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A PRACTICAL TECHNIQUE FOR ANCHORING TO CONCRETE MEMBERS

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ABSTRACT

Designing an anchor fastener on a purely theoretical basis does not give reliable results as a rule, since accurate modeling for complicated load-material behavior cannot be achieved. Consequently, experimental work usually founds the basis of anchor fastening design. In this work, an efficient and inexpensive technique for anchoring to concrete members is investigated. First, the anchor fastening technique is explained and the structural and manufacturing aspects of the loading device are illustrated in detail. Next, the technique for measuring, recording, and interpreting the results is outlined. A study of different factors influencing the ultimate loads such as the diameter of anchor, length of anchor, and angle of anchor are included in the work. The case of bonding the anchor using a chemical bonding agent is also considered. The failure pattern of anchor fasteners for each case is depicted. Design equations, charts, and tables are concluded. Results are compared with other existing anchoring methods.

Keywords: anchors; embedments; concrete.

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Several applications in the field of construction industry require anchoring of new structural components to existing concrete structures. Extensions of existing buildings, renovations, and rehabilitation of older structures are examples of such applications. In this respect, one finds that anchoring to concrete members has received relatively little attention in the structural codes. Also, design codes do not clearly define embedment requirements, nor specify provisions to prevent brittle failure in the base-material as opposed to anchor ductile failure. Consequently, designers would usually rely on anchorage performance criteria based on experimentation (ACI 1997).

American Concrete Institute Committee 349 (ACI 1980) developed a nuclear structure code requiring stringent design criteria for nuclear applications. Canon et al. (Canon 1981) presented a guide to the design of anchor bolts and other steel embedments. They proposed a modification to Appendix B of ACI 349 nuclear structure code, which is less stringent, that would apply to industrial buildings and other structures. Shipp and Haninger (Ship 1983) highlighted the need for a complete design procedure for anchor bolts for larger loads and for a proposed probability-based design philosophy. Marsh and Burdette (Marsh 1985) described various types of anchorage devices, discussed their behavior, and presented appropriate design guidelines for implementation in industrial building construction. They discussed the two basic anchor types: cast-in-place and drilled-in anchors. Scacco (Scacco 1992) developed several design charts for anchor bolt interaction of shear and tension loads for high strength bolts, and compared the results with AISC equations for A36/A307 and A325 bolts (AISC 1989). In Egypt, one of the widely spread - yet relatively expensive - anchoring technique is Hilti (Hilti 1993).

In this work, a practical and inexpensive technique for drilled-in anchors is presented. This type of anchors is chosen since it is often quite impossible to anticipate future required embedments. The experimentation is limited to direct tensile loading. The anchors used in the research are deformed high tensile steel 36/52 bars (ECCS 2001) of different diameters, since smooth 24/36 bars offer much less development of strength along its length. Two types of anchoring systems are used: unbonded and chemically bonded. For the bonded case, ductility is assured by causing a failure mode that is controlled by yielding of the anchor steel bar, rather than brittle tensile base-material (concrete) failure mode.

To this end, the rest of this work is organized as follows. First, the experimental setup is described. This includes the design of the pull-out device, description of the measuring device, and outline of the experimental procedure. Next, several cases are presented, discussed, and assessed, followed by the conclusions.

EXPERIMENTAL SETUP

The testing device developed in this work is shown in Fig. 1. It consists of five separate parts as shown in the figure. Each part is briefly described as follows. Part A is a circular steel ring clamp split into two pieces to surround and hold the upper edge of the steel rod; part C. Part B is a 150 × 150 × 900 mm solid steel bar fitted to rest upon the two 32 ton hydraulic jacks. Part C is a solid steel rod made of steel 72 of diameter 30 mm along its length except for its upper and lower edges where the diameter is enlarged to 50 mm in order to fit inside the two-piece clamps. Part D is a 150 × 75 mm two-piece clamp connected together by four 16 mm

