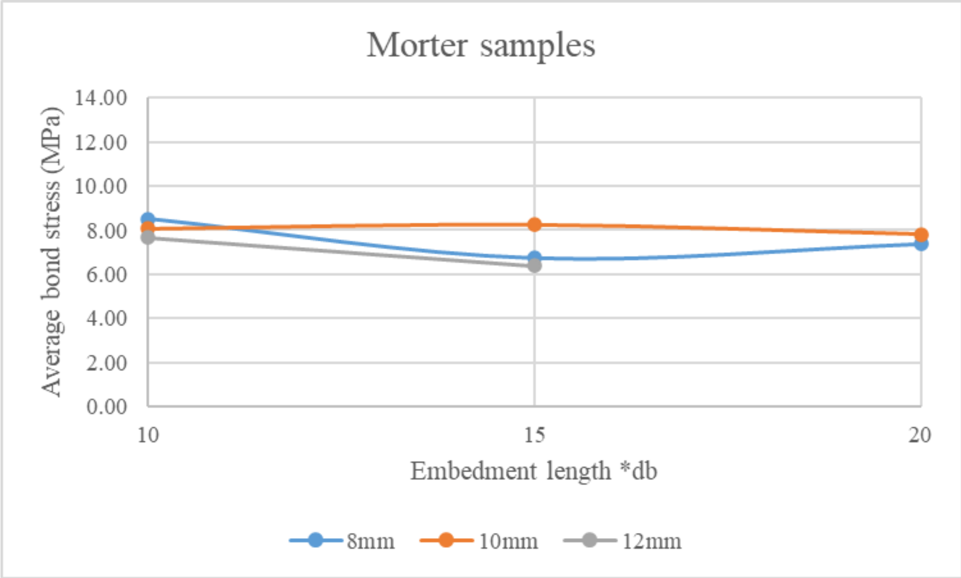


Fig. 2- 6 Relationship between average bond stress and embedment depth with different brands of adhesives (Zeyad and Shihada, 2014.)

2.4 Problem statement

With the available resources, no researches have been found that deals with the comparison of the adhesive brands and grouted anchors ultimate bond capacity that available at Erbil's local market in 2022. There was no clear trend about the effect of the drilled hole size on the ultimate bond capacity of post-installed anchors with the available resources. Also, there was different point of view on the effect of water-saturation on the concrete during post-installed anchors installations.

The following variable have been tested:

1- Different bonding agent brands (HIT-RE10, ROX.GU80, DUBELL.F1331 and FLO.Grout11)

2- Different drill hole size (db+4mm, db+8mm and db+12mm) for adhesive anchor and grouted anchors with a diameter of 10mm,12mm and 16mm.

3- Different cleaning methods were tested for adhesive anchor and grouted anchors with a diameter of 10mm,12mm and 16mm.
4- Anchors installed into dry concrete and fully saturated concrete have tested for anchor diameter 10mm,12mm and 16mm for Adhesive anchor and grouted anchors.
5- Also, there are different point of view about the relation of the uniform bond stress and the embedment depth.
6- Hole cleaning may have an effect on the bonding strength of cementitious and polymer grouted anchors. There has been lack of research investigating the effect of hole cleaning on grouted anchors (Zamora et al., 2003) .
7- There was a different idea about the effect of installation of the anchors in saturated concrete.

2.6 Summary

The following points have been summarized:

1. The ultimate load capacity rose as anchor diameter of post-installed anchors (adhesive and grouted) increased.
2. The ultimate load capacity of post installed anchors (adhesive and grouted) increases when the compressive strength increase.
3. Increase of the tensile strength of steel leads to increase ultimate load capacity of post installed anchors.
4. Anchors ultimate load capacity of post installed anchors (adhesive and grouted) increase where the embedment length increased.
5. Drilling operation and cleaning method has a significant effect on the ultimate load capacity of post installed anchors (adhesive and grouted).

6. There was no clear trend about the influence of the drilled hole size effect on the ultimate bond strength of post installed anchors.
7. The ultimate capacity of grouted anchors decreases when it is installed in fully saturated concrete.

CHAPTER THREE

EXPERMENTAL PROGRAM

3.1 Introduction

This chapter explains experimental program as well as the materials that used in this research study, such as concrete, anchor bars and various adhesives and grouts.

The program involved casting a concrete slab (Fig. 3-1) with a thickness 0.33m and a plan dimension equal to (4.5m*6m). Nine anchors were installed during casting of the concrete slab with various embedment length depth (5db,10db and 15db) for each anchor diameter 10mm,12mm and 16mm.

After 28 days, (126) anchor holes were drilled, and anchors with diameters of 10mm, 12mm, and 16mm will be installed into the hardened concrete using various adhesives and grouts.

In this chapter, details of the site's situations and the experiment's methodology are presented.

3.2 Sample description

The experimental program involved casting a concrete slab with 330mm thickness as shown in (Fig. 3-1) (thickness is larger than maximum embedded length 15db(240mm) plus two times the larger anchor diameter used 2db (32mm) according to ACI 355.4M-11 with a plan dimension equal to (4.5m*6m). Nine 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, (126) anchor holes were drilled, and steel reinforcement bars with diameters of 10mm, 12mm, and 16mm have been installed into the concrete holes using various adhesives.

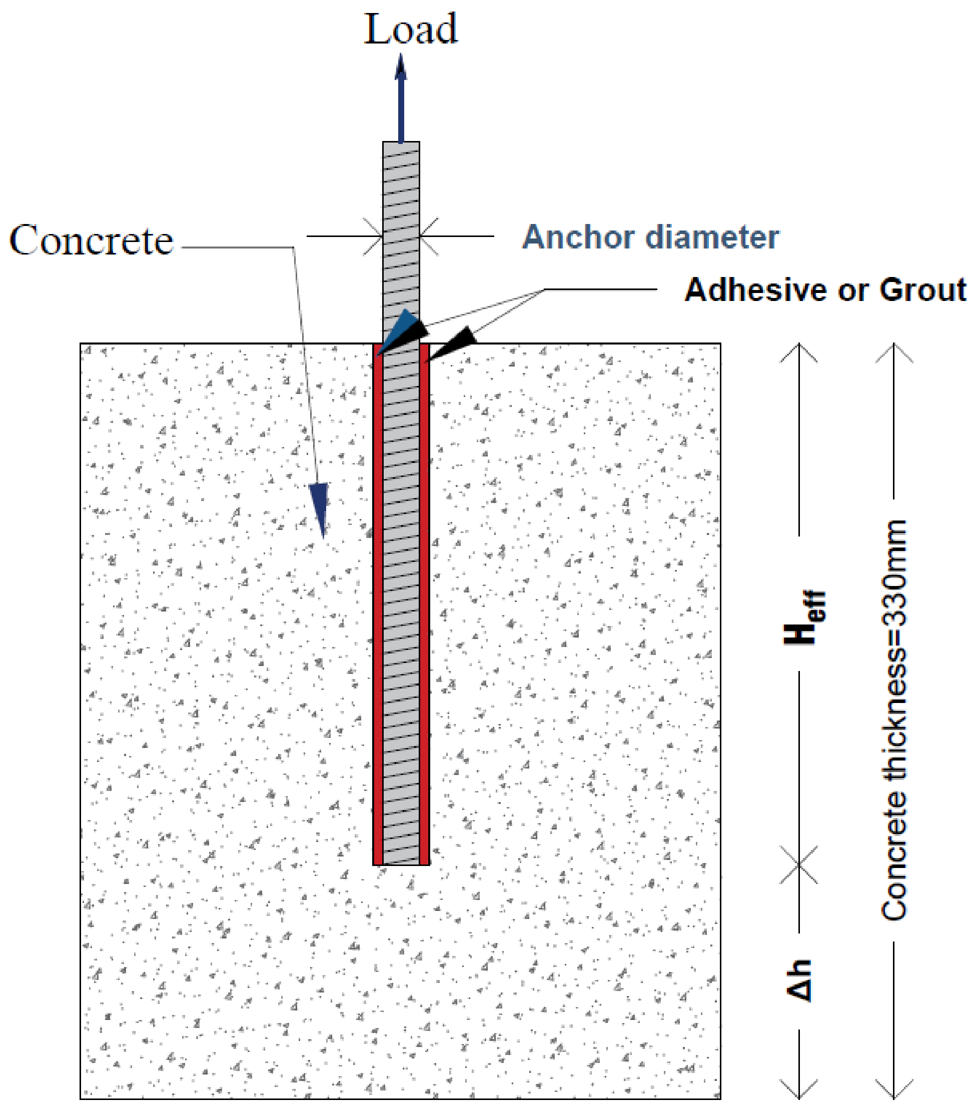


Fig. 3- 1 Details of the adhesive/grouted anchor

3.3 Materials

It is crucial to know the characteristics of all materials used in this research, such as concrete, cement, steel reinforcement, and adhesives.

3.3.1 Cement

Mass Ordinary Portland Cement was used for production Concrete Mix from GOGCA company. The physical and chemical properties of cement are tested as shown in Table (3-1) and verified according to the specifications of (ASTM - C150).

Table 3- 1 Physical properties of cement

Physical tests	Results	Limitations
Initial setting time	120 min	At least should be more than 45 min
Final setting time	6.25 hour	Not more than 10 hours
Compressive strength (at 3 days)	22.68MPa	Should be more than 15MPa
Compressive strength (at 7 days)	32.25MPa	Should be more than 23 MPa
Specific gravity	3.15	
Density(kg/m^3)	1400	

3.3.2 Fine aggregate

The fine aggregate (natural sand) used in the present study from the Aski-Kalak location. The bulk specific gravity equal to 2.56 Kg/m^3 and bulk density of 1675 Kg/m^3, also the fineness modulus of fine aggregate equal to 2.78 and maximum grading curve is showed in (Fig.3-2). the limits of the (ASTM - C33) standard also presented.

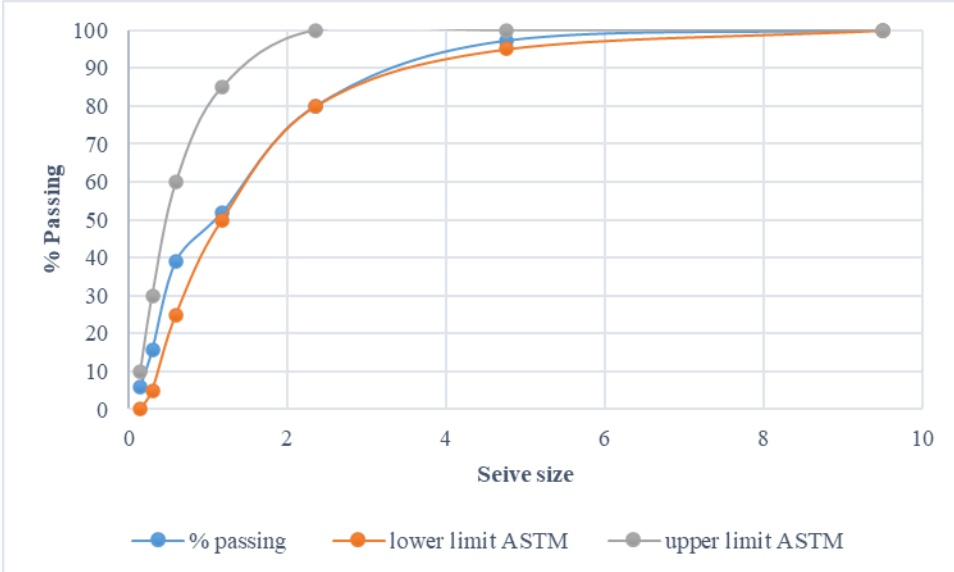


Fig. 3- 2 Grading curve of fine aggregate with ASTM limitations

3.3.3 Coarse aggregate

Crushed aggregate used in the present study with a specific gravity and bulk density equal to 2.678, 1615 kg/m^3, respectively, and the gradation of the aggregate is detailed in (Fig. 3-3).

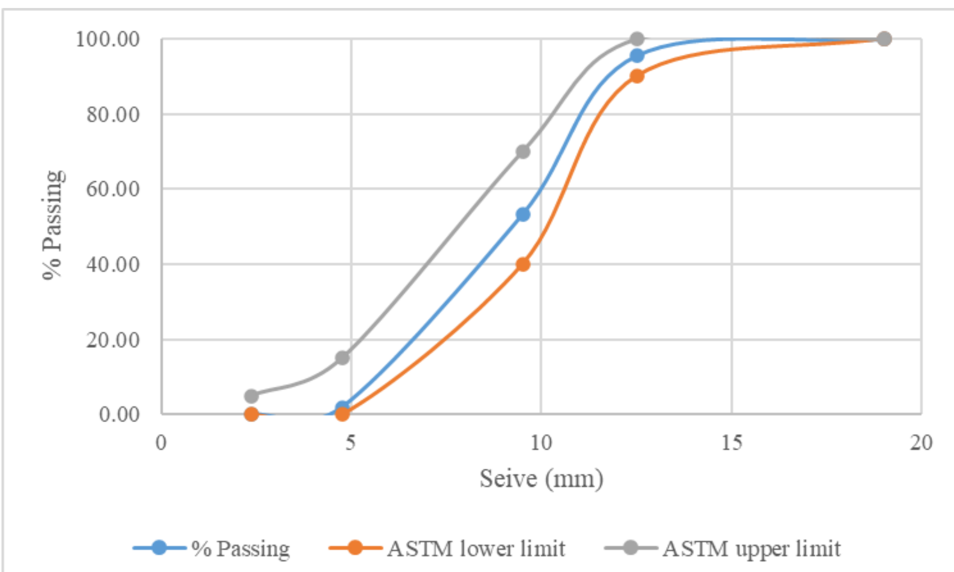


Fig. 3- 3 Grading curve of the coarse aggregate with ASTM limits

3.3.4 Water

Tap water was used in the production of concrete mix, as well as the curing of the concrete and cubes in addition to the drilled holes were cleaned using tap water.

3.3.5 Adhesives

Three different epoxy brands (*HIT-RE10, ROX GU80, and DUBELL.F1331*) shown in (Fig.3-4) and one non-shrinkage grout (*FLO-GROUT2*) in (Fig. 3-5) used in the current research; these brands were locally used in Erbil city on 2022.

Fig. 3- 4 Adhesive brands

Fig. 3- 5 Flo-grout 2

Table 3- 2 Technical data of Flo-grout2 from DCP company (As reported by the manufacture)

Compressive strength (ASTM C109)	>25MPa at 1day >50MPa at 7 days >60MPa at 28 days
Flexural strength (ASTM C348)	>2MPa at 1 day >8.5MPa at 7 day >9.5 MPa at 28 days
Color	Grey and white
Expansion characteristics (ASTM C827)	Up to 3%
Bleeding (ASTM C940)	Nil
Application temperature	4 to 50
Initial setting time at 25^o C (ASTM C191)	8hr
Final setting time at 25^o C (ASTM C191)	12hr
Service temperature	-20 to 200^o C

Table 3- 3 Reaction time according to the level of temperature for ROX-GU80 Adhesive brand

Temperature (C°)	Time
+5 to +10	12 min to 120 min
+10 to +20	6 min. 80 min
+20 to +25	4 min to 40 min
+25 to +30	3 min. 30 min
+30 to +35	2 min. 20 min
+35 to +40	1.5 min. 15 min
+40 over	1.5 min. 10 min

Table 3- 4 Material properties of HIT-RE 10 adhesive

Bond Strength ASTM C882 2-day cure 14-day cure	 21.2 MPa 23.1 MPa
Compressive Strength ASTM D6951	88.1 MPa
Tensile Strength 7-day ADTM D638	53.2 MPa
Elongation at break ASTM D638	1.30%
Heat Deflection Temperature ASTM D648	58°C
Absorption ASTM D570	0.06%
Linear Coefficient of Shrinkage on Cure ASTM D2566	0.0007

Table 3- 5 Typical properties of cured adhesive DUBELL.F1331 brand

Service temperature	-40°C - +80°C
Compressive strength (EN 12190)	Class R2 82 MPa
Chloride ion content (EN 1015-17)	0.0056%
Glass transition temperature (Tg) (EN 12614)	74°C
Reaction to fire (EN 13501-1)	Euro class E

3.3.6 Reinforcement steel bars

Deformed steel bars with a diameter of 16mm,12mm and 10mm made by Mass factory in Sulaymaniyah used as anchors in the current study. The tensile strength of reinforcements was evaluated by hydraulic machine as shown in (Fig. 3-6) with a capacity (600 kN), The qualities of these bars are shown in the Table (3-6).

Fig. 3- 6 Hydraulic machine for tensile test

Table 3- 6 Reinforcement properties

Anchor diameter (mm)	Actual diameter (mm)	Average Elongation %	Average yield stress (MPa)	Average ultimate stress (MPa)
10	9.2	12.37	749	850.96
12	11.1	14.35	646.7	782.91
16	15.0	18.81	627.5	734.97

3.4 Mixing of the concrete, casting and curing procedures:

The experimental program involved casting a concrete slab with concrete cube compressive strength equal to 45.64 MPa at 28 days with a mix proportion (1:2.61:2.83) of (Cement: Fine aggregate: Coarse aggregate) and water cement ratio (W/C) (0.52), the workability was measured through slump test which was equal to 90mm. The temperature was equal to (20C^o) during the concrete casting. The concrete slab and control cube samples were cured for 7 days.

Fig. 3- 7 Site preparation for the concrete slab

Fig. 3- 8 Placement of the concrete

Fig. 3- 9 Curing of the concrete

Table 3- 7 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				

Table 3- 8 Compressive strength of the cubes & density of the concrete

Sample No.	Age (days)	Weight (Kg)	Average density* (Kg/m^3)	Compressive strength (MPa)	Average cube compressive strength (MPa)
1	7	8.314	2470.41	45.569	41.02
2		8.267		35.244	
3		8.432		42.267	
4	28	8.036	2359.80	41.609	45.64
5		7.830		46.471	
6		8.027		48.844	

∗ The average density is air dried density .

3.5 Drilling of the holes

A rotating hammered drill (Fig. 3-10) was used to drill all of the holes (drill and vibrator).

Fig. 3- 10 Rotating drill hammer drill

3.6 Cleaning of the holes

Different combinations of compressed air and water with wire brush (Fig. 3-11) were used to clean and remove all of the loose concrete particles from drilled holes and to increase the potential bond surface.

Fig. 3- 11Wire brush

3.7 Preparation and injection the adhesives and grouts:

According to the manufacturer's recommendations, the adhesives (ROX-GU80) were mixed. A silicon container-loaded "gun" was used for injecting the adhesives into the holes. (Fig.3-13) with the required bottle of adhesives and then placed into the sample holes that drilled earlier together with anchors. The grouts (FLO-GROUT2) were mixed with water at a 3.66:1 water/ grout ratio (Fig. 3-14) as per the manufacture recommendation.

Fig. 3- 12 Different adhesive guns

Fig. 3- 13 Grout mixing procedure

3.8Anchor installations:

The holes filled with the adhesive or grout with a depth equal to 2/3 of the hole depth, then the anchors inserted into the holes by twisting slowly, which provide a complete bond between the anchor and the concrete. The excess adhesive or grout that come out through the hole after anchor installation was removed.

3.9 Group descriptions

The experimental was divided according to four different categories. see Table (3-8). In all groups, three different diameters (db) of 10mm ,12mm and 16mm were used with three different embedded length of 5db,10db and 15db. The details of each group are detailed in Table (3-10)

3.9.1 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 were tested.

Both of the drilling and cleaning for the drilled holes performed when the concrete was dry for adhesive and grouted anchors. Adhesive anchors were installed in dry concrete. However, for the grouted anchors, the concrete was filled with water for more than 12 hours as shown in (Fig-3.15) to provide a saturated surface dry concrete before the installation stage.