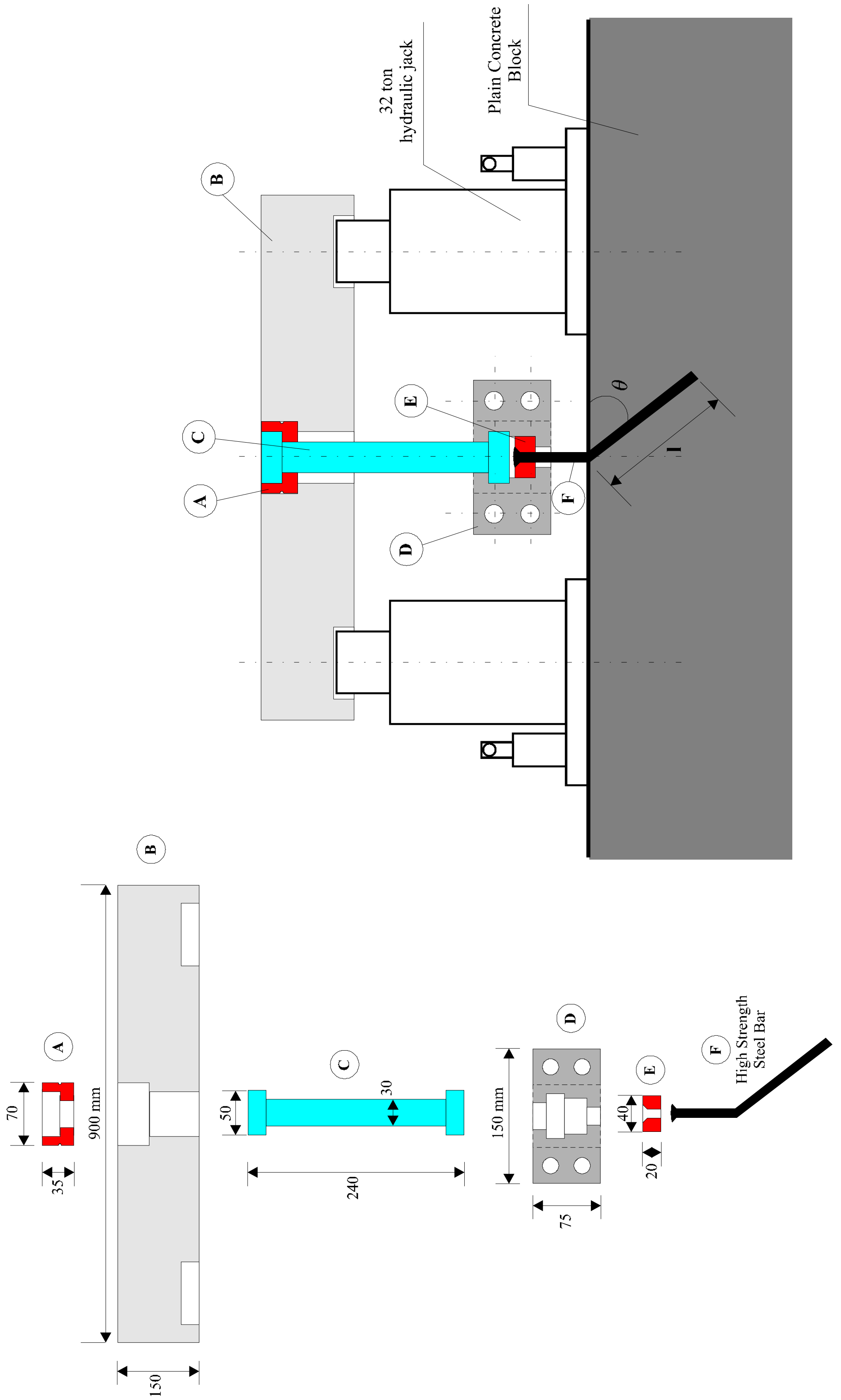

Fig. (1): Schematic Layout for the Testing Pull-out Device

bolts. This clamp holds the lower edge of the steel rod and the welded head of the steel anchor being tested. Part E is a 40 mm steel ring welded to the anchor (Part F).

The normal pull-out force is measured using a strain gauge measuring cell, mounted on the solid cylindrical rod of Part C. Two strain gauge units are connected to form a half bridge connection. The measurements are performed under amplification of 1mV/V, which means a gain of 1000. Shielded cables with length of about 1.5 m are used to avoid the effect of any foreign electric signals. Before carrying out the experiments, the resistance and capacitance of the cable and the connecting junctions are compensated using fine adjustable potentiometers. Figure 2 shows a photocopy of the experiment setup.

During the pull-out test, the two hydraulic jacks are carefully raised simultaneously causing Part B of the device to move upwards. This movement causes an increasing tensile force in both the high tensile steel rod (Part C) and the anchor (Part F). When failure of the anchor is visualized, the corresponding failure load is recorded.

Three concrete blocks (f_{cu} = 300 kg/cm^2) of dimensions 1200 × 1200 × 600 mms are used in this work. The procedure starts by drilling a hole at a specified angle measured from the concrete surface on which anchoring will take place. An angle $\theta = 30^o$ means that the anchor is deviated by 60^o from the normal to the surface. An angle $\theta = 90^o$ means that the anchor is driven perpendicular to the surface without any deviations. For the unbonded case, the diameter of the hole is equal to the anchor diameter. Once the hole is drilled down to the required embedment length, *l*, all debris and dust are removed from the hole and the anchor is driven inside the grove using a hammer. For the bonded case, the diameter of the hole is usually 4 mms wider than the anchor diameter. The groove is then filled with a chemical bonding material (Epoxy 2003) and the anchor is placed inside the groove while the Epoxy is wet. For angles different than $\theta = 90^o$, the length of the anchor protruding outside the concrete is bent to be perpendicular to the surface as shown in Fig. 1.

RESULTS AND DISCUSSION

First, experimentation with anchor fasteners at angles of 45^o for bar diameters of 10, 12, 16, and 18 mms is introduced. Each bar is driven into the concrete a distance ranging from 9 to 12 times the bar diameter, after drilling a hole with an equal diameter. No bonding agent is used for this case. Different embedment lengths are considered. Table 1 shows different bar diameters, ϕ (mms), different embedment lengths, *l* (mms), and their corresponding failure loads, F (tons). Average failure loads and corresponding allowable forces, using a factor of safety of 1.5, are also presented in the table. Ratios of allowable force values to yield forces values are also included. Failures of the same pattern are observed for all bar diameters. A concrete break-out mode of failure is caused by continuous increasing bearing forces that result in tensile stresses beyond the tensile strength of the base-material (concrete), followed by gradual straightening of the anchor, and ending with its slippage out of the concrete. Figure 3 illustrates the failure pattern for this case. It shows the concrete wedge and the bar shape after failure.

Test data of Table 1 are displayed in Fig. 4, for each diameter. Average values for each set of data are also shown. Clearly, larger failure forces are achieved for bigger diameters. It is deduced that an exponential function relationship relates the area of the bar to the ratio F_{allow}/F_y. This relation for θ=45^o is demonstrated in Fig. 5 and through the following equation