Fig. 3- 14 Drilled holes filled with water to provide saturated surface for the grouted anchors

3.9.2 Group two: drilled hole size

This group aimed to assess how the drilled hole size affected the bond capacity. The anchors were installed using adhesive brand of ROX-GU80 and grout brand of FLO-GROUT2 using three different hole sizes (db + 4mm, db + 8mm and db +12mm).

3.9.3 Group three: cleaning methods

This group aimed to evaluate the effects of the cleaning methods (stated below) on the bond capacity:

A. Adhesive (ROX-GU80)

I. Method I (Air+ Wire brush +Air)

II. Method II (Air only)

III. Method III (Wash +Wire brush +Wash)

B. Grout (FLO-GROUT2)
C. Method I (Air+Wire brush +Air)
D. Method II (Air only)

3.9.4 Group four: Sensitivity to installation in wet and -fully saturated dry concrete

This group is aimed to study the assess the effect of the existence of the water in the holes during anchors installation on the ultimate load capacity.

The drilling and cleaning of the holes performed when the concrete was dry for both adhesive and grouted anchors. The holes filled with water for 8 days to provide a wet saturated concrete. In the installation stage, the water removed from the holes then the anchors installed with grout or adhesives.

Below some definition of three different concrete cases that subjected to water:

I. **Dry concrete**: it is referred to the concrete that did not subjected to water before 14 days.
II. **Saturated surface dry concrete**: it is referred to the concrete that subjected to water not more than 12 hours.
III. **Wet saturated concrete:** is the concrete that filled with water more than 8 days before installation.

Table 3- 9 Water existence cases

Cases	**Casting Of the concrete**	**Concrete situation**		
		Drilling	**Installation**	**Testing**
Dry	7 days cured	Dry	Dry	Dry
Saturated	7 days	Dry	12 hours submerged with water *	Dry
Wet saturated	7 days	Dry	8 days submerged with water *	Dry

*All water was removed from drilled holes at the installation stage.

Table 3- 10 Group details

Types of the anchors	Bonding agent	Anchor diameter (mm)	Embedment length	Drilled hole size	Cleaning methods	Concrete condition: Drilling stage	Concrete condition: Cleaning stage	Concrete condition: installation stage	No of Anchor bars in each group
Cast-in-place	**Cast-in-place**	10 12 16	5db,10db,15db	-------	-------	-------			9
Adhesives	**ROX-GU80**	10 12 16	5db,10db,15db	db+4mm db+8mm db+12mm	Method (I)	Dry	Dry	Dry	27
	ROX-GU80	10 12 16	5db,10db,15db	db+4mm	Method (II) Method (III)	Dry	Dry	Dry	18
	ROX-GU80	10 12 16	5db,10db,15db	db+4mm	Method (I)	Dry	Dry	Wet saturated	9
	HIT-RE10	10 12 16	5db,10db,15db	db+4mm	Method (I)	Dry	Dry	Dry	9
	DUBELL F1331	10 12 16	5db,10db,15db	db+4mm	Method (I)	Dry	Dry	Dry	9
Grout	**FLO-GROUT2**	10 12 16	5db,10db,15db	db+4mm db+8mm db+12mm	Method (I)	Dry	Dry	Saturated	27
	FLO-GROUT2	10 12 16	5db,10db,15db	db+4mm	Method (II)	Dry	Dry	Saturated	9
	FLO-GROUT2	10 12 16	5db,10db,15db	db+4mm	Method (I)	Dry	Dry	Wet saturated	9
	FLO-GROUT2	10 12 16	5db,10db,15db	db+4mm	Method (I)	Dry	Dry	Dry	9
Total number of adhesive and grouted anchor bars									**135**

3.10 Confined Pull-out test:

The pull-out tests started after 14 and 28 days after the installation of the adhesive and grouts, respectively.

The pull-out tests were done using a calibrated hollow hydraulic jack with a 220KN capacity as shown in the Fig. 3-15 and Fig.3-16, A base plate was 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 calculated according to ACI 355.4M-11 code.

Base plate dimension equal to:

Width of the plate =300mm ≥ 100mm (specified by ACI 355.4M-11)

Thickness of the plate =16mm (t_{plate} = 16 mm ≥ db (16))

Hole diameter in the center of the plate = 25mm(1.5db-2.0db)

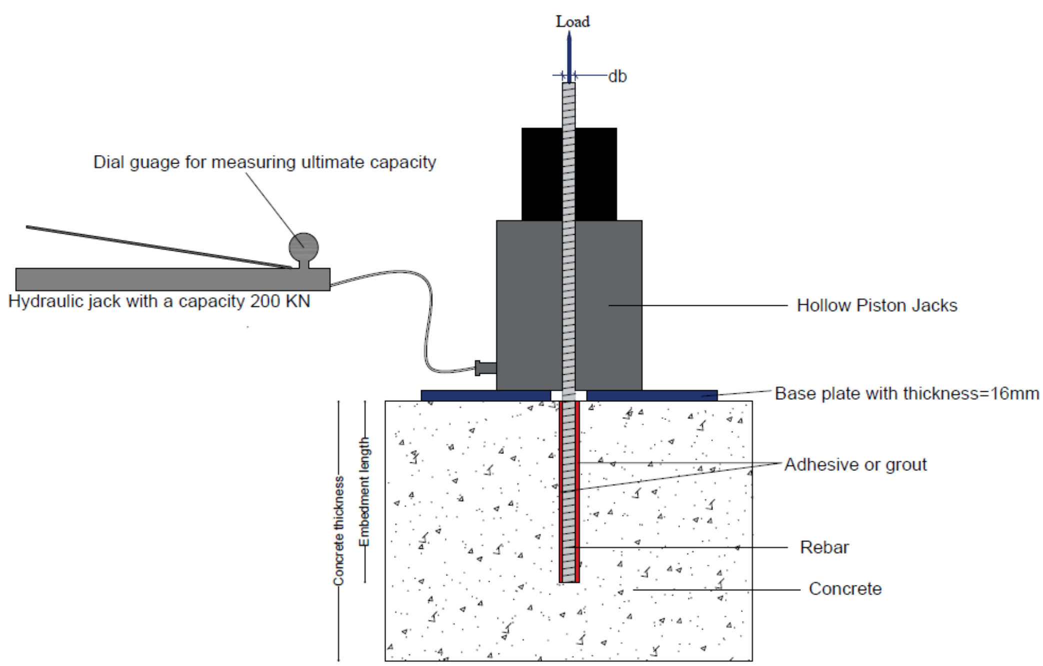


Fig. 3- 15 Pullout test details

Fig. 3- 16 Pullout test configuration

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1Introduction:

This chapter illustrate and discuss the results of the pull-out tests divided into five categories. The results that are presented are the ultimate load capacity of the anchors for the variables presented.

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

Three different epoxy brands (*HIT-RE10, ROX GU80, and DUBELL.F1331*) and non-shrinkage grout (*FLO-GROUT2*) that were locally used in Erbil city on 2022 have been tested for anchor diameters 10mm 12mm and 16mm for embedment length of 5db ,10db and 15db. The results were compared the pull-out tests with the cast-in-place anchors.

4.2.1 Ultimate load capacity

The results of the experimental work (Table 4-1 and Table 4-2) and (Fig. 4-1 to Fig. 4-3) show that in the majority the ultimate load capacity of the post installed anchors (adhesive and grouted) is more than the ultimate load capacity of cast-in-place anchors for the embedment length (10db and 15db) for most of brands due to higher bond area of adhesive and grouted anchors compared to the cast in place anchors bonded area. This confirm to the results of (Müsevitoğlu et al., 2020) who reported that where the embedment length of the post installed anchors is more than 10db, the ultimate load capacity is equal or more than ultimate load capacity of cast-in-place anchors but the anchors ultimate load capacity of post installed anchors is less than cast-in-places ultimate load capacity in low embedment length (5db).

However, (Haidar et al., 2020) stated that the anchors ultimate load capacity of cast-in-place is more than post installed anchor's ultimate load capacity.

But when the embedment length was equal to 5db, the ultimate load capacity of cast-in-place anchors found to be greater than the ultimate load capacity of post-installed anchors. This behavior was also observed by (Gamache) who reported that the performance of the concretes near surface for anchoring is less consistent compared with the interior concrete part. This can be characterized by a larger concentration of concrete paste on the top layer of concrete, shrinkage cracks, and contact to environmental factors. Also comparing the anchors installed in the formed side of the concrete to the anchors that installed on the unformed side, the capacity reduction might be about 30%. Typically, there will be more aggregate concentration on the formed side.

Furthers, the current study results showed that the ultimate load capacity also increase with the increase in the embedment length and anchor diameter because when the anchor diameter or embedded length increased also bonded area increased .This is in an agreement with the results of (Müsevitoğlu et al., 2020**,** Haidar et al., 2020 and Zeyad and Shihada, 2014)**.**

Further, it has been observed that the failure happens with the grout/adhesive itself in small embedment length (5db), while the failure happens at the grout/adhesive concrete interface at large embedment length (10db and 15db).

The detailed results are presented in the following paragraphs;

I. Anchors with 10mm diameter

The results presented in Table (4-1 and 4-2) and (Fig. 4-1) present the ultimate load capacity of post installed anchors of different brands (adhesive and grout) and cast-in-place anchors that installed with a dimeter equal to 10mm.

Anchors installed by HIT-RE10 epoxy brands achieved 80% ,114.28% ,111.48% of the cast-in-place's ultimate load capacity for embedment length equal to 5db, 10dband 15db, respectively.

The anchors were installed with the ROX GU80 epoxy brands had an ultimate load capacity of 72% ,78.57% and 101.35% of the cast-in-place's ultimate load capacity for embedment length 5db, 10db and 15db, respectively.

Also anchors installed with DUBELL.F1131 epoxy brands had an ultimate load capacity of 48% ,89.28% and 101.35% of cast-in-place's ultimate load capacity when the depth of embedment length was used 5db, 10db and 15db, respectively.

The grouted anchors had ultimate load capacity similar to cast-in-place anchors where the embedment length was equal to 10db and 15db. But when the embedment length equal to 5db, it had an ultimate load capacity 41.6% of cast-in-place's ultimate load capacity.

II. Anchors with 12 mm diameter

The results illustrated in Table (4-1and 4-2) and (Fig. 4-2) show that the ultimate load capacity of post installed anchors of different brands (adhesive and grouted) and cast-in-place anchors for a 12mm diameter.

The anchors were installed by HIT-RE10 epoxy brands had an ultimate load capacity of 130.76% ,140% and 137.5% of the cast-in-place's ultimate load capacity for the embedment length 5db,10dband 15db, respectively.

The ultimate load capacity of anchors was installed by ROX-GU80 epoxy brands had a capacity 80.76%,100 % and 109.37% of cast-in-place's ultimate load capacity for the embedment length 5db, 10db and 15db, respectively.

The ultimate load capacity of the post anchors installed by DUBEL.F1331 epoxy brands with the embedment length equal to 5db, 10dband 15db; The ultimate load capacity is 69.23 %,100% and 125% of cast-in-place ultimate load capacity, respectively.

When the anchors installed with the grouts, it achieved the ultimate load capacity of 60%,130% and 128.12% of the cast-in-place ultimate load capacity for the embedment length was equal to 5db, 10dband 15db, respectively.

III. Anchors with 16 mm diameter

The results shown in Table (4-1 and 4-2) and (Fig.4-3) illustrate the ultimate load capacity of post installed anchors of different brands and cast-in-place anchors for a 16mm diameter.

In the bar chart, it shows that post installed anchors using HILTI-RE10 epoxy brands it carries the ultimate load capacity of 135 % 116.36% and 112.5% of cast-in-place's ultimate load capacity where the embedment length was equal to 5db, 10db and 15db, respectively.

When the anchors installed by ROX GU80 epoxy brands with the embedment length equal to 5db, 10db and 15db, it had an ultimate load capacity 157.14%,98.18% and 93.75% of cast-in-place's ultimate load capacity, respectively.

The anchors installed by using DUBELL F1332 epoxy brands it had an ultimate load capacity 71.42%, 90.9% and 112.5% of cast-in-place's ultimate load capacity where the embedment length was equal to 5db, 10db and 15db, respectively.

Grouted anchors achieved an ultimate load capacity equal to 110.71% ,110.9% and 103.12% for the embedment length equal to 5db, 10db and 15db, respectively.

Table 4- 1 Ultimate load capacity of Post installed anchors (Grouted and Adhesive) and Cast-in-place anchors *

Anchor diameter (mm)	**Embedment length**	**Ultimate load capacity (KN)**					**Failure mode**
		Cast-in-place (Reference)	**HIT-RE10**	**ROX GU80**	**DUBELL.F1331**	**FLO-GROUT2**	
10	5db	40	32	28.8	19.2	16.64	Mode II
	10db	44.8	51.2	35.2	40	44.8	Mode III
	15db	47.36	52.8	48	48	47.36	Mode III
12	5db	41.6	54.4	33.6	28.8	24.96	Mode II
	10db	48	67.2	48	48	62.4	Mode III
	15db	51.2	70.4	56	64	65.6	Mode III
16	5db	44.8	60.48	70.4	32	49.6	Mode II
	10db	88	102.4	86.4	80	97.6	Mode III
	15db	102.4	115.2	96	115.5	105.6	Mode III

- ∗ Post installed anchors installed in dry concrete.
- ∗ The holes drilled with a drill hole equal to (db+4mm) for each anchor bars.
- ∗ The drilled holes were cleaned with method I (Air+Wire brush+Air).

Table 4- 2 Relative ultimate load capacity compared to cast-in-place anchors

Anchor diameter (mm)	Embedment Length	Relative ultimate load capacity *				
		Cast-in-place (Reference)	HIT-RE10 (%)	ROX GU80 (%)	DUBELL. F1331 (%)	Grout (%)
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

$$* \ Relative\ load\ \ capacity\ \% = \frac{Ultimate\ bond\ capacity\ of\ (adhesive\ or\ grout\ )}{ultimate\ capacity\ of\ cast-in-place} \quad ..4.1$$

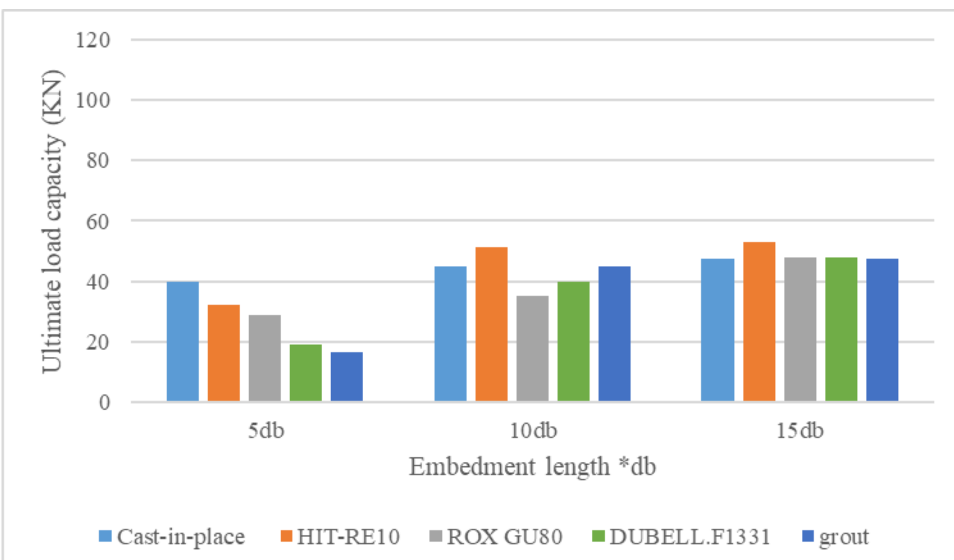


Fig. 4- 1 Experimental ultimate load capacity of epoxy brands, grout and cast-in-place with different embedment length for anchor diameter equal to 10mm

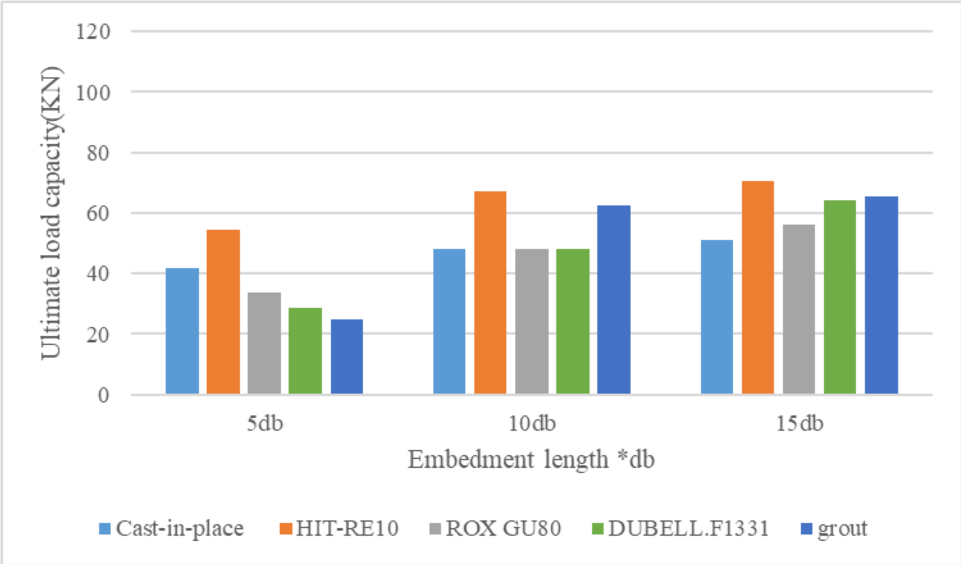


Fig. 4- 2 Experimental ultimate load capacity of epoxy brands, grout and cast-in-place with different embedment length for anchor diameter equal to 12mm

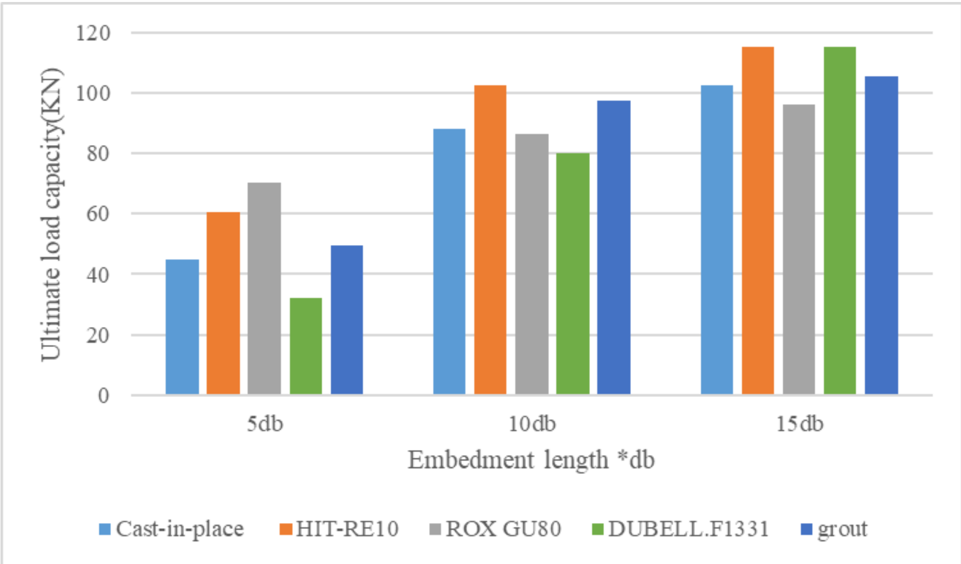


Fig. 4- 3 Experimental ultimate load capacity of epoxy brands, grout and cast-in-place with different embedment length for anchor diameter equal to 16mm

4.2.2 Failure modes between the anchors and concrete or Anchor and adhesive/grout

I. **Mode failure I**: When the anchor strength is lower than the bond strength between the anchor and the bonding agent (deep embedment length), this failure occurs between the anchor and the grout or adhesive see Fig.4-4.

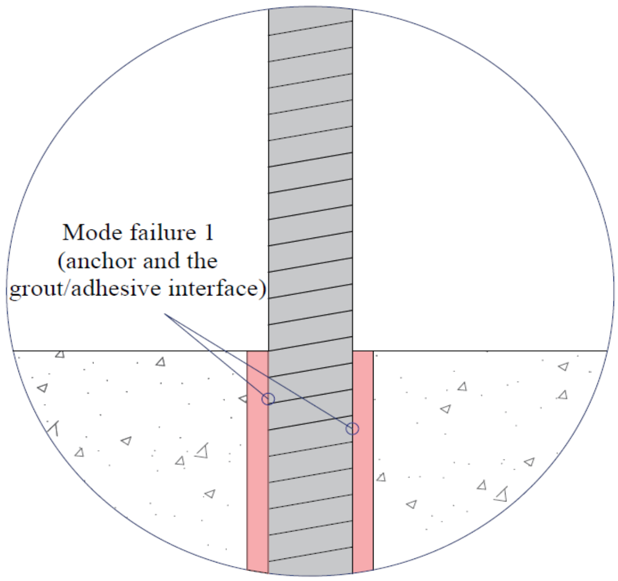


Fig. 4- 4 Mode failure I between anchor and the adhesive/grout

II. **Mode failure 2**: This type of failure happens when the stress inside grout/adhesive is less than bond strength between the steel and grout/adhesive interface or concrete and grout/adhesive interface (low embedment length) see Fig.4-5, Fig.4-7-b, Fig.4-8-b.

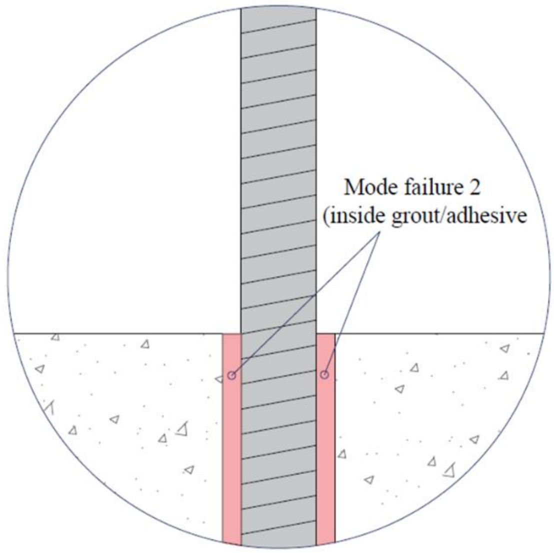


Fig. 4- 5 Mode failure II (inside the grout/adhesive)

III. **Mode failure 3**: This mode of failure happens at the grout/adhesive interface with the concrete when the bond strength is than bond strength between grout/adhesive interface with the steel (between deep embedment length and low embedment length) as shown in (Fig-4.6, Fig. 4-7-a and Fig. 4-8-a).

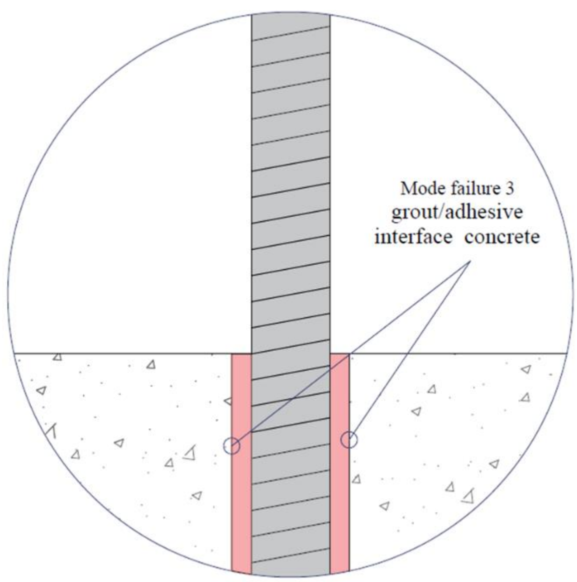


Fig. 4- 6 Mode failure III (between grout/adhesive interface with the concrete)

A) Concrete -adhesive interface (Mode 3) B) Adhesive (Mode 2)

Fig. 4- 7 Adhesive bond failure interface zone

A) Concrete -grout interface (Mode 3) B) Grout (Mode 2)

Fig. 4- 8 Grout bond failure interface zone

4.2.3 Average bond stress

The findings of the current study (Table 4-3 and Figs. 4-9 to 4-13) demonstrate that for cast-in-place, HIT-RE10, ROX-GU80, and DUBELL F.1331 epoxy brands, as well as grouted anchors, the average bond stress reduced as the embedment length increased from 10db to 15db. This confirms to the results obtained by (Müsevitoğlu et al., 2020 Zeyad and Shihada, 2014 ,Luke, 1984, Li et al., 2005 and LANG, 1979)**.**

However, (Ajamu et al., 2020) found that the increase in the embedment depth leads to an increase in the average bond stress for some brands they tested (12mm and 16mm) anchor diameter for three epoxy brands (Araldite, 4minutes and Hilti) with the embedment length equal to (10db and 15db). they found that the average bond stress increased for Araldite epoxy brand when embedment length increased from 10db to 15db for both diameters.

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

Detailed results are shown below:

I. Cast-in-place

Firstly, the average bond stress reached 25.47 MPa ,14.26 MPa and 10.05 MPa for the embedment length of 5db,10db and 15db respectively, for 10mm anchor diameter.

Secondly, when the anchor diameter 12mm was used, a lower Average bond stress achieved compared to the anchor diameter 10mm. the average bond stress found to be 18.40 MPa ,10.61 MPa and 7.54 MPa for the embedment length 5db,10db and 15db, respectively.

Finally, when the anchor diameter 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, 10db and 15db, respectively.

II. HIT-RE10

when the embedding depth was equal to 5 db, the post installed anchors using HIT-RE10 epoxy brands with the diameter equal to 10mm,12mm and 16mm had an average bond stress 20.38 MPa and 24.06 MPa and 15.04 MPa, respectively.

For all diameters (10mm,12mm and 16mm), the average bond stress has started to decline for the embedment length was equal to 10db if compared to 5db embedded length which found to be 16.30 MPa ,14.86 MPa and 12.73 MPa, respectively. For the embedment length equal to 15db, the average bond stress equal to 11.21 MPa,10.38 MPa and 9.55 MPa for the diameter 10mm,12mm and 16 mm, respectively.

III. ROX-GU80

The anchors installed by ROX-GU80 epoxy brands with the embedment length equal to 5db had an average bond stress 18.34 MPa,14.86 MPa and 17.51 MPa for anchors diameters equal to 10mm,12mm and 16mm, respectively.

But when the embedment length increased to 10db for the diameters was equal to 10mm,12mm and 16mm recorded a lower average bond stress it was 11.21 MPa ,10.61 MPa and 10.74 MPa, respectively.

Also, when the embedment length increased to 15db, in comparison to embedding lengths of 10db and 15db, there is a smaller variation in the average bond stress. witch it is calculated 10.19 MPa, 8.25 MPa and 7.96 MPa for diameter 10mm,12mm and 16mm, respectively.

IV.DUBELL.F1331

When the anchors installed with DUBEL.F1331 epoxy brands, the average bond stress achieved 12.22MPa,12.73MPa and 10.19MPa for the embedment length 5db,10db and 15db, respectively for the diameter is equal to 10mm.

But when 12mm anchor diameter was used, the average bond stress was equal to 12.73 MPa,10.61 MPa and 9.43 MPa for the embedment length equal to 5db, 10db and 15db, respectively.

In 16 mm anchor diameters, average bond stress found to be 7.96MPa for the embedment length equal to 5db, average bond stress increased to 9.95 MPa and 9.55 MPa when the embedment length increased to 10db and 15db, respectively.

V.Grouted anchors

In grouted anchors, the average bond stress found for the anchor diameter equal to 10mm with the embedment length of 5db,10db which it is equal to 10.59 MPa and 14.26 MPa, respectively but when the embedment length increased into to 15dbaverage bond stress decreased to 10.05MPa.

When the anchor diameter 12mm was used, the average bond stress was equal to 11.04 MPa and 13.80 MPa and 9.67 MPa for the anchor depth 5db,10dband 15db, respectively.

When 16 mm anchor bar installed with grouts, the average bond stress equal to 12.34 MPa for the embedment length 5db, average bond stress decreased into 12.14 MPa when the depth increased into to 10db, after that average bond stress continue decreasing to 8.75 MPa for the depth 15db.

Table 4- 3 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	ROX GU80	DUBELL. F1331	Grout
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

* Adhesive anchors installed in dry concrete but grouted anchors installed in saturated concrete.
* The holes drilled with a drill hole equal to (db+4mm) for each anchor bars.
* The drilled holes were cleaned with method I (Air+Wire brush+Air).

$$**Average\ bond\ stress(MPa) = \frac{Experimental\ ultimate\ load\ capacity}{Embeded\ anchor\ area}$$

$$= \frac{Experimental\ ultimate\ load\ capacity\ (N)}{\pi * Anchor\ diamater\ (mm) * Embedment\ length(mm)} \ ....4.2$$

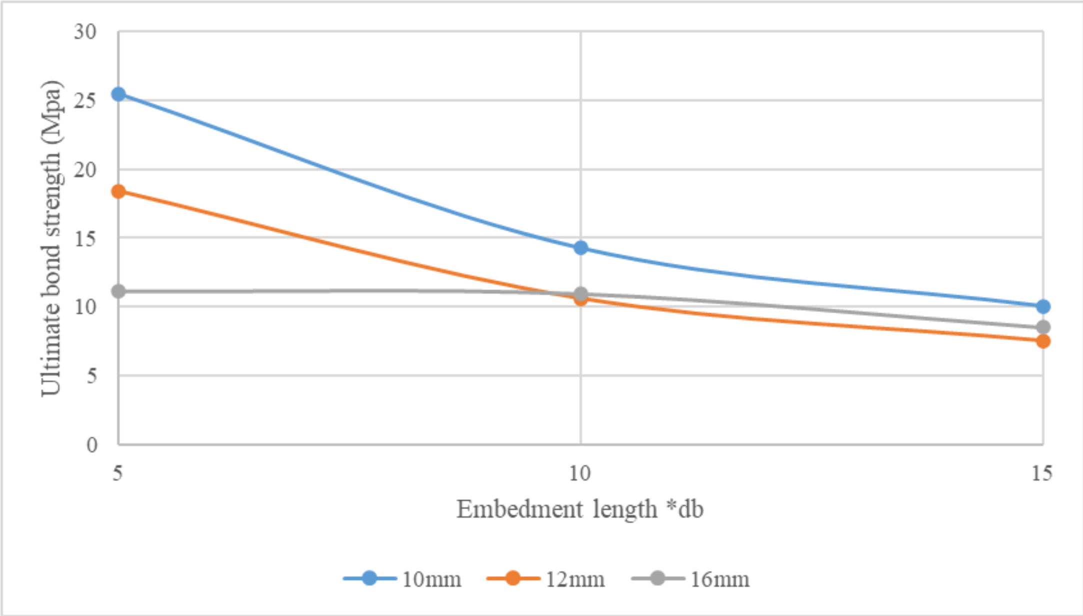


Fig. 4- 9 Relationship between average bond stress vs embedded length for cast-in-place anchors

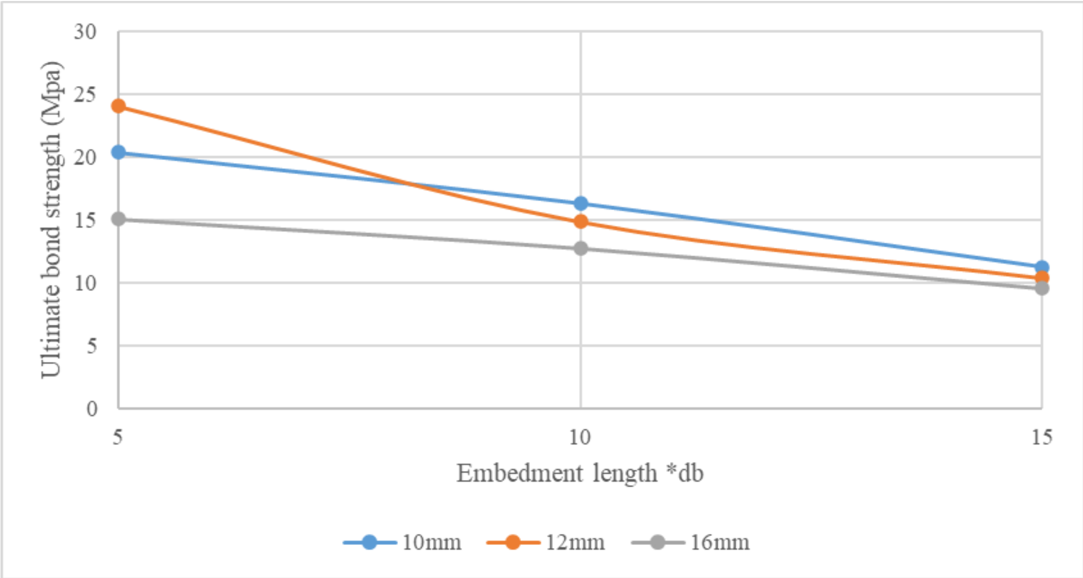


Fig. 4- 10 Relationship between Average bond stress vs embedded length for HILTI-RE10 Epoxy

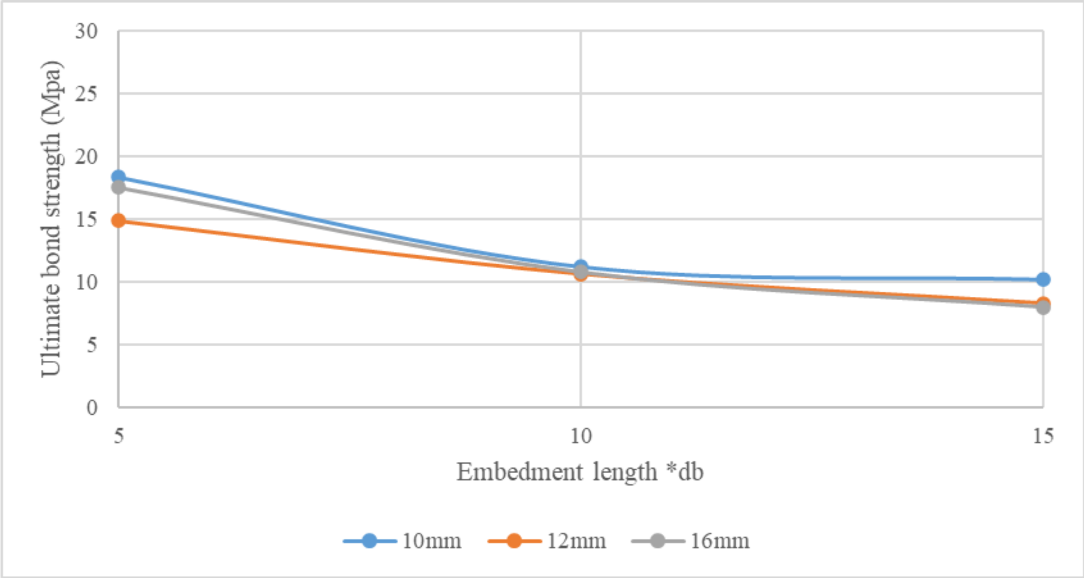


Fig. 4- 11 Relationship between Average bond stress vs embedded length for ROX-GU80 Epoxy

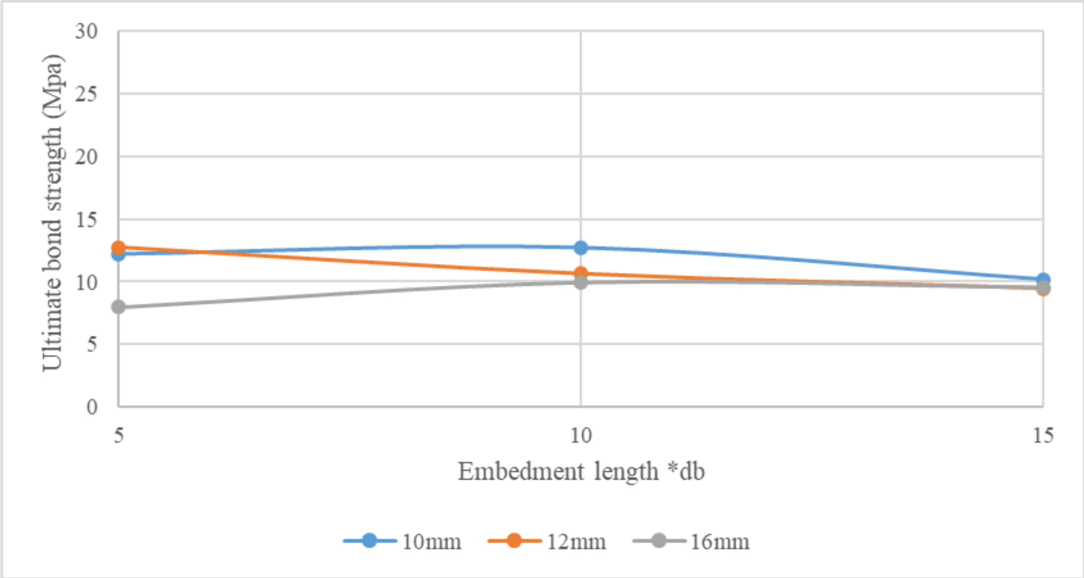


Fig. 4- 12 Relationship between Average bond stress vs embedded length for DUBELL.F1331 Epoxy

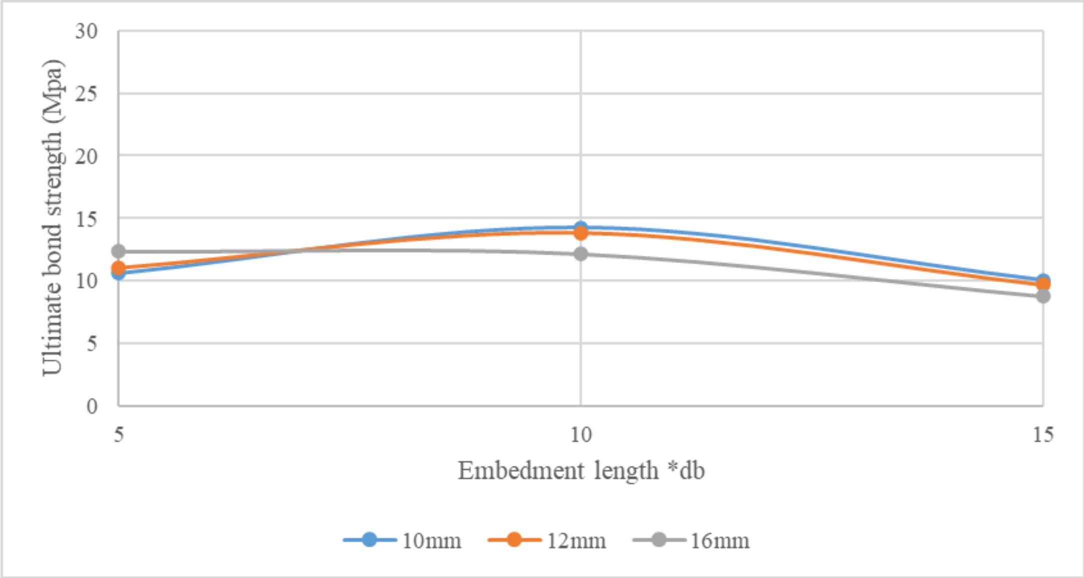


Fig. 4- 13 Relationship between Average bond stress in grouted anchors vs embedded length for grouted anchors

4.3 Group two: drilled hole size

Results of the current study (Table 4-4 to 4-5 and Fig. 4-14 to 4-19) show the effect of drilled hole size on the ultimate load capacity of the anchors, with drilled hole sizes of (14mm,18mm, and 22mm) for anchor diameters of 10mm and (20mm,24mm, and 28mm) drilled hole size for anchor diameters of 12mm and, (20mm,24mm, and 28mm) where anchor diameter equal to 16mm.