Fig. (2): The Experiment Setup

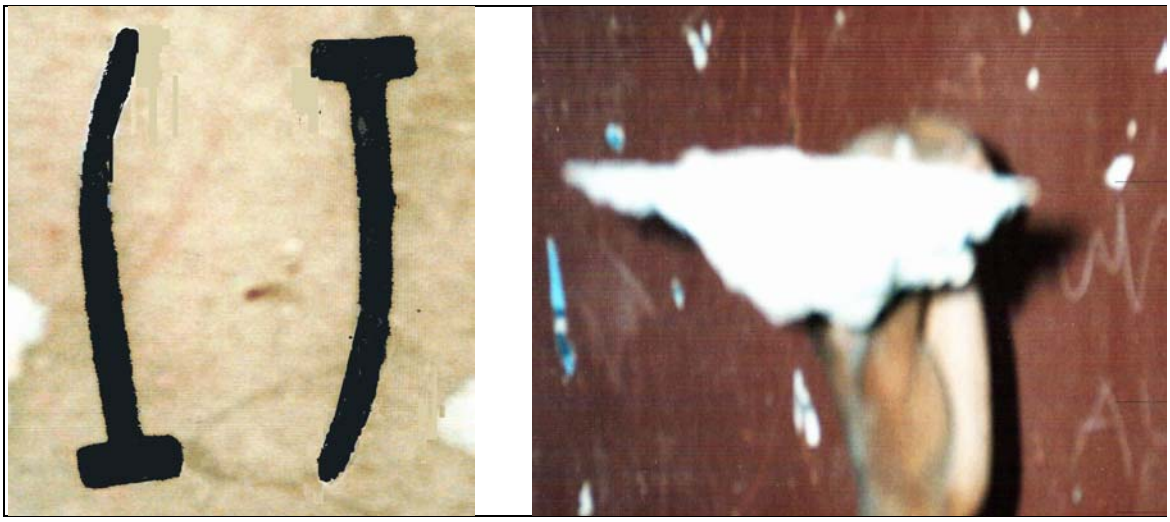

Fig. (3): Base Material Mode of Failure

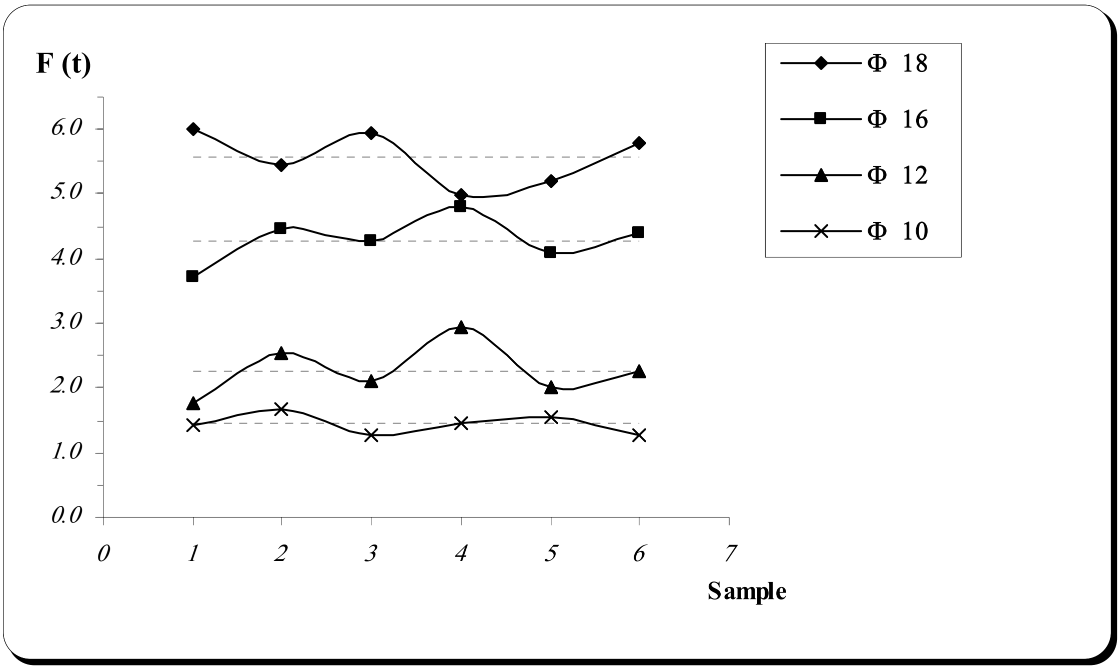

Fig . (4): Results of Ubonded Anchor at Angles of θ = 45⁰

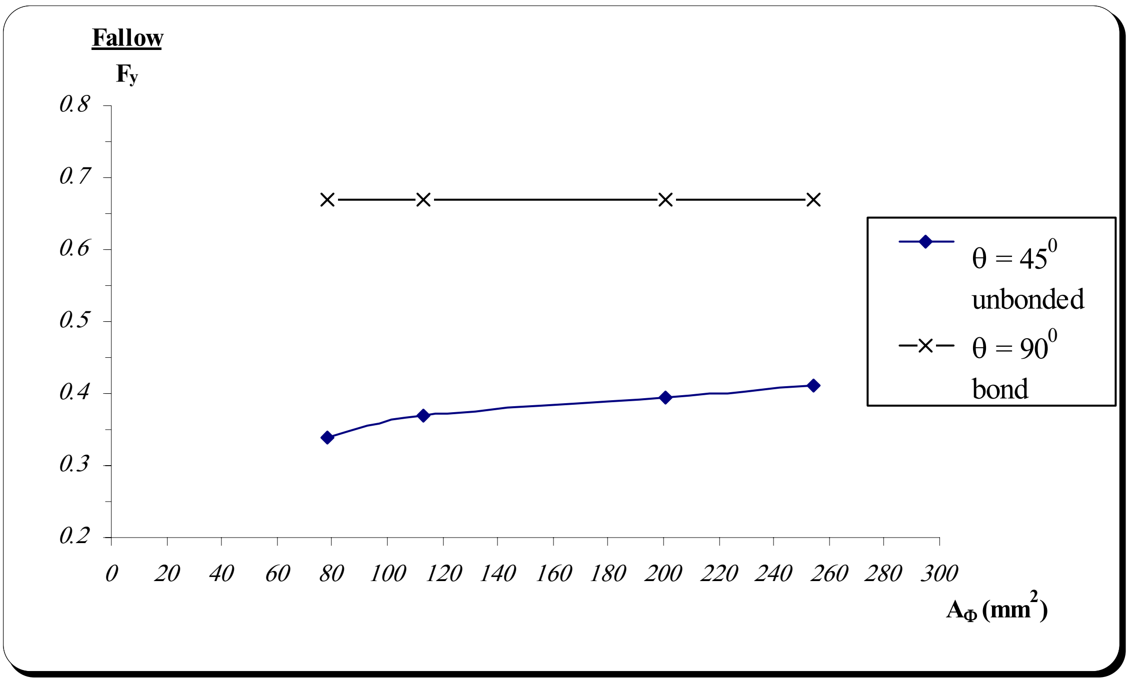

Fig . (5): Relationship between Anchor Cross-sectional Areas and Allowable Force Ratios

$$\frac{F_{allow}}{F_y} = 0.3222\, e^{(0.001 A_\phi)} \qquad (where\ R^2=0.9961) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where A_ϕ represents the area of the anchor bar in mm^2 and F_y = 3.6 t/cm^2.