4.3.1 Adhesives (ROX-GU80)

The results of the current study show that for 5db embedment length, there was a decrease of 4.76% to 16.67% of the ultimate load capacity when the drilled hole size increased from +4mm to +8mm and +12mm because the quality of the concrete at the sub layers have higher percentage of aggregate concertation compared to top layer. But in 10db and 15db embedment length, the ultimate capacity increased by 3.3% to 42.73% when the drilled hole size increased when drilled hole size increased to 8mm and 12mm because of bonded anchors have higher bond area for the same anchor diameter.

But (Müsevitoğlu et al., 2020) , (González et al., 2018)and (Haidar et al., 2020b) stated that the increase in the drilled hole size did not significantly improve the anchoring capacity.

I. Embedment length equal to 5db

When the anchor diameter was equal to 10mm with the embedment length equal to 5db, the anchors ultimate load capacity declined from 28.8 KN to 24 KN where the drilling hole size changed from 14mm to 22 mm.

But when 12mm anchor diameter used for the same embedment length the ultimate load capacity decreased from 33.6 KN to 32 KN for drilled diameter 16mm and 24mm, respectively.

Also, there was a reduction in the ultimate load capacity where the diameter of anchor equal to 16mm for the 5db embedment length, it was recorded 70.4 KN ,64 KN and 60.8kN for drilled hole diameter 20mm,24mm and 28mm, respectively.

II. Embedment length equal to 10db

When the embedment length was equal to 10db, The anchors had an ultimate load capacity equal to 35.2 KN ,47.36 KN and 50.24 KN for the drilled hole size 14mm,18mm and 22 mm ,repectively for the anchor dimater equal to 10mm .

Also when 12mm anchor dimater was used the ultimate bond capacity recorded 48 KN , 65.6 KN and 64 KN for drilled hole size 16 mm , 20mm and 24mm ,respectively .

The anchors ultimate capcity recorded 86.4 KN,112 KN and 116.8 KN for drilled hole size 20mm,24mm and 28mm ,respectively where the anchor diameter was equal to 16mm .

III. Embedment legnth equal to 15db

When the embedment length was equal to 15db, The anchors ultimate bond capcity recorded 48KN , 49.6 KN when the drilled hole size increased from 14mm and 18mm for anchor dimater 10mm.

When the anchor dimater equal to 12 mm ,the ultimate bond capacity of anchors equal to 56 KN ,70.4 KN and 73.6 KN for the drilled hole size 16mm,20 mm and 24mm.

Also ultimate anchor capacity recorded 96 KN to 115.2 KN and 111.36 KN for drilled hole size 20mm ,24mm and 28mm ,respectively .

Table 4- 4 Ultimate load capacity of post installed adhesive anchors installed with ROX-GU80 adhesive brands for different drilled hole size

Anchor diameter (mm)	**Embedment length**	**Ultimate load capacity (KN)**			**Relative ultimate load capacity (%)**		**Failure modes**
		+4mm (Reference)	**+8mm**	**+12mm**	**+8mm**	**+12mm**	
10	5db	28.8	14.4	24	50	83.33	Mode II
	10db	35.2	47.36	50.24	134	142.7	Mode III
	15db	48	49.6	Failed	103	Failed	Mode III
12	5db	33.6	16	32	47.6	95.23	Mode II
	10db	48	65.6	64	136	133.33	Mode III
	15db	56	70.4	73.6	125.7	131.42	Mode III
16	5db	70.4	64	60.8	90.9	86.36	Mode II
	10db	86.4	112	116.8	129.6	135.18	Mode III
	15db	96	115.2	111.36	120	116	Mode III

- The holes drilled in dry concrete
- Anchors installed in dry concrete.
- The drilled holes were cleaned with method I (Air+Wire brush+Air).

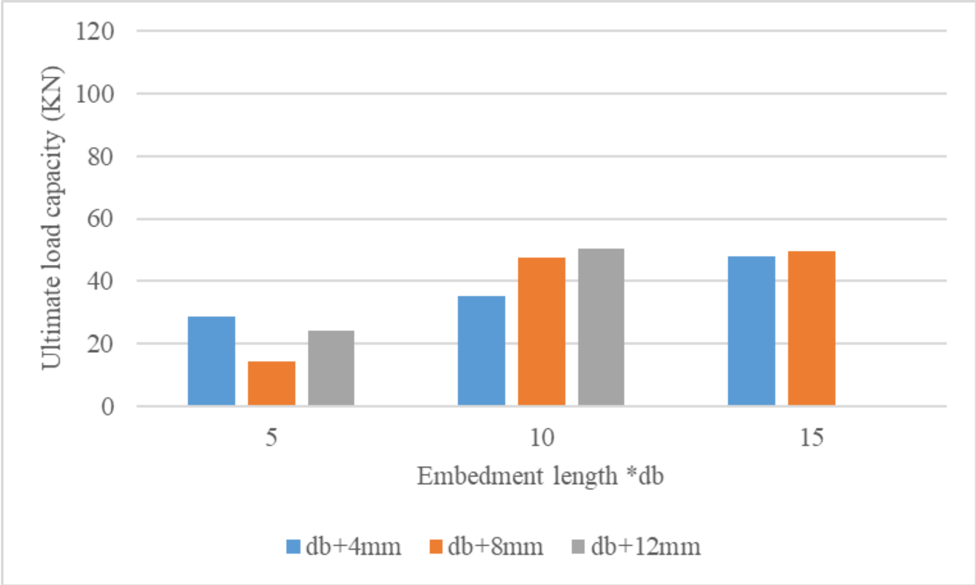


Fig. 4- 14 Effect of the drilled hole size on the ultimate load capacity of adhesive anchors for different embedment length with Φ=10mm

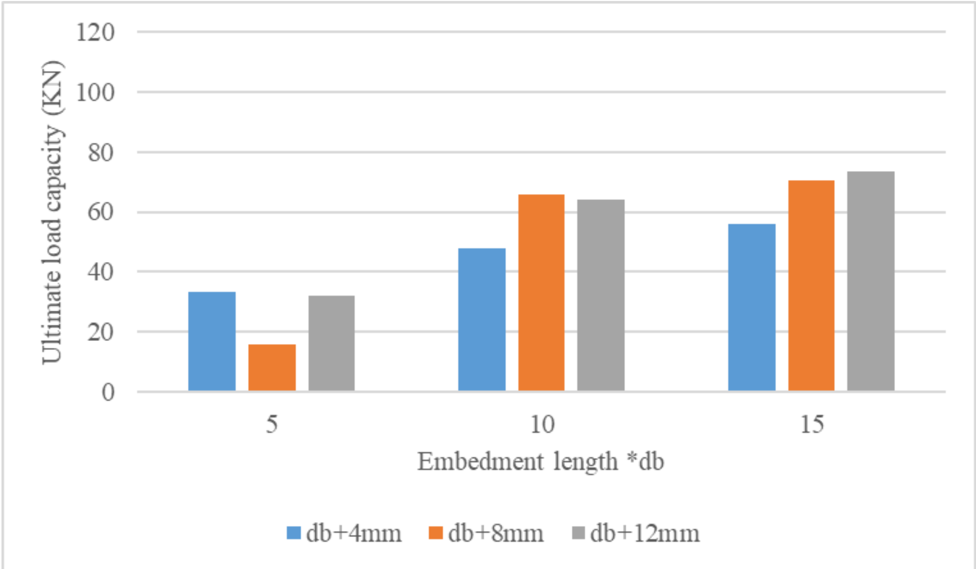


Fig. 4- 15 Effect of the drilled hole size on the ultimate load capacity of adhesive anchors for different embedment length with Φ=12mm

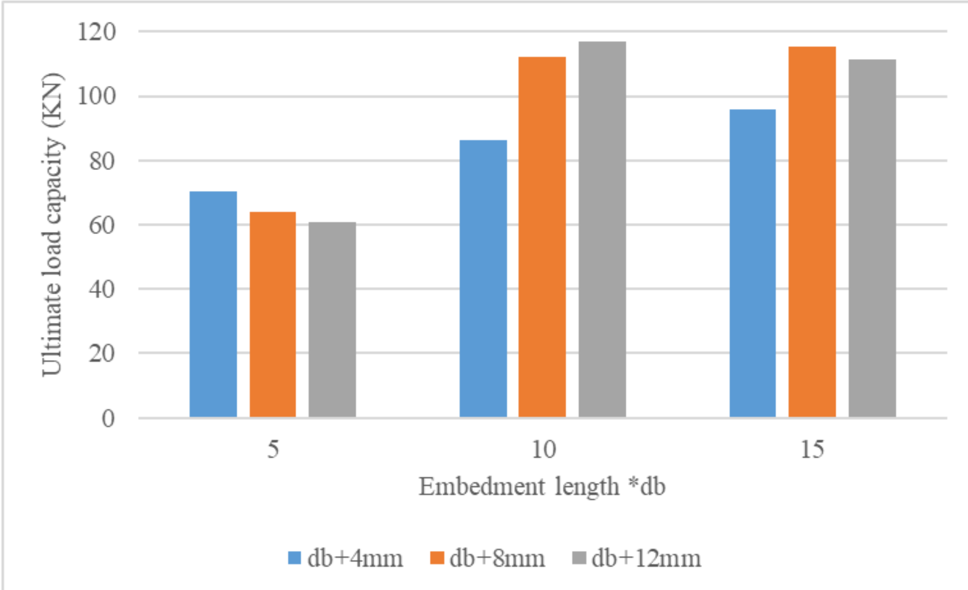


Fig. 4- 16 Effect of the drilled hole size on the ultimate load capacity of adhesive anchors for different embedment length with Φ=16mm

4.3.2 Grouted anchors (FLO-GROUT2)

According to the results of the current study (Table 4-5 and Figure 4-17 to 4-19), It has been shown when the drilled hole size equal to (db+8mm and db+12mm) there were a reduction of the ultimate load capacity (96.1% and 38.46% ,92.85 % and 75.0%, 97.97% and 96.62%) when the anchor for the embedded length 5db, 10db and 15db, respectively, where the drilled hole size increased by (db+8mm and db+12mm) for anchor diameter 10mm.

Also It has been shown when the drilled hole size increased to +8 mm there were a reduction of the ultimate load capacity (64.10% and 38.46% ,84.61 % and 71.79%, 97.07% and 95.12%) when the anchor for the embedded length 5db, 10db and 15db, respectively, where the drilled hole size was increased by (db+8mm and db+12mm) for anchor diameter 12mm.There was a reduction of the ultimate load capacity (85.80% and 63.22% ,98.03 % and 78.68%, 98.48% and 99.39%) when the anchor for the embedded length 5db, 10db and 15db, respectively, where the drilled hole size was equal to (db+8mm and db+12mm) for anchor diameter 16mm.

According to the results of the current study, in low embedment depth(5db), the drilled hole size (without changing the anchor diameter) had a significant influence on the ultimate load capacity but in (15db) embedment length, the drilled hole size had less influence on the ultimate load capacity.

(Cook et al., 2013) mentioned that until another failure mode takes place, the capacity of anchors was increased by increasing the size of the drilled hole, which also increases the surface area of the grout/concrete contact Also, Cook stated that increasing the drilled hole size might also result in grout failure. The result of the current study showed that there was a failure in the grouts for 5db but for 10db and 15db there was a bond failure between grout and steel interface and there was a small reduction in the ultimate capacity for this embedment length ratio.

Also, the following points have been monitored.

I. Anchors with 10mm diameter

Where 10mm anchor diameter was used with the 5db embedment length, it was found that the anchors ultimate load capacity is equal to 16.64 KN, 16 KN, 6.4 KN for the drilled hole size 14mm ,18mm and 22mm, respectively.

The reduction of the ultimate load capacity also decreased when the embedded length increased to10db which recorded 44.8 KN ,41.6 KN and 33.6 KN for the drilled hole size 14mm ,18mm and 22mm.

Where the embedment length equal to 15db, there was a little effect on the ultimate capacity which was 47.6 KN ,46.4 KN and 45.76 KN for the drilled hole size 14mm ,18mm and 22mm, respectively.

II. Anchors with 12 mm diameter

When the anchor dimeter equal to 12mm, it was found that the ultimate load capacity of anchors was equal to 24.96 KN ,16 KN and 9.6 KN for the drilled hole size 16mm,20mm and 24mm, respectively when the embedment length was equal to 5db.

Where the embedment length increased to 10db the ultimate load capacity found to be 62.4 KN,52.8 KN and 44.8 KN for the drilled hole size equal to 16mm ,20mm and 24mm, respectively.

The ultimate capacity was equal to 65.6 KN ,63.68 KN and 62.4 KN where the drilled hole size equal to 16mm ,20mm and 24mm, respectively for the embedded length equal to 15db.

III. Anchors with 16 mm diameter

For 16mm anchor diameter, it has been found that the anchors ultimate load capacity equal to 49.6 KN,42.56 KN and 31.36 KN for the drilled hole size 20mm, 24mm and 28mm, respectively for the embedment length 5db(80mm) were used.

The ultimate load capacity was found to be 97.6 KN ,95.68 KN and 76.8 KN for the drilled hole size 20mm,24mm and 28mm, respectively, for the embedment length equal to 10db.

Also, when the embedment length increased to 15db (240mm), the ultimate capacity achieved 105.6 KN,104 KN and 104.96 KN if the drilled hole size equal to 20mm, 24mm and 28mm, respectively.

Table 4- 5 Ultimate load capacity of grouted anchors (FLOW-GROUT2) for different diameters and different embedment length *

Anchor diameter (mm)	**Embedment length**	**Ultimate load capacity (KN)**			**Relative ultimate load capacity (%)**	
		db+4mm (Reference)	**db+8mm**	**db+12mm**	**db+8mm**	**db+12mm**
10	5db	16.64	16	6.4	96.1	38.46
	10db	44.8	41.6	33.6	92.85	75.0
	15db	47.36	46.4	45.76	97.97	96.62
12	5db	24.96	16	9.6	64.10	38.46
	10db	62.4	52.8	44.8	84.61	71.79
	15db	65.6	63.68	62.4	97.07	95.12
16	5db	49.6	42.56	31.36	85.80	63.22
	10db	97.6	95.68	76.8	98.03	78.68
	15db	105.6	104	104.96	98.48	99.39

- The holes drilled in dry concrete
- Anchors installed in saturated concrete.
- The drilled holes were cleaned with method I (Air+Wire brush+Air).

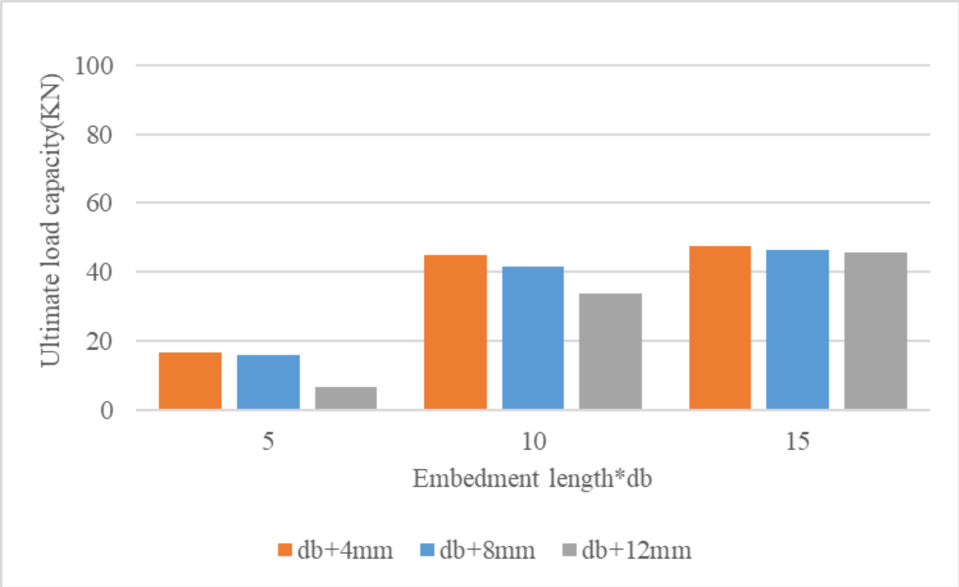


Fig. 4- 17 Effect of the drilled hole size on the ultimate load capacity of grouted anchor for different embedment length with Φ=10mm

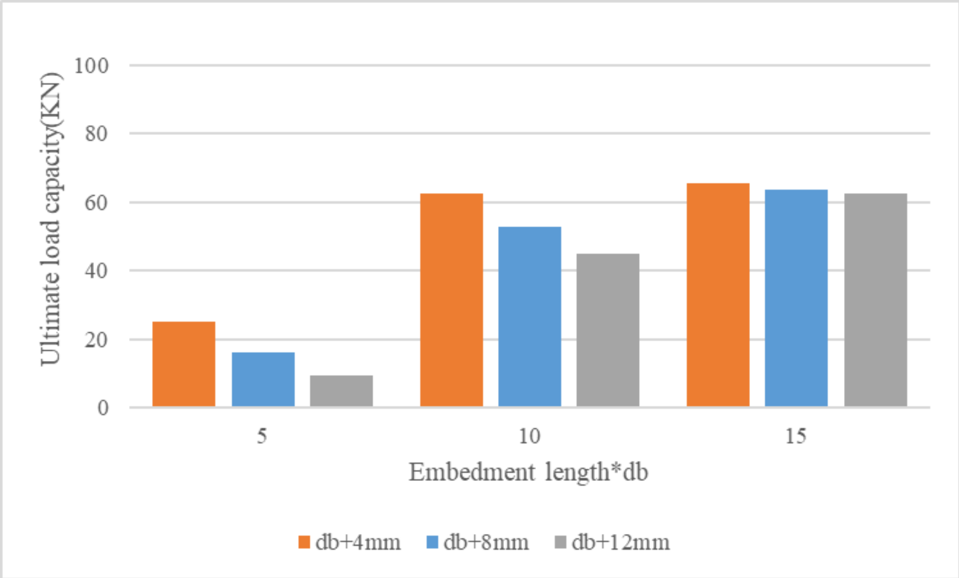


Fig. 4- 18 Effect of the drilled hole size on the ultimate load capacity of grouted anchor for different embedment length with Φ=12mm

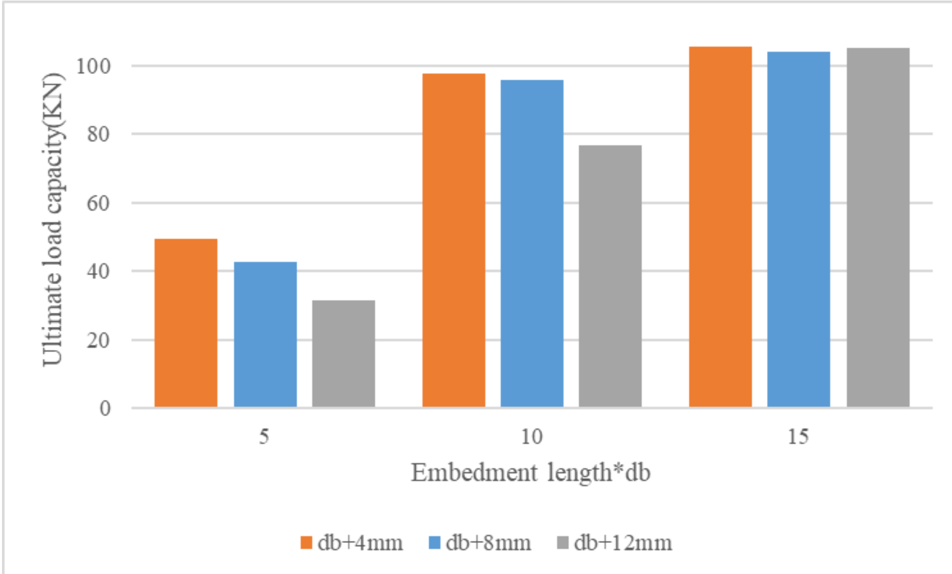


Fig. 4- 19 Effect of the drilled hole size on the ultimate load capacity of grouted anchor for different embedment length with Φ=16mm

4.4 Group three: cleaning methods

Effect of different cleaning methods on the ultimate load capacity evaluated on post installed anchors. Three different cleaning methods used for adhesive anchors which are Method I (Air +Brush +Air), Method II (Air only) and Method III (Wash Brush +Wash). Also, for the grouted anchors, two different cleaning methods have been used: Method I (Air +Brush +Air), Method II (Air only).

4.4.1 Adhesives (ROX-GU80)

The results of the current study in (Table 4-6 and Fig. 4-20 to 4-22) showed that the cleaning method had a big influence on the ultimate load capacity, drilled holes cleaned by Method I had an ultimate load capacity less than holes cleaned by Method II because the wire brush tends to polish drilled surface that reduce the capability of adhesive to create a mechanical interlock with the sides of the hole. The same trends has been observed by (Luke, 1984, Cook and Konz, 2001, FDOT ,2007) .

The drilled holes that cleaned by method III had an ultimate capacity more than previous cleaning methods because it removes the dust that produced during the drilling process that making a better bond between adhesive and concrete, which confirms the results obtained by (Müsevitoğlu et al., 2020)**.**

Detailed results are shown in the following paragraphs;

I. Anchors with 10 mm diameter

When the anchor diameter was 10mm used, the ultimate load capacity increased by 13.33% and 16.66% for the anchor holes that cleaned by method II and method III, respectively, if compared to anchors holes that cleaned by method I where the embedment length equal to 5db.

Also, the ultimate load capacity increased by 29.09% and 31.82% for the holes that cleaned by Method II and method III, respectively, if compared to anchor holes that cleaned by method I when the embedment length equal to 10db.

The effect of the cleaning become more pronounced at large embedment length equal to 15db, the results showed that the anchor holes cleaned by method II and Method III has larger bond strength by 2.66 % and 4.6%, respectively, compared to anchor holes cleaned by method I.

II.Anchors with 12 mm diameter

When the anchor diameter was equal to 12mm, the anchors ultimate load capacity had larger bond strength by 52.38% and 57.14% for holes cleaned by method II and Method III, respectively, if it compared to the anchor holes that cleaned by method I for the embedment length equal to 5db.

The anchors ultimate load capacity increased when the drilled holes cleaned by method II and method III by 2% into to 34.67% respectively, compared to cleaned by method I when the embedment length equal to 10db.

The effect of the cleaning was less effect when the embedment length was equal to 15db, it had found that holes cleaned by Method II and Method III has greater bond strength by 21.17% and 45.14%, respectively.

III. Anchors with 16 mm diameter

When the diameter of anchor was equal to 16mm with the embedment length equal to 5db, the ultimate load capacity increased when the drilled hole cleaned with method II and method III. The ultimate load capacity was increased by 2% and 13.64 % for method II, method III, respectively.

The ultimate load capacity of the anchor increased by 24.07% and 31.48% for cleaning method II and the cleaning method III, respectively, when it is compared the drilled holes that cleaned by method I for the embedment length equal 10db.

For the embedment length of 15db there was an increase of +12.33%, +35% in the ultimate load capacity for the cleaning method II and method III, respectively, compared with cleaning method I.

Table 4- 6 Ultimate load capacity of adhesive anchors with various cleaning methods installed with ROX-GU80 adhesive brands *

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

∗ The holes drilled in dry concrete with a drill hole size equal to (db+4mm)

∗ Anchors installed in dry concrete.

** Relative ultimate load capacity = Ultimate bond capacity of anchors cleaned by Method II or Method III / Ultimate bond capacity of anchors cleaned by Method I

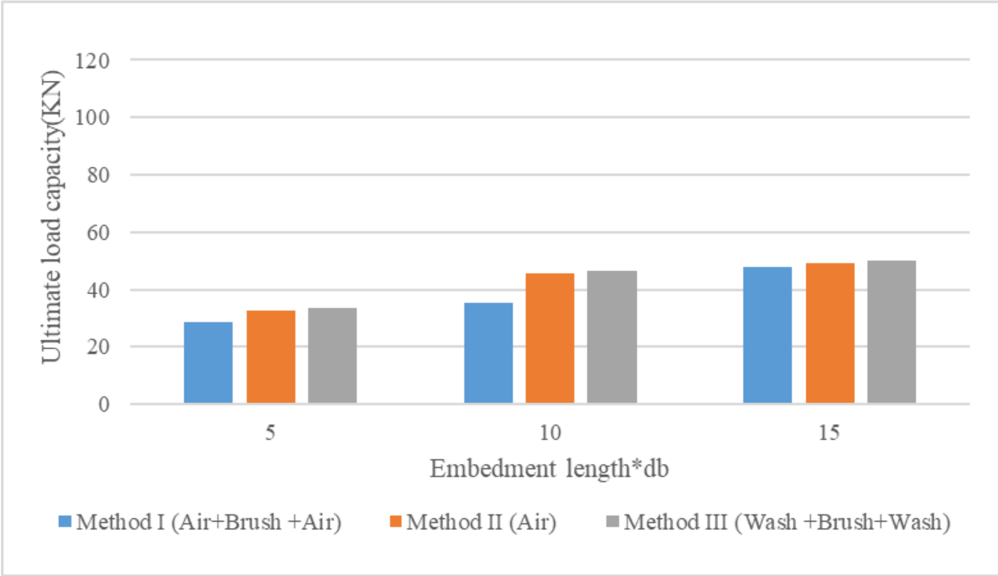


Fig. 4- 20 Ultimate load capacity for Anchor diameter equal to 10mm with different cleaning methods

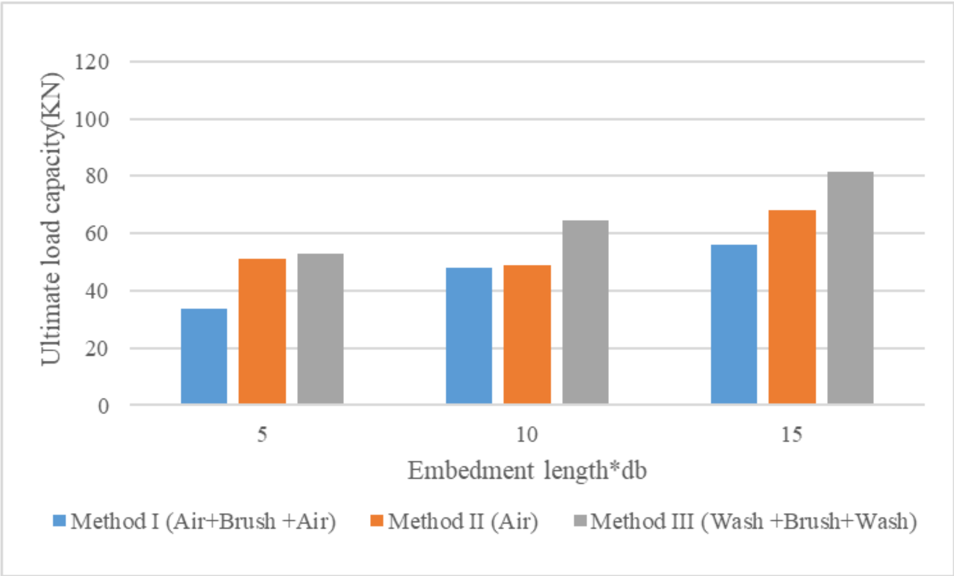


Fig. 4- 21 Ultimate load capacity for Anchor diameter equal to 12mm with different cleaning methods

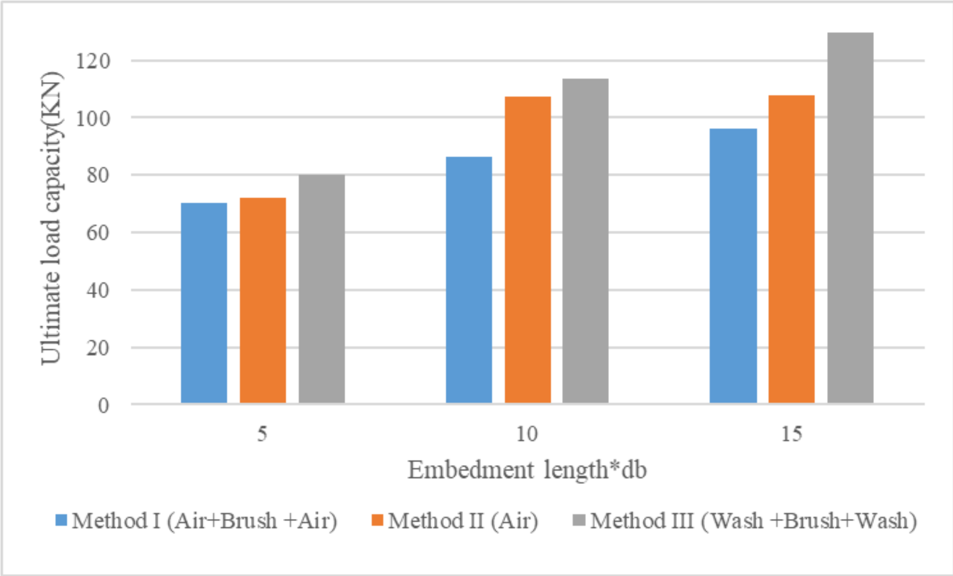


Fig. 4- 22 Ultimate load capacity for Anchor diameter equal to 16mm with different cleaning methods

4.4.2 Grouted anchors (FLO-GROUT2)

According to the results of the current study (Table 4-7 and Figure 4-23 to 4-25), the ultimate load capacity decreased for the grouted anchors when the drilled hole cleaned by method I compared to cleaning method II. This is because there are some dusts that produced in the holes during drilling operations, as a result, cause a weak bond between grout and concrete interface. But the percentage of the dusts in drilled holes that cleaned with method I (wire brush with air) is less than the holes that just cleaned with method II (air).

Detailed results are shown in the following paragraphs;

I.Embedment legnth equal to 5db

For the embedment length equal to 5db, for the anchor holes that cleaned by method II, it has been found that the ultimate load capacity of the grouted anchors founded were 96.15 % ,125.64% and 66.45%as ratio of the ultimate load capacity of anchors that cleaned by method I for the anchor diameter equal to 10mm, 12mm and 16 mm, respectively.

II. Embedment legnth equal to 10db

When the embedment length increased to 10db, it has been found that the ultimate load capacity of the grouted anchors is 66.21%,91.28% and 69.50% of the ultimate load capacity of anchors that cleaned by method I for anchor diameter equal to 10mm,12mm and 16mm, respectively.

III.Embedment legnth equal to 15db

If the anchor holes cleaned by method II, the Anchor ultimate load capacity recorded 91.89%, 92.68 % and 81.21 % of the ultimate load capacity of the anchors that cleaned by method I for the anchor diameter equal to 10mm, 12mm and 16mm, respectively.

Table 4- 7 Ultimate load capacity of adhesive anchors with various cleaning methods installed with FLO-GROUT2 grout brands*

Anchor diameter (mm)	**Embedment length**	**Ultimate load capacity (KN)**		**Relative ultimate load capacity (%)****	**Failure mode**
		Method I (Air+ Brush) (Reference)	**Method II (Air)**		
10	5db	16.64	16	96.15	Mode II
	10db	44.8	31.36	66.21	Mode III
	15db	47.36	43.52	91.89	Mode III
12	5db	24.96	31.36	125.64	Mode II
	10db	62.4	56.96	91.28	Mode III
	15db	65.6	60.8	92.68	Mode III
16	5db	49.6	32.96	66.45	Mode II
	10db	97.6	67.84	69.50	Mode III
	15db	105.6	85.76	81.21	Mode III

∗ The holes drilled in dry concrete with a drill hole size equal to (db+4mm)

∗ Anchors installed in saturated concrete.

** Relative ultimate load capacity = Ultimate bond capacity of anchors cleaned by Method II / Ultimate bond capacity of anchors cleaned by Method I

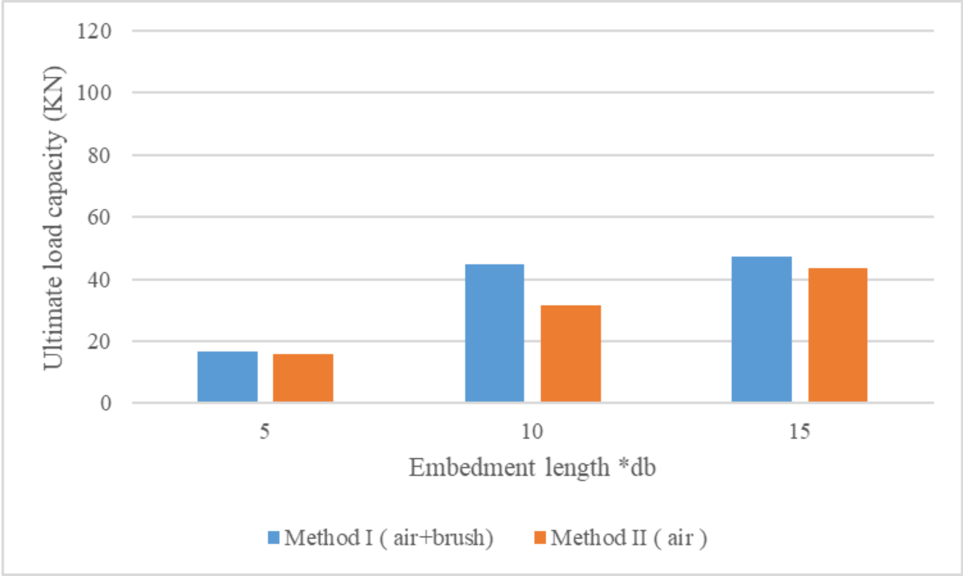


Fig. 4- 23 Ultimate load capacity for grouted anchor bar diameter =10mm with different cleaning methods

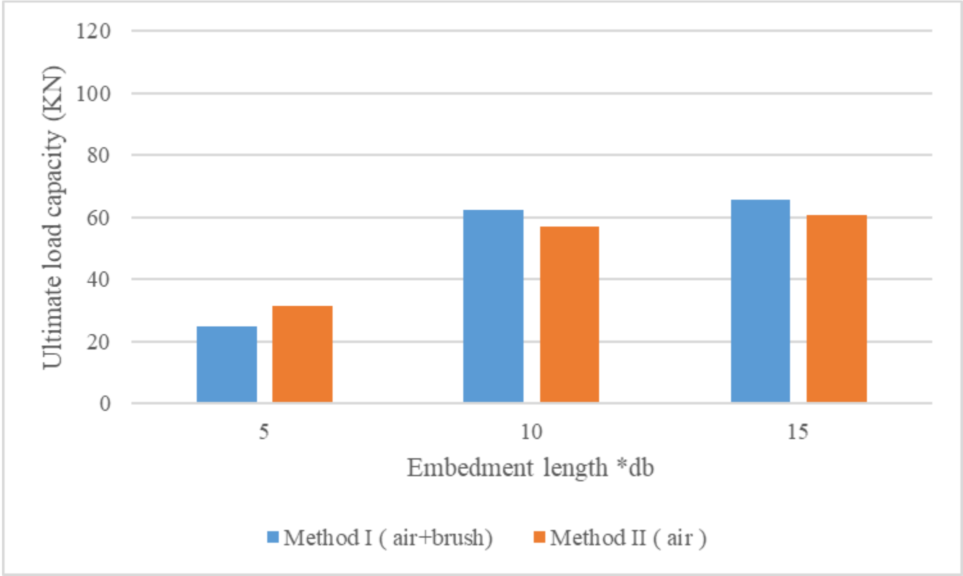


Fig. 4- 24 Ultimate load capacity for grouted anchor bar diameter =12mm with different cleaning methods

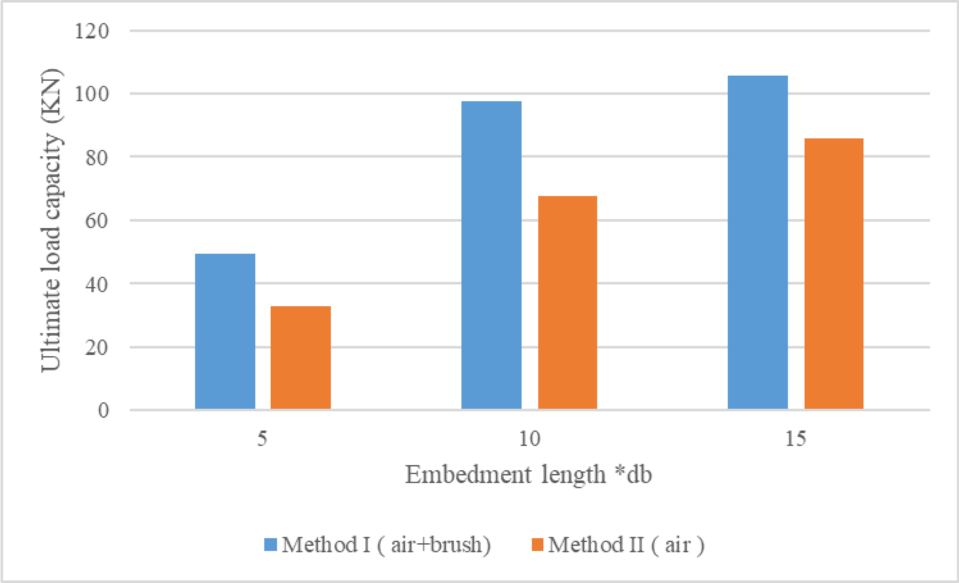


Fig. 4- 25 Ultimate load capacity for grouted anchor bar diameter =16mm with different cleaning methods

4.5 Group four: Sensitivity to installation in wet saturated, saturated and dry concrete

In this group, the effect of the drilled hole being immersed by water (wet saturated) during the installation for both adhesive and grouted anchors by comparing them with the case of the concrete not being subjected to water for 14 days during anchor installation (dry concrete).

4.5.1 Adhesives

The experimental results of the current study (Table 4-8 and Fig. 4-26 to 4-28) show that the anchors ultimate load capacity increased when it was installed into fully saturated concrete compared to the anchors installed into dry concrete.

This result is in agreement with (Blanchette, 2012) who stated that if there was a reduction in the ultimate load capacity when anchor is installed into fully saturated concrete it is related to dry cleaning methods or wet cleaning methods. Cleaning of the dry drilled hole is requiring less effort than cleaning wet drilled hole because some dusts remain at drilled hole that produced during drilling process in a fully saturated concrete.