Next, fasteners perpendicular ($\theta = 90^o$) to the surface, bonded with epoxy, are experimented for bar diameters of 10, 12, and 16 mms. A groove that is perpendicular to the surface is drilled with a diameter 4 mms greater than the specified bar diameter and down to a drilling depth equals to or greater than 13 times the bar diameter. Then, the hole is filled with Epoxy, which is the bonding material used in this work. The bar is driven down to the full depth of the groove while the epoxy is still wet. Table 2 summarizes the test results for different bar diameters, different embedment lengths, and corresponding failure loads. Average failure loads are also given. Figure 6 illustrates the previous results. Using a suggested factor of safety of 1.5 of the anchor yielding forces, the allowable force, F_{allow} , for each anchor diameter is also given in Table 2. The horizontal straight line shown in Fig. 5 also represents such values.

Values of Table 2 indicate that the force resistance levels for this bonded case go beyond the bars yield resistance and approach their ultimate strengths. The steel rupture failure pattern, shown by the right anchor in Fig. 7, is evident to this fact. In the process of analyzing the results, it is found that the bonding stress, f_b, of Epoxy is about 100 kg/cm^2. Using this value and the following two equations for θ=90^o, two bounding embedment length limits are deduced:

$$l_y = \frac{F_y}{\prod \Phi f_b} = \frac{f_y A_\Phi}{\prod \Phi f_b} = 9\Phi \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$l_u = \frac{F_u}{\prod \Phi f_b} = \frac{f_u A_\Phi}{\prod \Phi f_b} = 13\Phi \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where l_y is the embedment length at which yield of the steel bar occurs while l_u is the embedment length at which rupture of anchor takes place. Figure 8 shows that if the embedment length is less than 9 times the bar diameter, a slippage mode of failure, with a small cone of concrete splitting from the block, will occur, as shown by the left anchor in Fig. 7. On the other hand, if this length is greater than 13 times the bar diameter, a steel breakage will occur. However, if the embedment length ranges from 9ϕ to 13ϕ, either mode of failure may occur.

A further investigation is conducted in order to study the effect of embedment length on the force resistance levels. Table 3 and Fig. 9 summarize the results of ϕ 16 bars driven at angles of θ=45^o, bonded with epoxy, for different embedment lengths. A concrete break-out mode of failure due to bearing forces that produce tensile stresses exceeding those of the base-material occurs. Using nonlinear regression analysis, the following equation is deduced to represent the behavior for ϕ=16mm and θ=45^o:

Table (1): Results for Unbonded Anchors at Angles of θ = 45^0

Φ		Sample						$F_{aver.}$	F_{allow}	F_{allow} / F_y
		1	2	3	4	5	6			
18	F(t)	6	5.45	5.93	4.97	5.2	5.8	5.56	3.71	0.41
	l(mm)	165	170	170	170	170	170	170	170	
16	F(t)	3.7	4.46	4.27	4.79	4.08	4.4	4.28	2.86	0.395
	l(mm)	160	150	170	160	150	170	160	160	
12	F(t)	1.76	2.53	2.11	2.93	2.02	2.25	2.27	1.51	0.37
	l(mm)	140	150	140	140	150	140	143	143	
10	F(t)	1.43	1.68	1.26	1.46	1.55	1.26	1.44	0.96	0.34
	l(mm)	100	100	110	130	80	100	103	103	

Table (2): Results for Bonded Anchor at Angles of θ = 90^0

Φ		Sample						F_{aver}	$F_{allow} = F_y/1.5$
		1	2	3	4	5	6		
16	F(t)	11	11	9.87	11	9.87	9.87	10.44	4.82
	l(mm)	220	225	210	215	215	230	219	
12	F(t)	4.23	5.05	5.05	5.56	5.56	5.1	5.09	2.71
	l(mm)	140	140	150	170	130	170	150	
10	F(t)	4.23	4.23	4.23	4.57	3.81	4.02	4.18	1.9
	l(mm)	170	160	170	160	170	150	163	