According to Cook and Konz (2001), The degree of moisture in the hole has a major effect on the bonding capacity in two different ways. Moisture can restrict the ability of adhesives to penetrate concrete pores, reducing mechanical interlock, and moisture can obstruct the chemical reaction between the hardener and the resin, which confirms the results of the current study.

Detailed results shown in the following paragraphs;

I.Anchors with 10 mm diameter

When 10mm anchor diameter was used, the ultimate load capacity of anchors installed in a fully saturated concrete equal to 105.55 %, 127.27% and 100% of ultimate load capacity of anchors installed in dry concrete for the embedment length equal to 5db, 10db and 15db, respectively.

II.Anchors with 12 mm diameter

When anchor diameter was equal to 12mm, the anchors installed in a fully saturated concrete for the embedment length equal to 5db, 10db and 15dbhave an ultimate load capacity 100% ,129.75% and 114.28%, respectively in comparison to the ultimate load capacity of anchors installed in dry concrete.

III. Anchors with 16 mm diameter

The ultimate load capacity that installed in fully saturated concrete equal to 101.36% ,121.11 % and 115% of the ultimate load capacity of anchors that installed in dry concrete for the embedment length 5db,10db and 15db, respectively for the anchor diameter equal to 16mm.

Table 4- 8 Ultimate load capacity for adhesive anchors by (ROX-GU80) adhesive brand installed in dry concrete and wet saturated concrete*

Anchor diameter (mm)	Drilled hole size	Cleaning method	Embedment length	Ultimate load capacity (KN)		Relative ultimate load capacity %**	Failure mode
				Dry concrete (Reference)	Wet saturated concrete		
10	db+4mm	Method (I)	5db	28.8	30.4	105.55	Mode II
			10db	35.2	44.8	127.27	Mode III
			15db	48	48	100	Mode III
12			5db	33.6	33.6	100	Mode II
			10db	48	65.28	129.75	Mode III
			15db	56	64	114.28	Mode III
16			5db	70.4	71.36	101.36	Mode II
			10db	86.4	104.64	121.11	Mode III
			15db	96	110.4	115	Mode III

- ∗ The holes drilled in dry concrete with a drill hole size equal to (db+4mm)
- ∗ Anchors installed in dry and wet saturated concrete.

** Relative ultimate load capacity = Ultimate bond capacity of anchors installed in wet saturated concrete / Ultimate bond capacity of anchors installed in dry saturated concrete

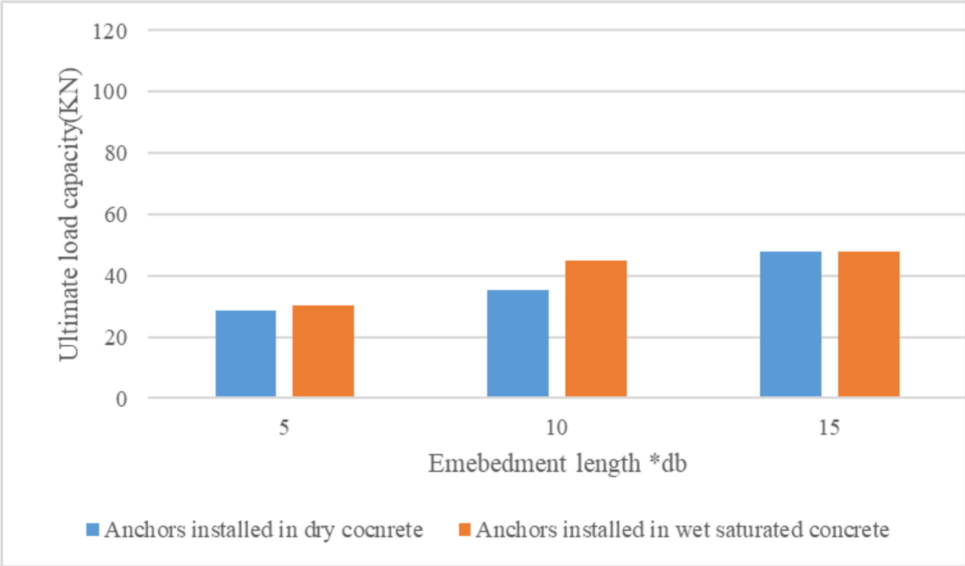


Fig. 4- 26 Ultimate load capacity for anchors installed by adhesives in dry concrete and wet saturated concrete for steel diameter =10mm

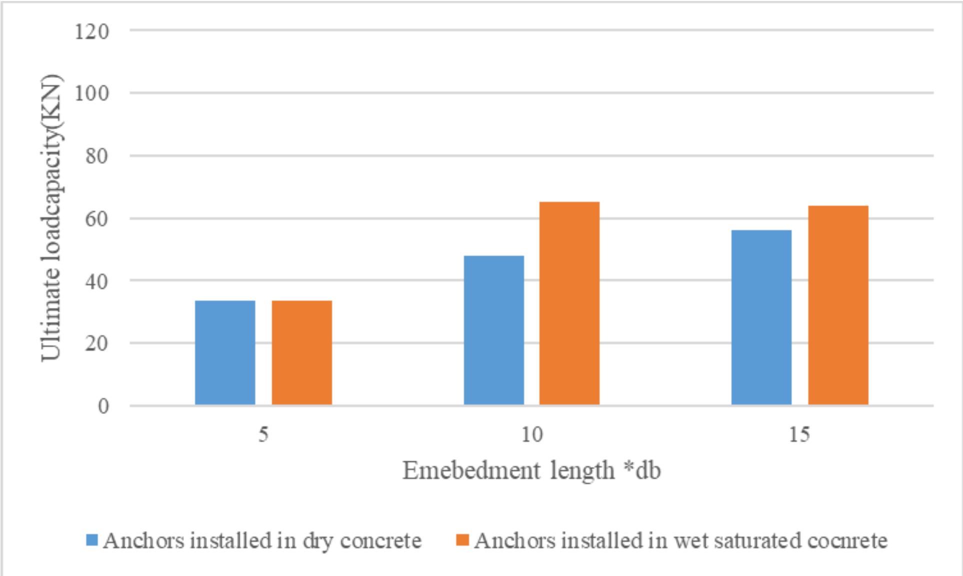


Fig. 4- 27 Ultimate load capacity for anchors installed by adhesives in dry concrete and wet saturated concrete for steel diameter =12mm

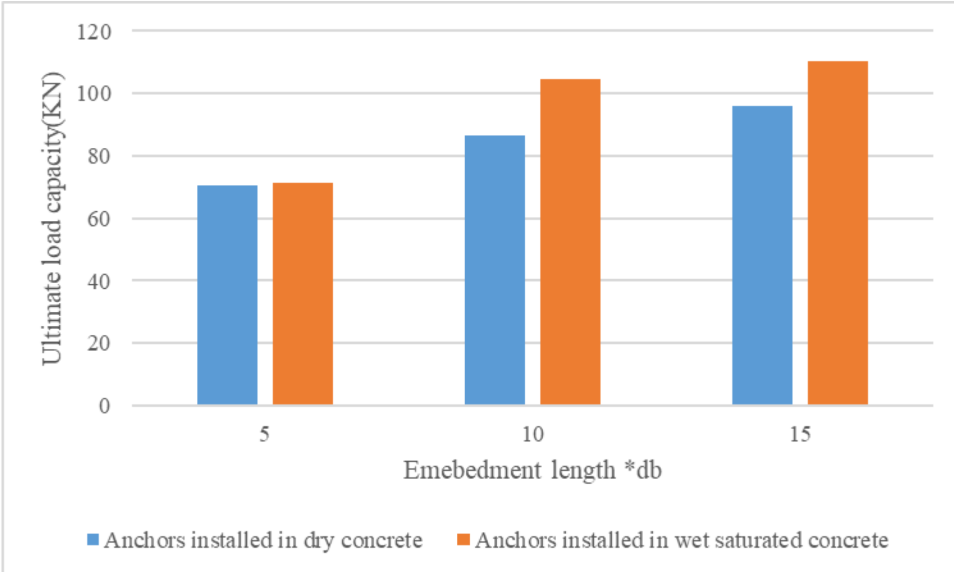


Fig. 4- 28 Ultimate load capacity for anchors installed by adhesives in dry concrete and wet saturated concrete for steel diameter =16mm

4.5.2 Grouted anchors

According to the results of the current research show in (Table 4-9 and Fig. 4-29 to 4-31) the cementitious grouted anchors installed in dry holes has ultimate bond strength less than the case of being installed in saturated concrete. This is because the dry hardened concrete will drain moisture away and prevent the grout from fully hydrating. In a similar manner, inserting cementitious grout into a hole that is too moist(wet saturated) potentially lower the ultimate bond strength of the anchor and raise the water/cement ratio as reported by (Cook et al., 2003) that lead to decrease the bond strength between concrete with the grout .

I. Wet saturated concrete

When 10mm anchor diameter was used, the ultimate load capacity of anchors installed in a wet saturated concrete equal to 94.23 %, 96.42% and 96.42 % of ultimate load capacity of anchors installed in saturated concrete for the embedment length equal to 5db, 10db and 15db, respectively.

When anchors diameter equal to 12mm were installed in a fully saturated concrete for the embedment length equal to 5db, 10db and 15db, they had an ultimate load capacity 70.51% ,87.17 and 98.04%, respectively compared to the ultimate load capacity of anchors installed in saturated concrete.

The ultimate bond strength of anchors installed in fully saturated concrete was 96.77%, 97.93%, and 96.59% of the ultimate bond strength of anchors installed in saturated concrete for the embedment lengths of 5db,10db, and 15db; respectively.

II. Dry concrete

When 10mm anchor diameter was used, the ultimate load capacity of anchors installed in a dry was equal to 92.54 %, 92.58 % and 95.59 % of the ultimate load capacity of anchors installed in saturated concrete for the embedment length equal to 5db, 10db and 15db; respectively.

For the anchor diameter equal of 12mm installed in a dry concrete for the embedment length equal to 5db, 10dband 15db, the ultimate load capacity was 89.74% ,84.10% and 95.12 %, respectively compared to the ultimate load capacity of anchors installed in saturated concrete.

The ultimate load capacity of anchors installed in dry concrete was equal to 89.5% ,93.44 % and 98.48% of the ultimate load capacity of anchors fixed in saturated concrete for the embedment length 5db,10dband 15db, respectively for the anchor diameter was equal to 16mm.

Table 4- 9 Ultimate load capacity for anchors installed by (FLO-GROUT2) grout in saturated, wet saturated and dry concrete *

Anchor diameter (mm)	Embedment length (mm)	Drilled hole size	Cleaning method	Ultimate load capacity (KN)			Relative ultimate load capacity (%)		Failure modes
				Saturated Concrete (Reference)	Wet saturated Concrete	Dry concrete	Wet saturated Concrete	Dry concrete	
10	5db	db+4mm	Method (I)	16.64	15.68	15.4	94.23	92.54	Mode II
	10db			44.8	43.2	41.6	96.42	92.85	Mode III
	15db			47.36	45.76	44.8	96.62	95.59	Mode III
12	5db	db+4mm	Method (I)	24.96	17.6	22.4	70.51	89.74	Mode II
	10db			62.4	54.4	52.48	87.17	84.10	Mode III
	15db			65.6	64.32	62.4	98.04	95.12	Mode III
16	5db	db+4mm	Method (I)	49.6	48	44.4	96.77	89.5	Mode II
	10db			97.6	95	91.2	97.93	93.44	Mode III
	15db			105.6	102	104	96.59	98.48	Mode III

* Anchors installed in saturated wet saturated and dry concrete.

** Relative ultimate load capacity = Ultimate bond capacity of anchors installed in wet saturated concrete or dry concrete / Ultimate bond capacity of anchors installed in saturated concrete

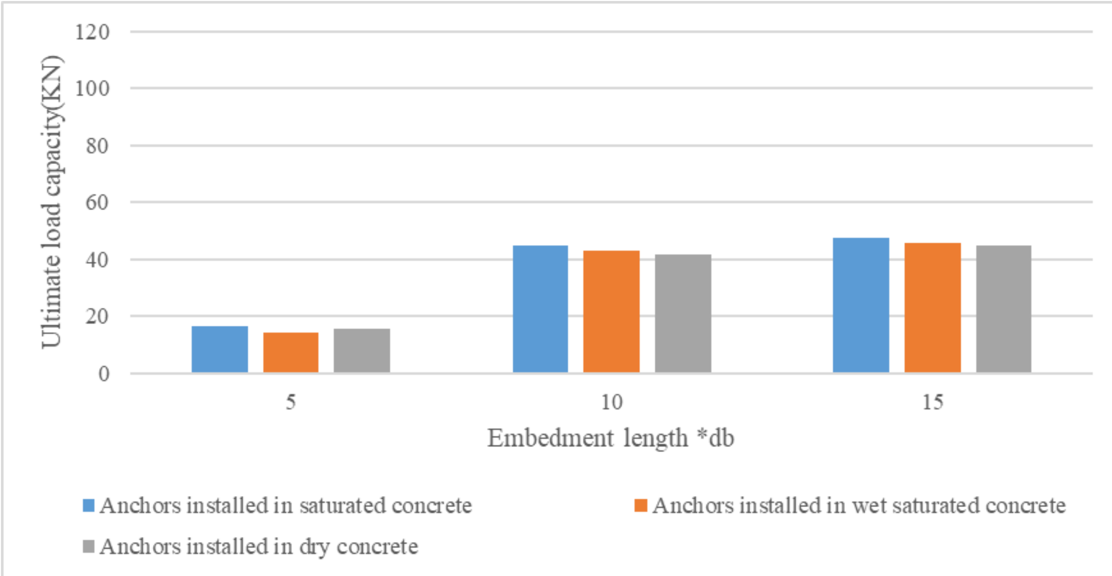


Fig. 4- 29 Ultimate load capacity of grouted anchors installed in saturated concrete, fully saturated concrete and dry concrete for steel diameter =10mm

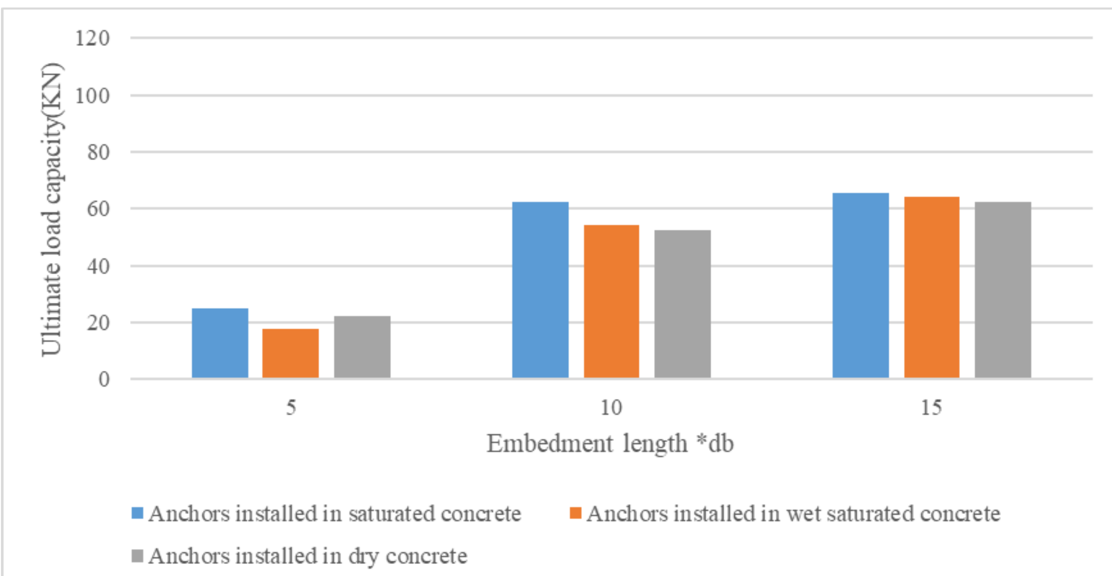


Fig. 4- 30 Ultimate load capacity of grouted anchors installed in saturated concrete, fully saturated concrete and dry concrete for steel diameter =12mm

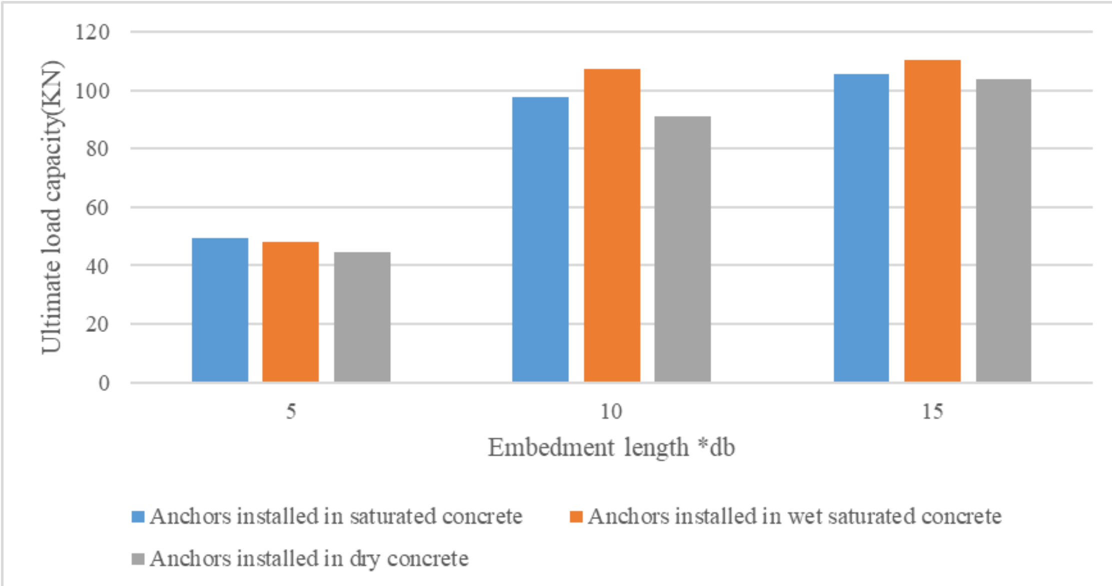


Fig. 4- 31 Ultimate load capacity of grouted anchors installed in saturated concrete, fully saturated concrete and dry concrete for steel diameter =16mm

4.6 Bond capacity factor (K) evaluation

CEB -FIP model code, 1993 stated that bond stress in the bar developed in confined test equal to the following value:

$$\tau\ (MPa) = K\sqrt{Fc_{cube}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.3$$

Where:

τ= Average bond stress

Fc_{cube}= Cube compressive strength at 28 days

K= 2.5 for good condition

K=1.25 for other condition equal to

And average uniform bond stress equal to:

$$\tau_{average\ uniform\ bond\ stress}\ (MPa) = \frac{Ultimate\ load\ capacity\ of\ anchors}{\pi * Anchor\ diamater * Embedement\ lenght} \quad \ldots 4.4$$

4.6.1 Adhesive (ROX-GU80):

The current study's findings in (Table 4-10 and 4-11 and Fig.4-32) indicate that for adhesive anchors, the maximum bond capacity factor (K) is equal to 3.455 for embedded lengths of 5db for anchor diameters of 12 mm used for anchor holes cleaned by method II , but the minimum bond capacity factor (K) is equal to 1.047 for anchor diameters of 12 mm for embedding lengths of 5db for the drilled hole size equal to db+8mm.

The average bond capacity factor (K), as determined by the data from the present study, is equivalent to 2.005 for anchors installed using adhesives with ROX-GU80 adhesive brand but the CEB -FIP model code, 1993 stated that bond capacity factor (K) varied between 2.5 to 1.25.

Table 4- 10 Ultimate load capacity for adhesive anchors installed with (ROX-GU80) adhesive brand

Anchor diameter (mm)	Embedment length	Ultimate load capacity (KN)							
		Experimental						Average Experimental	Base value ultimate load capacity (without K)*
10	5db	28.8	14.4	24	32.64	33.6	30.4	27.31	10.61
	10db	35.2	47.36	50.24	45.44	46.4	44.8	44.91	21.22
	15db	48	49.6	failed	49.28	50.24	48	49.02	31.84
12	5db	33.6	16	32	51.2	52.8	33.6	36.53	15.28
	10db	48	65.6	64	48.96	64.64	65.28	59.41	30.56
	15db	56	70.4	73.6	68.16	81.28	64	68.91	45.84
16	5db	70.4	64	60.8	72	80	71.36	69.76	27.17
	10db	86.4	112	116.8	107.2	113.6	104.64	106.77	54.33
	15db	96	115.2	111.36	107.84	129.6	110.4	111.73	81.50
Drilled hole size		db+4mm	db+8mm	db+12mm	db+4mm	db+4mm	db+4mm	----------------------	$Base\ value\ (KN) = \sqrt{Fcube} * \pi * db * heff$
Concrete condition	Drilling stage	Dry	Dry	Dry	Dry	Dry	Dry		
	Cleaning stage	Dry	Dry	Dry	Dry	Dry	Dry		
	Installation stage	Dry	Dry	Dry	Dry	Dry	Wet saturated		
Cleaning methods		Method (I)	Method (I)	Method (I)	Method (II)	Method (III)	Method (I)		

Table 4- 11 Bond capacity factor for adhesive anchors installed with ROX-GU80 adhesive brand

Anchor diameter (mm)	Embedment length	Relative(K) =Experimental ultimate load capacity/ Base value ultimate load capacity					
10	5db	2.714	1.357	2.262	3.076	3.166	2.865
	10db	1.659	2.231	2.367	2.141	2.186	2.111
	15db	1.508	1.558	failed	1.548	1.578	1.508
12	5db	2.199	1.047	2.094	3.351	3.455	2.199
	10db	1.571	2.146	2.094	1.602	2.115	2.136
	15db	1.222	1.536	1.605	1.487	1.773	1.396
16	5db	2.591	2.356	2.238	2.650	2.945	2.627
	10db	1.590	2.061	2.150	1.973	2.091	1.926
	15db	1.178	1.413	1.366	1.323	1.590	1.355
Drilled hole size		db+4mm	db+8mm	db+12mm	db+4mm	db+4mm	db+4mm
Concrete condition	**Drilling stage**	Dry	Dry	Dry	Dry	Dry	Dry
	Cleaning stage	Dry	Dry	Dry	Dry	Dry	Dry
	Installation stage	Dry	Dry	Dry	Dry	Dry	Wet saturated
Cleaning method		Method (I)	Method (I)	Method (I)	Method (II)	Method (III)	Method (I)
K_{max}		2.714	2.356	2.367	3.351	3.455	2.865
K_{min}		1.178	1.047	1.366	1.323	1.578	1.355
$K_{average}$		1.803	1.745	2.022	2.128	2.322	2.013
$K_{average}$ **for all data**		2.005					

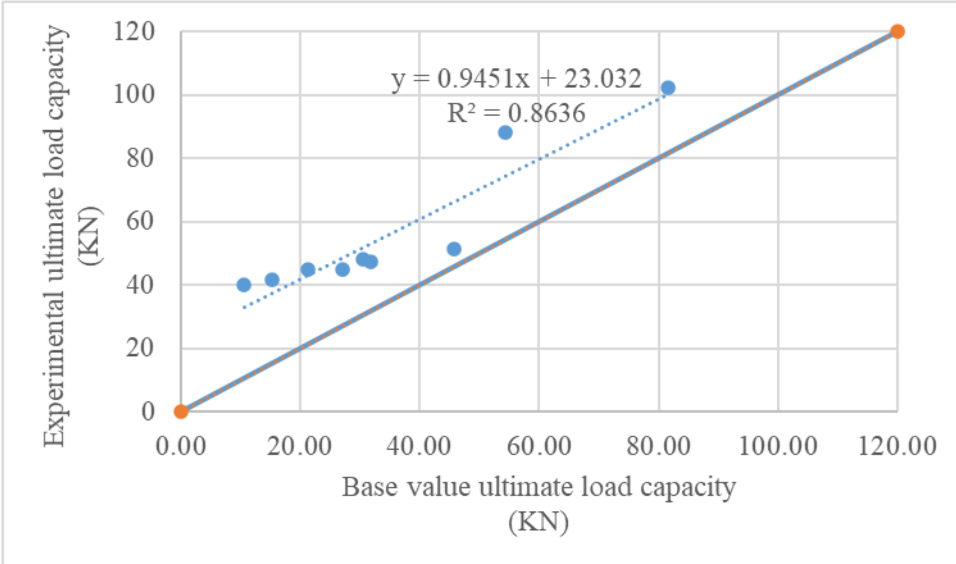


Fig. 4- 32 Relationship between base value and average experimental ultimate bond capacity for adhesive anchors installed with ROX-GU80 adhesive brands

4.6.2 Grouts (FLO-GROUT2)

According to the results of the current study (Table 4-12 and 4-13 and Fig. 4-33), for grouted anchor it has been shown that maximum ultimate bond capacity factor (K) equal to 2.11 for the embedded length equal to 10db for the diameter of 10mm where the drilled hole cleaned with Method I and installed in saturated concrete but minimum ultimate bond capacity factor equal to 0.6 for the anchor diameter equal to 10mm for the embedment length equal to 5db for the drilled hole equal to db+12mm in

According to the findings of the current study, grouted anchors have an average bond capacity factor (K) equal to 1.503.

Table 4- 12 Ultimate bond capacity for grouted anchors installed with FLO-GROUT 2 grout brand

Anchor diameter	Embedment length	Ultimate load capacity (KN)							
		Experimental						Average Experimental	Base value (without K) *
10	5db	16.64	16	6.4	16	14.4	15.4	14.14	10.61
	10db	44.8	41.6	33.6	31.36	43.2	41.6	39.36	21.22
	15db	47.36	46.4	45.76	43.52	45.76	44.8	45.60	31.84
12	5db	24.96	16	9.6	31.36	17.6	22.4	20.32	15.28
	10db	62.4	52.8	44.8	56.96	54.4	52.48	53.97	30.56
	15db	65.6	63.68	62.4	60.8	64.32	62.4	63.20	45.84
16	5db	49.6	42.56	31.36	32.96	48	44.4	41.48	27.17
	10db	97.6	95.68	76.8	67.84	107.2	91.2	89.39	54.33
	15db	105.6	104	104.96	85.76	110.4	104	102.45	81.50
Drilled hole size		db+4mm	db+8mm	db+12mm	db+4mm	db+4mm	db+4mm	------------------------	$*base\ value = \sqrt{Fc\ cube} * \pi * db * heff$
Concrete condition	**Drilling stage**	Dry	Dry	Dry	Dry	Dry	Dry		
	Cleaning stage	Dry	Dry	Dry	Dry	Dry	Dry		
	Installation stage	Saturated	Saturated	Saturated	Saturated	Wet saturated	Dry		
Cleaning methods		Method (I)	Method (I)	Method (I)	Method (II)	Method (I)	Method (I)		

Table 4- 13 Bond capacity factor for grouted anchors installed with FLO-GROUT 2 grout brand

Anchor diameter (mm)	**Embedment length**	**Experimental**					
10	5db	1.568	1.508	0.603	1.508	1.357	1.451
	10db	2.111	1.960	1.583	1.478	2.035	1.960
	15db	1.488	1.457	1.437	1.367	1.437	1.407
12	5db	1.633	1.047	0.628	2.052	1.152	1.466
	10db	2.042	1.728	1.466	1.864	1.780	1.717
	15db	1.431	1.389	1.361	1.326	1.403	1.361
16	5db	1.826	1.567	1.154	1.213	1.767	1.634
	10db	1.796	1.761	1.413	1.249	1.973	1.679
	15db	1.296	1.276	1.288	1.052	1.355	1.276
Drilled hole size		db+4mm	db+8mm	db+12mm	db+4mm	db+4mm	db+4mm
Concrete condition	**Drilling stage**	Dry	Dry	Dry	Dry	Dry	Dry
	Cleaning stage	Dry	Dry	Dry	Dry	Dry	Dry
	Installation stage	Saturated	Saturated	Saturated	Saturated	Wet saturated	Dry
Cleaning method		Method (I)	Method (I)	Method (I)	Method (II)	Method (I)	Method (I)
K_{max}		2.111	1.960	1.583	2.052	2.035	1.960
K_{min}		1.296	1.047	0.603	1.052	1.152	1.276
$K_{average}$		1.688	1.521	1.215	1.457	1.584	1.550
$K_{average}$ for all data		1.503					

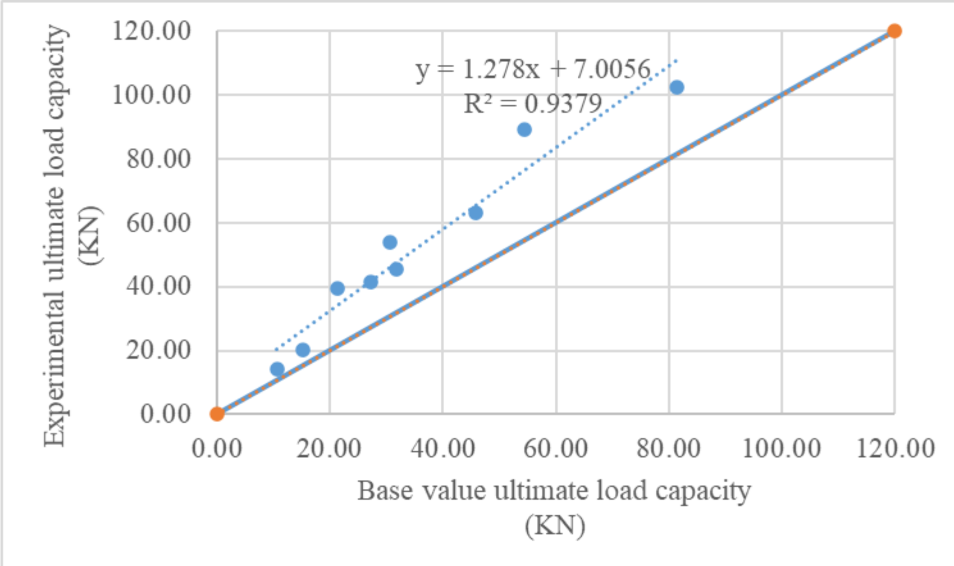


Fig. 4- 33 Relationship between base value and average experimental ultimate bond capacity for grouted anchors installed with FKO-GROUT2

For cast-in- place anchors, the results of the current study illustrate that maximum bond capacity factor (K) equal to 3.769 for the embedded length 5db with a diameter equal to 10mm but the minimum value of the bond capacity factor (K) equal to 1.117 for anchor diameter 12mm with the embedded length equal to 15db.

4.6.3 HIT-RE10

For anchors installed with HIT-RE10, the maximum bond capacity factor (K) is equal to 3.56 for an anchor with a diameter of 12mm and an embedded length of 5db, whereas the minimum bond capacity factor (K) is equal to 1.413 for an anchor with a diameter of 16mm and an embedded length of 15db.

4.6.4 DUBELL. F1331

The maximum bond capacity factor (K) for anchors installed with DUBELL. F1331 is equal to 1.885 for an anchor with a diameter of 12 mm and an embedded length of

10 db, whereas the minimum bond capacity factor (K) is equal to 1.178 for an anchor with a diameter of 16 mm and an embedded length of 5 db.

Table 4- 14 Ultimate load capacity Cast-in-place, HIT-RE10 and DUBELL.F1331 anchors

Anchor diameter (mm)	**Embedment length**	**Ultimate load capacity (KN)**			
		Cast-in-place	**HIT-RE10**	**DUBELL.F1331**	**Base value***
10	5db	40	32	19.2	10.61
	10db	44.8	51.2	40	21.22
	15db	47.36	52.8	48	31.84
12	5db	41.6	54.4	28.8	15.28
	10db	48	67.2	48	30.56
	15db	51.2	70.4	64	45.84
16	5db	44.8	60.48	32	27.17
	10db	88	102.4	80	54.33
	15db	102.4	115.2	115.2	81.50
Drilled hole size		db+4mm			*Base value = $\sqrt{Fc\ cube} * \pi * db * heff$
Concrete condition	**Drilling stage**	Dry			
	Cleaning stage	Dry			
	Installation stage	Dry			
Cleaning method		Method (I)			

Table 4- 15 Comparison of the experimental ultimate bond capacity and base value ultimate capacity for cast-in-place anchors and anchors installed with HIT-RE10,DUBELL.F1331 adhesive brands

Anchor diameter (mm)		**Embedment length**	**Relative =Experimental ultimate load capacity /Base value of the ultimate load capacity**		
			Cast-in-place	**HIT-RE10**	**DUBELL.F1331**
10		5db	3.769	3.015	1.809
		10db	2.111	2.412	1.885
		15db	1.488	1.659	1.508
12		5db	2.722	3.560	1.885
		10db	1.571	2.199	1.571
		15db	1.117	1.536	1.396
16		5db	1.649	2.226	1.178
		10db	1.620	1.885	1.472
		15db	1.256	1.413	1.413
Drilled hole size			db+4mm		
Concrete condition	**Drilling stage**		Dry		
	Cleaning stage		Dry		
	Installation stage		Dry		
cleaning method			Method (I)		
K_{max}			3.769	3.560	1.885
K_{min}			1.117	1.413	1.178
$K_{average}$			1.923	2.212	1.569

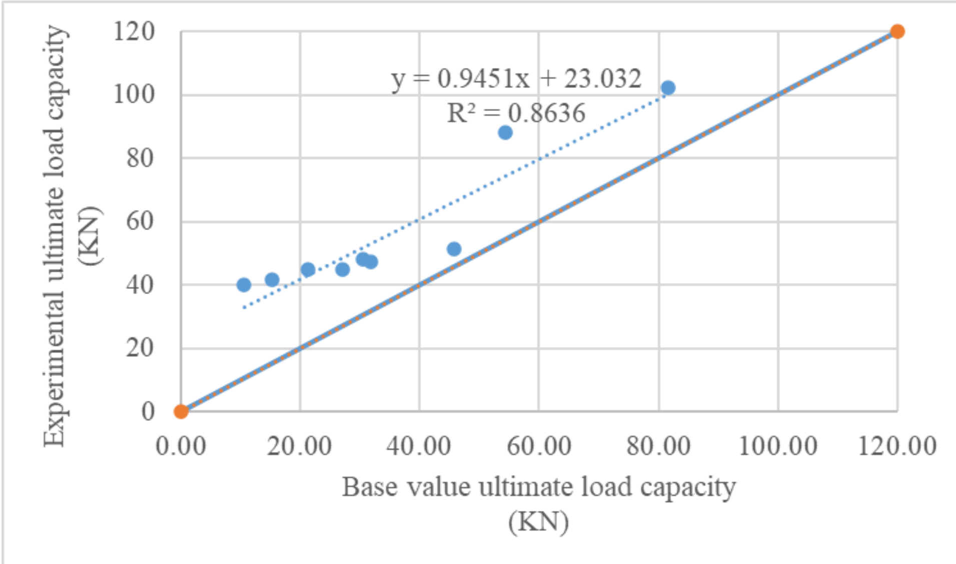


Fig. 4- 34 Relationship between experimental ultimate load capacity and base value ultimate load capacity for Cast-in-place anchors

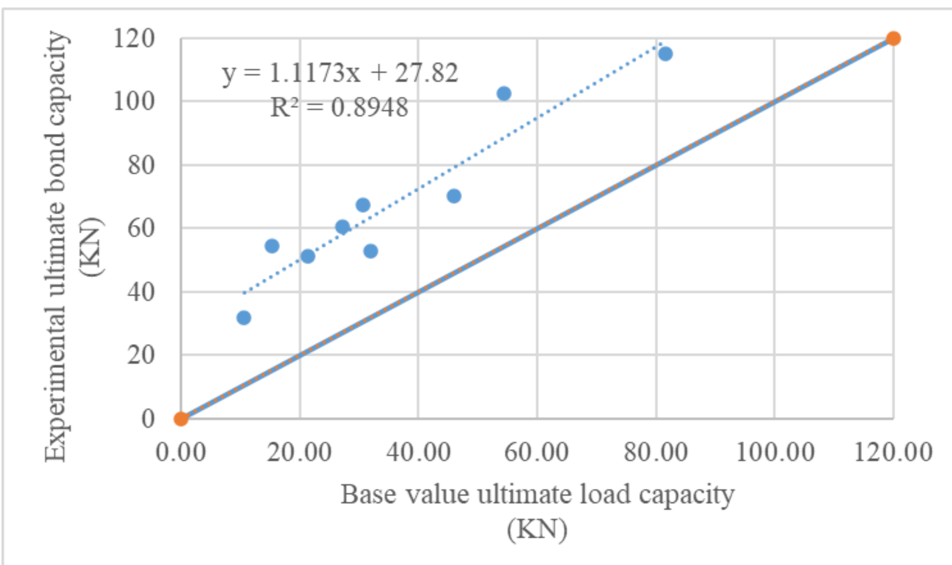


Fig. 4- 35 Relationship between experimental ultimate load capacity and base value ultimate load capacity for adhesive anchors installed with HIT-RE10 adhesive brand

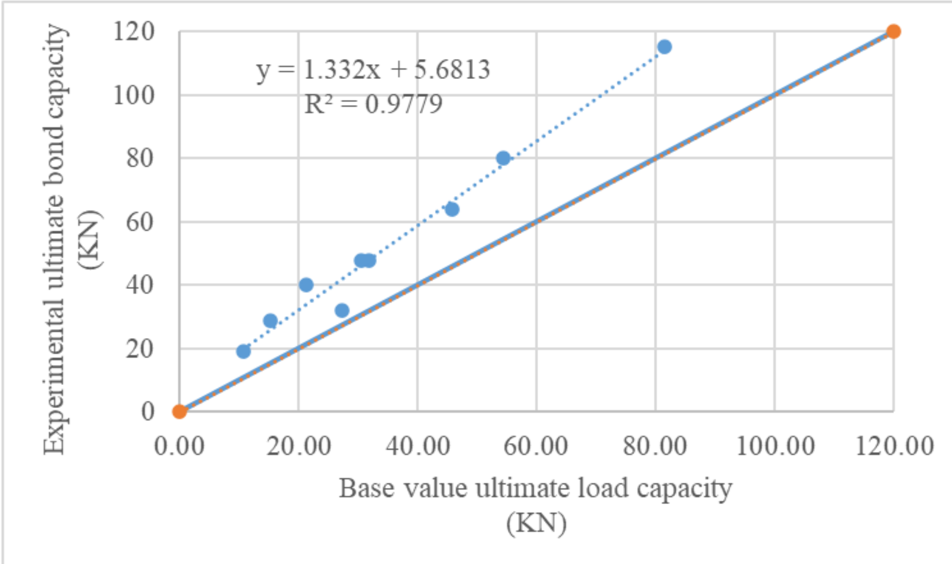


Fig. 4- 36 Relationship between experimental ultimate load capacity and base value ultimate load capacity for adhesive anchors installed with DUBELL.F1331 adhesive brand

4.6.5 Theoretical ultimate bond capacity versus experimental ultimate bond capacity

In this section (Table 4-15 ,4-16 and 4-17), the experimental ultimate bond capacity for cast-in-place, HIT-RE10, ROX-GU80,DUBELL.F1331 andFLO-GROUT2 of post installed anchors and compared with their theoretical factored ultimate load capacity value**.**

According to the results of the current study, it has been shown that the ratio of the experimental ultimate load capacity to theoretical factored ultimate load capacity for all anchors decrease when the embedment depth increases.