Table (3): Results for Bonded Φ =16 at Angles of θ = 45^0

F(t)	2.48	2.78	3.51	5.05	8.52
l(mm)	110	120	130	150	175

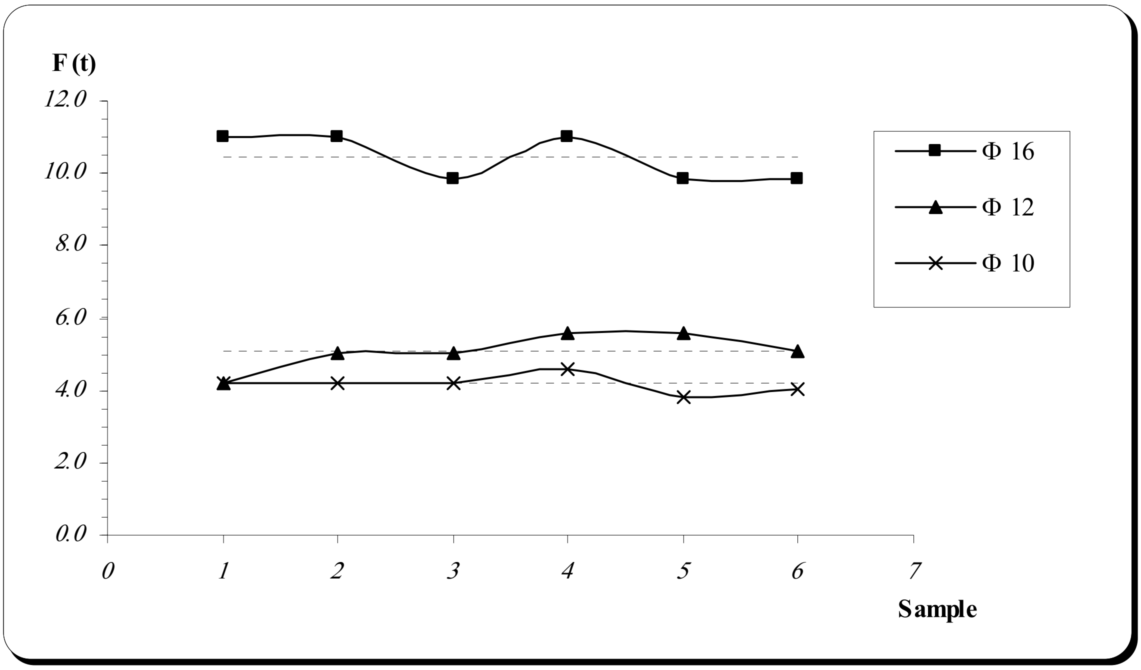

Fig . (6): Results for Bonded at Anchors Angle of θ = 90^{0}

Fig . (7): Slippage of Bars and Steel Rupture Failure Patterns

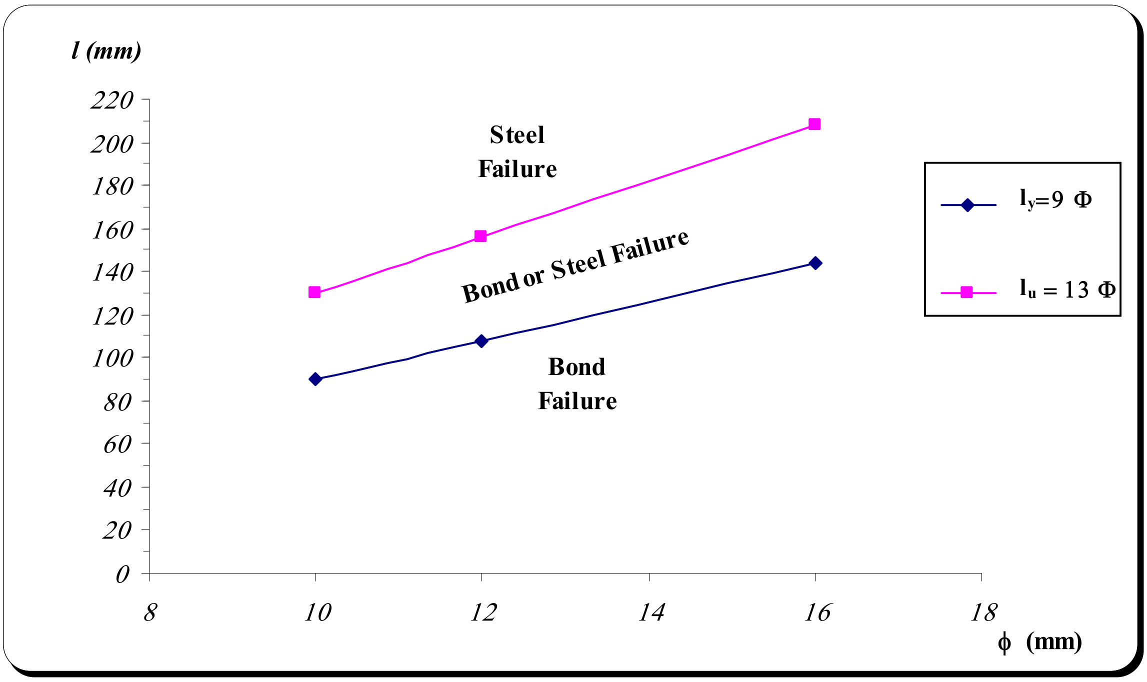

Fig. (8): Bounding Limits for Different Failure Modes, $\theta = 90^o$

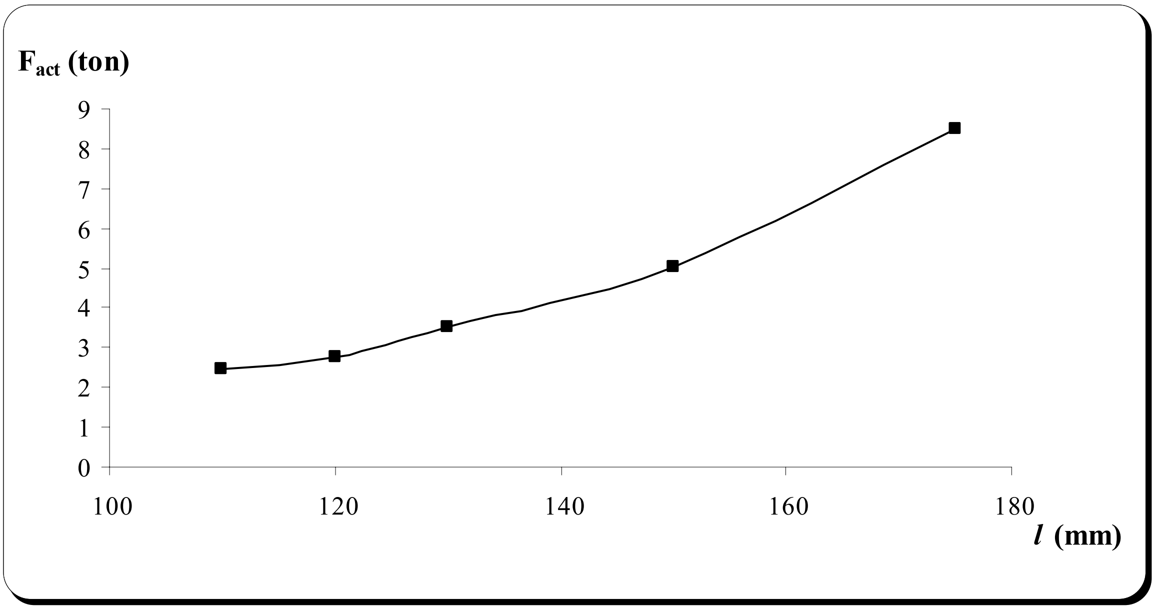

Fig. (9): Failure Force for Bonded ϕ 16 at Angle of $\theta = 45^0$
Versus Embedment Length

$$F_{act} = 0.2846\, e^{(0.0193\, l)} \qquad (where\ R^2=0.9304) \ \ldots\ldots\ldots\ldots\ldots\ldots \ (4)$$

Similar experimentation is done for anchors perpendicular (θ=90^o) to the surface. Table 4 and Fig. 10 illustrate the results for this case. The behavior can be approximated by a bi-linear curve. The first portion represents a linear relationship between embedment length and failure forces. Slippage modes of failure are detected for this interval. When the embedment length reaches or exceeds 9 times the bar diameter, the bonding resistance exceeds the yielding capacity of the anchor; and hence failure of steel occurs.