I.Cast-in-place

When the embedded length equal to 5db, anchors experimental ultimate load capacity recorded 1.96,1.42 and 0.86 compared to factored base value of ultimate load capacity for anchor diameter 10mm,12mm and 16mm, respectively.

Anchors experimental ultimate load capacity recorded 1.10 ,0. 82 and 0.84 compared to factored base value of ultimate factored load capacity for anchor diameter 10mm,12mm and 16mm, respectively for the embedded length equal to 10 db.

Where anchor diameter equal to 10mm,12mm and 16mm anchors experimental ultimate load capacity recorded 0.77 ,0.58and 0.65 respectively, compared to factored base value of ultimate load capacity for the embedded length equal to 15db.

II. HIT-RE10

Anchors experimental ultimate load capacity recorded 1.36,1.61 and 1.01 compared to factored base value of ultimate load capacity for anchor diameter 10mm,12mm and 16mm, respectively for the embedded length equal to 5 db.

Where anchor diameter equal to 10mm,12mm and 16mm anchors experimental ultimate load capacity recorded 1.09,0.99 and 0.85, respectively, compared to factored base value of ultimate load capacity for the embedded length equal to 10db.

When the embedded length equal to 15db, anchors experimental ultimate load capacity recorded 0.75,0.69 and 0.64 compared to factored base value of ultimate load capacity for anchor diameter 10mm,12mm and 16mm, respectively.

III. ROX-GU80

Anchors experimental ultimate load capacity recorded 1.35,1.10 and 1.29 compared to factored base value of ultimate load capacity for anchor diameter 10mm,12mm and 16mm, respectively for the embedded length equal to 5 db.

Where anchor diameter equal to 10mm,12mm and 16mm anchors experimental ultimate load capacity recorded 0.83,0.78 and 0.79, respectively, compared to factored base value of ultimate load capacity for the embedded length equal to 10db.

When the embedded length equal to 15db, anchors experimental ultimate load capacity recorded 0.75,0.61 and 0.59 compared to factored base value of ultimate load capacity for anchor diameter 10mm,12mm and 16mm, respectively.

IV. DUBELL.F1331

When the embedded length equal to 5db, anchors experimental ultimate load capacity recorded 1.15,1.20 and 0.75 compared to factored base value of ultimate load capacity for anchor diameter 10mm,12mm and 16mm, respectively.

Anchors experimental ultimate bond capacity recorded 1.20,1.00 and 0.94 compared to factored base value of ultimate load capacity for anchor diameter 10mm,12mm and 16mm, respectively for the embedded length equal to 10 db.

Where anchor diameter equal to 10mm,12mm and 16mm anchors experimental ultimate load capacity recorded 0.96,0.89 and 0.90, respectively, compared to factored base value of ultimate load capacity for the embedded length equal to 15 db.

V. FLO-GROUT2

Where anchor diameter equal to 10mm,12mm and 16mm anchors experimental ultimate load capacity recorded 1.04,1.09 and 1.21, respectively, compared to factored base value of factored ultimate load capacity for the embedded length equal to 5 db.

Anchors experimental ultimate load capacity recorded 1.40,1.36 and 1.2 compared to factored base value of factored ultimate load capacity for anchor diameter 10mm,12mm and 16mm, respectively for the embedded length equal to 10 db.

When the embedded length equal to 15db, anchors experimental ultimate load capacity recorded 0.99,0.95and 0.86 compared to theoretical factored base value of ultimate load capacity for anchor diameter 10mm,12mm and 16mm, respectively.

Table 4- 16 Experimental ultimate load capacity for cast-in-place, adhesive and grouted anchors

<table>
<tr><th rowspan="3" colspan="2">Anchor diameter (mm)</th><th rowspan="3">Embedment length</th><th colspan="5">Experimental Ultimate load capacity (KN)</th></tr>
<tr><th rowspan="2">Cast-in-place</th><th colspan="3">Adhesive</th><th>Grout</th></tr>
<tr><th>HIT-RE10</th><th>ROX-GU80</th><th>DUBELL.F1331</th><th>FLOW-GROUT2</th></tr>
<tr><td rowspan="3" colspan="2">10</td><td>5db</td><td>40</td><td>32</td><td>28.8</td><td>19.2</td><td>16.64</td></tr>
<tr><td>10db</td><td>44.8</td><td>51.2</td><td>35.2</td><td>40</td><td>44.8</td></tr>
<tr><td>15db</td><td>47.36</td><td>52.8</td><td>48</td><td>48</td><td>47.36</td></tr>
<tr><td rowspan="3" colspan="2">12</td><td>5db</td><td>41.6</td><td>54.4</td><td>33.6</td><td>28.8</td><td>24.96</td></tr>
<tr><td>10db</td><td>48</td><td>67.2</td><td>48</td><td>48</td><td>62.4</td></tr>
<tr><td>15db</td><td>51.2</td><td>70.4</td><td>56</td><td>64</td><td>65.6</td></tr>
<tr><td rowspan="3" colspan="2">16</td><td>5db</td><td>44.8</td><td>60.48</td><td>70.4</td><td>32</td><td>49.6</td></tr>
<tr><td>10db</td><td>88</td><td>102.4</td><td>86.4</td><td>80</td><td>97.6</td></tr>
<tr><td>15db</td><td>102.4</td><td>115.2</td><td>96</td><td>115.2</td><td>105.6</td></tr>
<tr><td colspan="3">Drilled hole size</td><td rowspan="5">----</td><td colspan="3">db+4mm</td><td>db+4mm</td></tr>
<tr><td rowspan="3">Concrete condition</td><td colspan="2">Drilling stage</td><td colspan="3">Dry</td><td>Dry</td></tr>
<tr><td colspan="2">Cleaning stage</td><td colspan="3">Dry</td><td>Dry</td></tr>
<tr><td colspan="2">Installation stage</td><td colspan="3">Dry</td><td>Saturated</td></tr>
<tr><td colspan="3">Cleaning method</td><td colspan="3">Method I</td><td>Method I</td></tr>
<tr><td colspan="3">Average K calculated (used)</td><td>1.923</td><td>2.212</td><td>2.005</td><td>1.569</td><td>1.503</td></tr>
</table>

Table 4- 17 Base value of the ultimate load capacity for cast-in-place, adhesive and grouted anchors

Anchor diameter (mm)	Embedment length	Base value of the ultimate load capacity (KN)*K					Factored base value of ultimate load capacity
			Adhesive			Grout	
		Cast-in-place	HIT-RE10	ROX-GU80	DUBELL.F1331	FLOW-GROUT2	
10	5db	20.40	23.46	21.27	16.647	15.94	21.28
	10db	40.80	46.93	42.54	33.294	31.89	42.55
	15db	61.22	70.43	63.83	49.957	47.85	63.83
12	5db	29.38	33.79	30.63	23.974	22.96	30.64
	10db	58.76	67.59	61.27	47.949	45.93	61.28
	15db	88.15	101.39	91.90	71.923	68.89	91.92
16	5db	52.24	60.10	54.47	42.630	40.83	54.47
	10db	104.47	120.17	108.93	85.244	81.65	108.94
	15db	156.72	180.27	163.40	127.874	122.49	163.41
Drilled hole size		-----	db+4mm			db+4mm	
Concrete condition	**Drilling stage**		Dry			Dry	
	Cleaning stage		Dry			Dry	
	Installation stage		Dry			Saturated	
Cleaning method			Method I			Method I	
Average K calculated		1.923	2.212	2.005	1.569	1.503	

*Factored base value = $K\sqrt{Fc\ cube} * \pi * db * heff$

Table 4- 7 Relative ultimate load capacity for cast-in-place, adhesive and grouted anchors

Anchor diameter (mm)	Embedment length	Ratio= (Experimental / Factored base value) ultimate load capacity: Cast-in-place	Adhesive: HIT-RE10	Adhesive: ROX-GU80	Adhesive: DUBELL.F1331	Grout: FLOW-GROUT2
10	5db	1.96	1.36	1.35	1.15	1.04
	10db	1.10	1.09	0.83	1.20	1.40
	15db	0.77	0.75	0.75	0.96	0.99
12	5db	1.42	1.61	1.10	1.20	1.09
	10db	0.82	0.99	0.78	1.00	1.36
	15db	0.58	0.69	0.61	0.89	0.95
16	5db	0.86	1.01	1.29	0.75	1.21
	10db	0.84	0.85	0.79	0.94	1.20
	15db	0.65	0.64	0.59	0.90	0.86
Drilled hole size		------	db+4mm			db+4mm
Concrete condition	**Drilling stage**		Dry			Dry
	Cleaning stage		Dry			Dry
	Installation stage		Dry			Saturated
Cleaning method			Method I			Method I
Average K calculated (used)		1.923	2.212	2.005	1.569	1.503
Maximum relative *		1.96	1.61	1.35	1.20	1.40
Minimum relative *		0.58	0.64	0.59	0.75	0.86

*Ratio equal to the experimental ultimate load capacity to factored base value of the ultimate load capacity

4.7 : Summary

The following points have been taken as a result of the present study's findings:

1. Anchors installed at low depth (5db) have an ultimate load capacity less than cast-in-place anchor ultimate load capacity but in (10db or 15db) embedment length ultimate load capacity of post-installed anchors more than ultimate load capacity of cast-in-place anchors.
2. When the anchor embedment length is increased from 10db to 15db, the average bond stress decreases.
3. It has been found that the average bond capacity factor (K) for ROX-GU80 equal to 2.005 and 1.503 for anchors installed with FLO-GROUT2.
4. In Adhesive anchors, the maximum ratio of experimental ultimate load capacity to the factored base value ultimate load capacity equal to 1.96 but the minimum experimental to the practical ultimate load capacity equal to 0.58.
5. The ratio of the ultimate load capacity to the experimental ultimate load capacity rose from 5db to 15db because cleaning quality is greater in shallow holes than in cleaning quality in deeper holes.
6. Adhesive anchors ultimate load capacity increased when the drilled hole size increased (without changing the anchor diameter) but in grouted anchors when the drilled hole size increased (without changing the anchor diameter), the ultimate load capacity decrease.
7. Adhesive anchors ultimate capacity increased when the anchors drilled holes cleaned by method II and method III compared to holes cleaned by method I,

also the grouted anchors ultimate load capacity increased when the drilled holes cleaned by method II compare to holes cleaned by method I.

8. The ultimate load capacity of the adhesive anchors installed in fully saturated concrete more than the ultimate load capacity of the adhesive anchors installed in dry concrete. But Grouted anchors installed in saturated concrete have larger ultimate load capacity compared to anchors installed in dry and fully saturated concrete.

CHAPTER FIVE

CONCLUSIONS AND RECOMENDATIONS

5.1 Conclusions:

The following study conclusions are detailed after reporting the test results for all samples.

The results demonstrated that post-installed rebar connections are appropriate for strengthening and repairing of the structures, and results show that post-installed anchors with adhesives provide similar pull-out strength or more to cast-in-place concrete with a same embedment length.

Post-installed bars with adhesives can provide precise and reliable estimations of the strength of the concrete that is already in place with very basic and inexpensive equipment. The most essential step of this process is completing all of the fixing the bar processes as described in previous chapter, including cleaning the holes and filling them with enough adhesives to completely surround the bar.

The following conclusions and recommendations could be drawn from the current study:

A. Cast-in-place Anchors

1. Cast-in-place anchors exhibited larger capacity than post-installed anchors at low embedded lengths.
2. According to the experimental results, the average bond capacity factor (K) for cast-in-place anchors equal to 1.923

B. Adhesive Anchors

1. Among the three studied adhesive brands (*HIT-RE10*, *ROX-GU80* and *DUBELLF1331*), the brand HIT-RE10" achieved the largest ultimate load capacity.
2. Cleaning methods has a significant effect on the capacity of post-installed anchors installed with adhesives.
3. Anchors can be installed in moist concrete using adhesive.
4. Adhesive anchors, as the embedment length and the bar diameter increased, the ultimate load capacity increased. The embedded length parameter is appeared to be more effective than the anchor diameter.
5. Adhesive anchors can be installed into fully saturated concrete and produce higher strength that cleaned with dry cleaning method then submerged the hole with water than those anchors installed into dry concrete that cleaned with the same cleaning methods.
6. In adhesive anchors, the cleaning method had a notable effect on the ultimate load capacity, where the cleaning method III (wash +wire brush +wash) produced the largest ultimate load capacity, followed by method I (air +Wire brush +air) then method II (air only)
7. When the thickness of the adhesives increased by (+4 mm, +8 mm and +12 mm), the ultimate load capacity decreased in 5db embedded length but there was an increase in the ultimate load capacity for the embedment length 10db and 15db.
8. In adhesive anchors, as the embedment length and the bar diameter increased, the ultimate load capacity increased. The embedded length parameter is appeared to be more effective than the anchor diameter.

9. In 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.
10. According to the results from this research, the average bond capacity factor (K) for anchors installed using adhesives of the ROX-GU80 adhesive brand is 2.005.
11. According to the results current study, the average bond capacity factor (K) for anchors installed using (HIT-RE10, DUBELL. F1331) adhesive brand is equal to 2.212 and 1.569.

C. Grouted anchors

1. Anchors can be installed in moist concrete using grouts.
2. Method of cleaning has a significant effect on the capacity of post-installed anchors installed with grouts.
3. The grouted ultimate load capacity increased when anchors installed with saturated concrete but there was a drop in the ultimate load capacity of grouted anchor if it was installed into fully saturated concrete because it will increase the water / grout ratio.
4. Grouted anchors should be installed into a saturated concrete to provide a complete hydration process.
5. Grouted anchors installed into dry concrete has lower capacity compared to the grouted anchor that installed into saturated concrete.
6. In grouted anchors, the ultimate load capacity decreased when the thickness of grout increased from +4mm to +8mm and +12mm, the reduction percentage decreased for 15db embedded length compared to 5db and 10db.

7. In grouted anchors, the cleaning method using method I(air with wire brush) had the higher bond strength compared with those cleaned by method II(air only).
8. The ultimate load capacity of grouted anchors rose as the embedment length and bar diameter increased. The anchor diameter seemed to be less effective than the embedded length parameter.
9. In both the grouted anchors, apart from the small embedment length ($5d_b$), the average bond stress for grouted anchors decreased with the increase of the embedment length.
10. According to the findings of the current study, grouted anchors have an average bond capacity factor (K) equal to 1.503.

5.2 Future work

The following are some suggests for further research:

1. Study the ultimate load capacity of anchors installed with different epoxy brands in low compressive strength concrete.
2. Compare the displacement of adhesive, grouted and cast-in-place anchors in the short-term and long-term.
3. Study the effect of the temperature at installation on the adhesive and grouted anchors.
4. Study the effect of the curing time on adhesive and grouted anchors.
5. Investigate the influence of grip pattern on the ultimate load capacity of adhesive and grouted anchors.

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ليكۆڵينەوەيەكى تاقيكارييە لە تواناى ئەو ئەنكەرانەى كە چەقێندراون لەناو كۆنكرێتدا بۆ هەلگرتنى هێزى ڕاكێشان

نامەيەكە

پێشكەشى ئەنجومەنى كۆلێژى تەكنيكى ئەندازيارى هەولێر كراوە لە زانكۆى پۆليتەكنيكى هەولێر

وەكو بەشێك لە پێداويستيەكانى بەدەست هێنانى پلەى ماستەر لە زانستى ئەندازيارى تەكنيكى شارستانى

لە لايەن

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بەسەرپەرشتيارى

د. سركوت اسعد حسن

پوختە

لەم تویژینەوەیەدا ئەوپەری توانای ئەنکەری چەقێندراو لەناو کۆنکرێتدا بۆ هەرسێ براندی ئیپۆکسی(-HIT RE10ROX-GU80,DUBELL F1331) لە گەل گراوتی (FLO-GROUT 2) هەلسەنگێندراون بە شێوازێکی پراکتیکیانە وە توانای ئەم شیشە چەقێندراوانە بە ئیپۆکسی و گراوت بەراورد کراوە لەگەل توانای شیشی دانراو لەناو کۆنکرێتی فرێشدا.

لەم تویێژینەوەدا شیشی (10ملم و12ملم لەگەل 16ملم) بەکار هاتوون بەرێژەی قولی جیاواز بۆ هەریەکێکیان (5db,10db and 15db) وە هەروەها کاریگەری رێگاکانی تاقیکردنەوە لە سەر توانای ئەنکەرەکان دیراسەکراوە کە بە ئیپۆکسی یان گراوت چەقێندراون وە هەروەها کاریگەری ئەستوری چینی ئیپۆکسی و گراوت لەسەر توانای ئەنکەری چەقێندراو دیراسەکراوەو وە توانای ئەنکەری زەرعکراو بە ئیپۆکسی یان گراوت لە کۆنکرێتی وشك و شێدار و تەڕ بەراورد کراوە.

لە ئەنجامی تاقیکردنەوەی شیشە چەقێندراوەکان بە ئیپۆکسی دەرکەوت کە ئەنکەری چەقێندراو بە ئپۆکسی -HIT RE10) گەورەترین توانی بۆندی هەیە .هەروەها دەرکەوت کە شیشی چەقێندراو بە ئیپۆکسی و گراوت بەرگری هێزی راکێشانی زیاترە لە بەرگری هیزی راکێشانی ئەو ئەنکەرانەی کە داندراون لەناو کۆنکرێتی فرێشدا بە قولی (5 ئەوەندەی تیرەی ئەنکەرەکە) وە تێکرای بۆند سترێس کەم دەکات بە زیاد بوونی قولی ئەنکەری چەقێندراو .وە جێگای ئاماژە پێکردنە کە توانای ئەنکەرەکان بەگشتی بۆ هەلگرتنی هێزی راکێشانی ئەکسیاڵ زیاد دەکات بە زیادکردنی قولی چەقێندراو و تیرەی ئەنکەری چەقێندراو.

ئەو شیشانەی کە پێش چەقاندنیان بە ئیپۆکسی کونەکانیان خاوێنکراونەتەوە بە کۆمپرێسەری هەوا توانای بەرگریان بۆ هێزی راکێشان زیاترە لەو شیشانەی کە کونەکانیان خاوێنکراونەتەوە بە فلچەی تێل و کۆمپرێسەری هەوا بەلام

ئو کونانەی کە خاوێن کراونەتەوە بە شوشتن بە ئاو لەگەڵ فلچەی تێل بەرگرییان بۆ هێزی راکێشان زیاترە لەو شیشانەی کە خاوێنکراونتەوە بە دوو رێگاکەی پێشوو.

بەشێوەیەکی گشتی شیشی چەقێندراو بە ئیپۆکسی زیادکردنی ئەستوری ئیپۆکسی توانی بەرگری بۆ هێزی راکێشان زیاد دەکاتن بەلام لە و شیشانەی کە چەقێندراون بە گراوت پێچەوانەیە بە زیادکردنی ئەستوری چینی گراوتەکە توانی بەرگری بۆ هێزی ڕاکێشان کەم دەکاتن.

ئەو ئەنکەرانەی لە کۆنکرێتی تەڕدا چەقێندراون بە ئیپۆکسی بەرگریان زیاترە لە و ئەنکەرانەی کە لە کۆنکرێتی وشکدا چەقێندراون بەلام ئەو ئەنکەرانەی کە چەقێندراون بە گراوت لە کۆنکرێتی شێدار بەرگریان زیاترە بۆ هێزی ڕاکێشان بەراورد بە و ئەنکەرانەی کە زەرعکراون لە کۆنکرێتی وشك و کۆنکرێتی تەر.