A comparison of the results shown in Fig. 9 for $\theta = 45^o$ and Fig. 10 for $\theta = 90^o$ indicates that higher resistances are achieved for the later case, for the same embedment lengths, for bonded $\phi 16$ anchors. This is due to the fact that concrete break-out mode of failure (base-material failure) occurs before slippage or steel breakage modes of failure for higher levels of forces, as in the case of bigger diameters. However, this distinction tends to vanish for smaller forces. In other words, similar failure values are achieved for bonded $\phi 12$ for the case of θ = 45^o and θ = 90^o, reasonably embedded into concrete ($l > 9\phi$), with a steel rupture mode of failure most likely to occur.
Other embedment angles are also investigated. Figures 11 and 12 show comparisons between unbonded cases for angles of 30^o and 45^o, for $\phi 12$ and $\phi 16$, respectively. Clearly, better results are achieved for θ = 45^o. This is because concrete break-out occurs for smaller embedment angles at smaller forces.

Finally, a comparison is conducted between the anchoring technique developed in this work and Hilti anchoring technique. Table 5 and Fig. 13 compare the results for unbonded anchors for angles of θ = 45^o. It can be seen that Hilti provides better results for this case. The other comparison is conducted for θ = 90^o , for bonded anchors. Figure 14 and Table 6 show that better results are achieved for the bonded case for the anchoring method investigated in this work over Hilti results.

CONCLUSIONS

A practical and efficient anchoring method is investigated in this work. A pull-out testing device is developed. Different anchor diameters, different anchoring angles, and different embedment lengths are considered. Bonded and unbonded anchors are investigated. The following conclusions are drawn:

1. Higher force levels are achieved for bigger diameters (Figs. 4 and 6).
2. Design tables are developed for unbonded and bonded cases (Tables 1 and 2).
3. Embedment lengths of 9 to 13 times the anchor diameter are recommended for ductile behavior.
4. Bonding the anchor using chemicals improves its behavior drastically (Fig. 5).
5. Bonding the anchor for θ = 45^o yields similar results as when bonding it for θ = 90^o, for $\phi 10$ and $\phi 12$ diameters. This provides anchoring flexibility for cases where some obstacles, such as reinforcement, prevent drilling the anchor perpendicular to the surface. However, for bigger diameters (e.g. $\phi 16$), higher force levels are achieved for the θ = 90^o bonded case over the θ = 45^o bonded case (Figs. 9 and 10).
6. For unbonded cases, results for embedment angles of θ = 45^o overrides those for angles of θ = 30^o, for different diameters (Figs. 11 and 12).

Table (4): Results for Bonded Φ =16 at Angles of $\theta = 90^0$

F(t)	5.05	9.87	11	9.87	11
***l*(mm)**	120	140	150	210	240

Table (5): Comparison between Hilti and this Work (Unbonded, $\theta = 45^0$)

Φ	**$F_{allow.}$ (t)**	
	Hilti	**This work**
10	1.36	0.96
12	1.98	1.51
16	3.42	2.86

Table (6): Comparison between Hilti and this Work (Bonded, $\theta = 90^0$)

Φ	**$F_{allow.}$ (t)**	
	Hilti	**This work**
10	1.04	1.9
12	1.5	2.71
16	2.57	4.82

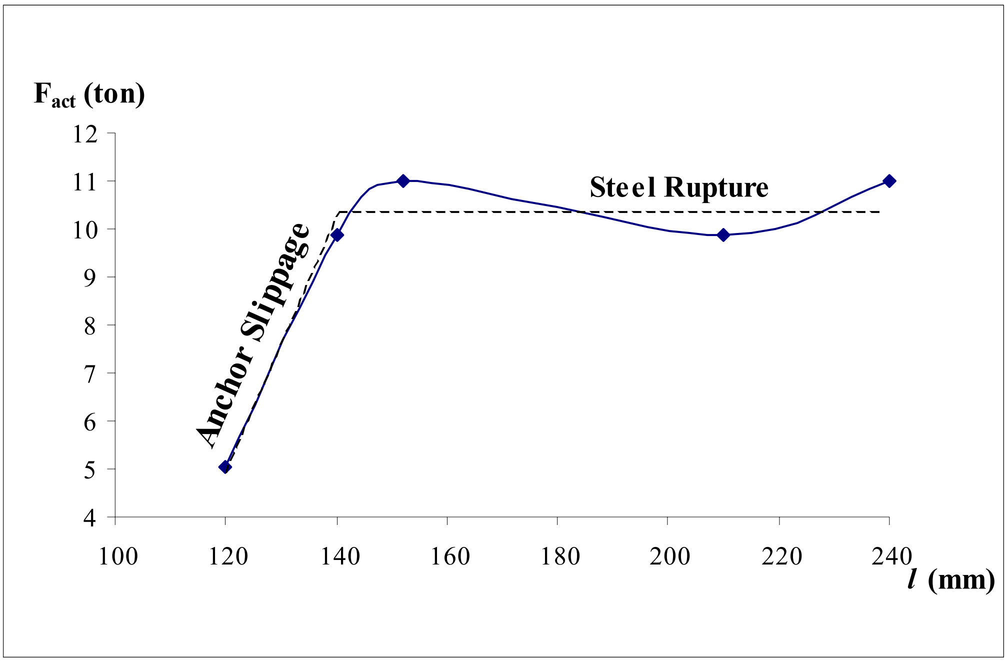

Fig. (10): Failure Force for Bonded ϕ 16 at Angle of $\theta = 90^0$ Versus Embedment Length

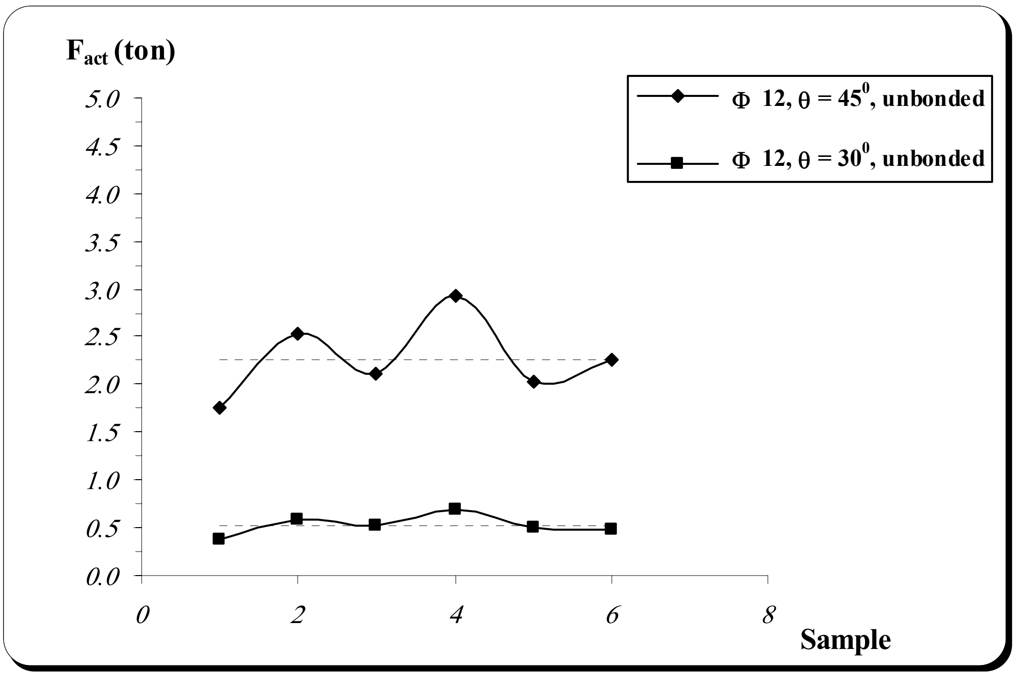

Fig. (11): Comparison for Different Embedment Angle for ϕ 12

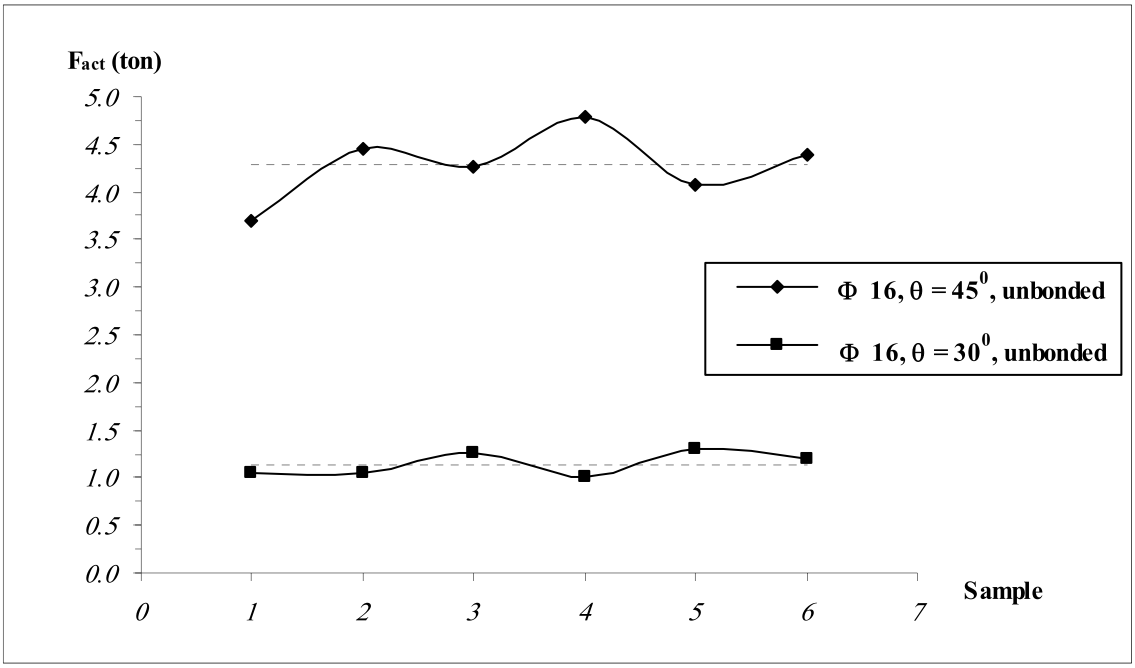

Fig. (12): Comparison for Different Embedment Angle for ϕ 16

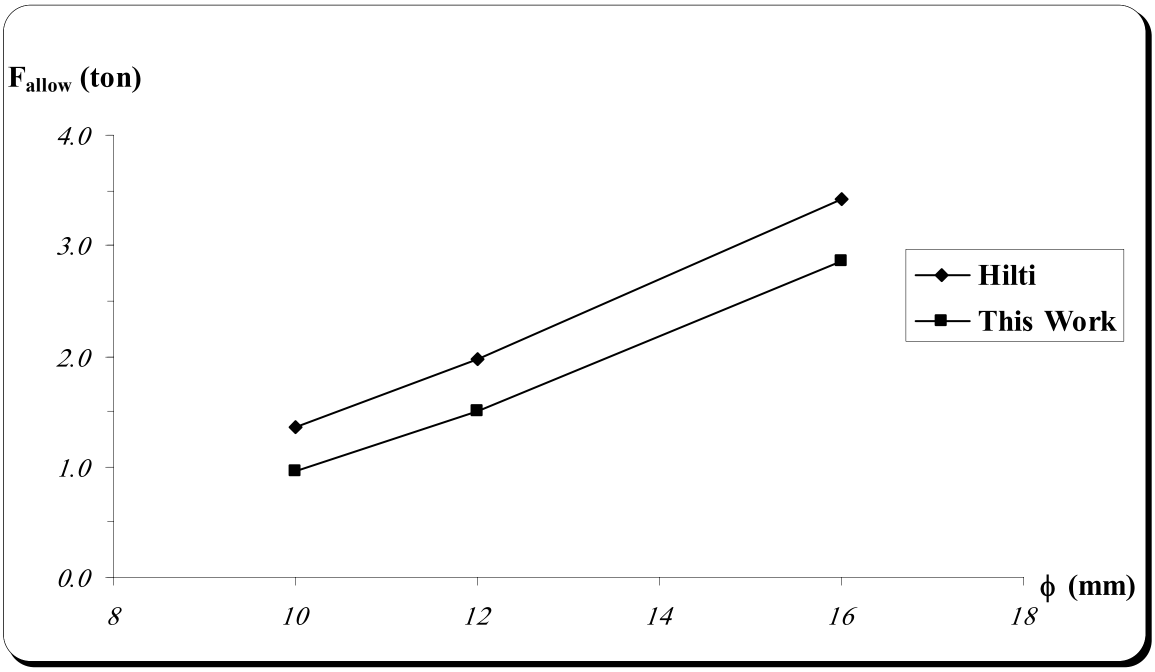

Fig. (13): Comparison of Unbonded Anchor at Angle $\theta = 45^0$ with Hilti Values

7. For unbonded cases, Hilti anchoring technique provides better results (20 - 40 %) than the technique developed in this work, for embedment angles of $\theta = 45^o$ (Fig. 13).

8. For bonded cases, the method investigated in this work supercedes (80 - 90 %) Hilti anchoring technique for anchors perpendicular to the surface, for a cost that is less than 10% of the price (Fig. 14).

It is important to note that several aspects remain open for future research. Shear loading, combined shear and tension loading, group effect, edge distances, anchoring to reinforced concrete, and usage of higher steel grades for the anchors, are some of these topics.

ACKNOWLEDGMENTS

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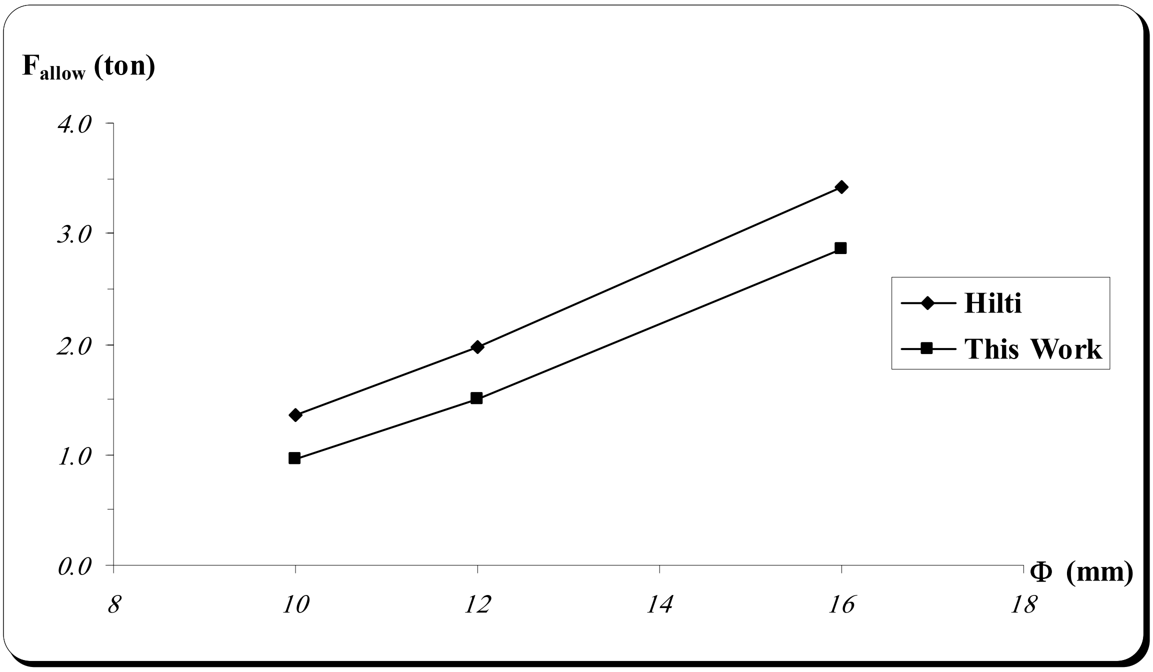

Fig. (14): Comparison of Bonded Anchor at Angle $\theta = 90^0$ with Hilti Values

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ملخص

إن تصميم المسامير الرابطة بالعناصر الخرسانية بناءاً على أسس نظرية لا يؤدى – كقاعدة عامة – إلي نتائج دقيقة، حيث أن التمثيل الدقيق لسلوك المواد والأحمال شيء لا يمكن تحقيقه. بالنتيجة، فإن الاختبارات المعملية تمثل عادة الأسس المعتمدة لتصميم المسامير. يقدم هذا البحث طريقة اقتصادية وذات كفاءة للربط بالعناصر الخرسانية. يبدأ البحث بتقديم شرح مفصل لجهاز التحميل الذي تم تصميمه في هذا العمل مع وصف جهاز القياس المستخدم وطريقة القياس. تمت دراسة تأثيرات العناصر المختلفة التي تؤثر على مقاومة المسامير مثل قطر المسمار وطول الرباط وزاوية الربط. أيضاً تمت دراسة حالات تثبيت المسمار باستخدام مواد كيميائية رابطة. وأخيراً يعرض البحث إلى أشكال الانهيار في الحالات المختلفة مع تقديم جداول ومعادلات ورسومات كمساعدات للتصميم. وأخراً تقدم هذه الدراسة مقارنة بين الطريقة المقدمة في هذا العمل وبعض أساليب التثبيت المعروفة.

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