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Non-destructive Testing Method to Evaluate the Load Carrying Capacity of Nails

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ABSTRACT. Anchor nails are commonly used in the construction industry. They are categorized as epoxy and friction nails. Epoxy nails are stronger but they require skilled labor for installation and are expensive. For general applications mechanically installed friction nails are preferred. Till date there exists no non-destructive testing method to estimate the load carrying capacity of these nails. The study presents a newly developed non-destructive testing method to estimate load carrying capacity by relating the rebound value of Schmidt hammer to the pull-out load carrying capacity of nail. Factors affecting the rebound hammer such as hardness of the nail head, embedment length, diameter, concrete strength, the damage caused inside the concrete, nail alignment and the interfacial frictional bond are also studied. A relationship between pull-out strength and rebound value R for 50 and 38 mm diameter nails with embedment lengths of 10 and 20 mm is presented.

Keywords: Concrete friction nails, Non-destructive testing, Schmidt rebound hammer, Impact load, Pull-out strength, Capacity evaluation.

List of Symbols:

R=	Rebound Value
$R_{1,2,3}$=	Recorded Rebound Reading
R_{avg}=	Average Rebound Value
P=	Pull-out Strength Capacity
V=	Vertically Aligned Anchor
NV=	Non-vertical Anchor
BI=	Bent Inside
D=	Stress reduction ratio, q_{fioe}/q_{yi}
q_f =	Frictional force per unit length on detached/de-bonded interface
q_y=	Maximum force per unit length

1. Introduction

Anchoring nails are extensively used in the construction industry. Their applications range from supporting temporary non-structural elements to fixing support elements in wooden housing industry. They are also used for a variety of general purposes such as for installing netting to prevent damage caused from falling debris, installing plastic sheets to prevent moisture movement, supporting temporary structures etc. Mainly there are two types of anchoring nails used in the construction industry.

a) Mechanically installed concrete anchor nails installed using impact loading without drilling hole that owe their strength capacity to frictional force.

b) Epoxy anchors installed by drilling hole and fixing the anchor using epoxy resin.

Although the epoxy anchors are stronger but they are difficult to install and require more care, time and skilled labor whereas for general purposes where time and space are limited the mechanically installed anchor nails are more efficient and effective. Even though these types of nails are widely used in the construction industry, still there does not exist any non-destructive method to estimate their strength capacity. Takiguchi et al. [1] investigated the pull-out capacity of large anchor bolts embedded in reinforced concrete shear walls in nuclear power plants using a destructive method. However, for small nails installed using impact loading there exist no field testing method. In this regard, the presented study is a pioneer as it presents the non-destructive capacity evaluation method for small nails by relating Schmidt hammer rebound value to the pull-out strength of nails.

Schmidt hammer developed in 1948 [2] by a Swiss engineer Ernest Schmidt is a portable, cost-effective instrument capable of estimating the elastic strength of hardened concrete. It is a practical non-destructive method that has been used worldwide as an index test for evaluation of strength of hardened concrete. Miller and Barton et. al. [3-4] correlated the rebound value to the compressive strength of rocks, furthermore Murat [5] developed an Artificial Neural Networks (ANN) based model for the prediction of the unconfined compressive strength of rock from Schmidt hardness. Torabi [6] developed a new approach to establish a relationship between N and UCS of a rock mass under particular geological circumstances. Several researchers in the past [7-10] have worked on developing empirical relationship between rebound readings and compressive strength determined from standard testing. There are two types of Schmidt hammers. *L*-type, usually used for rock and *N*-type, used for concrete. The degree of rebound varies, depending upon the concrete elastic properties. Bilgin et. al. [11] used *N*-type Schmidt hammer rebound values with success for the performance prediction in Istanbul metro tunnel drivages.

2. Materials and Methods

Figure (1) shows the anchor nail installation procedure. Nails were installed in concrete using impact loading from air gun. A wooden guide block was placed on the surface of concrete to guide the anchor nail installation. Table (1) shows the values of anchor nail lengths, wooden guide thickness and penetration depth used in this study.

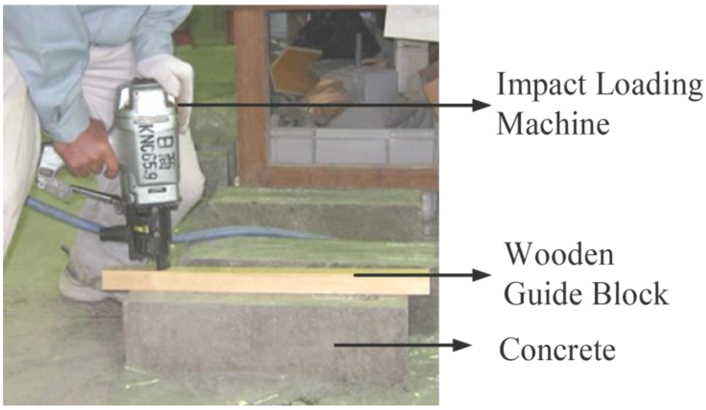

Fig. (1). Installation of anchor nail

Table (1). Anchor nail length, wooden guide thickness and penetration depth values

No.	Anchor Nail Length (mm)	Wooden Guide Thickness (mm)	Penetration Depth (mm)
1	38	30	10
2	38	30	20
3	50	40	20

Four specimens of 150 x 150 x 530 mm were prepared using normal strength concrete with water content 160 kg/m^3, cement 288 kg/m^3, air entrained 4.1%, sand and gravel 828 kg/m^3 and 1043 kg/m^3 respectively and the water–cement ratio (w/c) was 55.5%. The slump was 16.3 cm and 7 day compressive strength was 28.5 MPa where high early strength cement was used. The maximum size of the aggregate was 20mm. Steel anchor nails with Rockwell hardness (HRC) number 53 ± 3 and diameter of 2.75 mm were used for the experiment. The specimens were placed on a flat concrete floor surface. After the installation of anchor nail the guide block was removed and test hammer rebound readings were taken at the head of anchor nail as shown in the inset of Figure (2). The objective of the block was to facilitate vertical penetration of nail in concrete but during experimentation it was observed that the recoil of the air gun had a profound effect on the nail verticality. In case of controlled recoil of the air gun, vertical penetration was observed. However, in-case when the air gun recoiled uncontrollably, non-vertical nail installation was observed. Hence, in-order to attain vertical nail installation the recoil of the air gun should be controlled. The vertical alignment of test hammer with anchor nail was adjusted by visual inspection and the test hammer tip was arranged perpendicular to nail head. Three readings were categorized as one set and the average value was used for further calculations.

Fig. (2). Rebound reading and welded screw rod

A screw rod was welded to the head of anchor nail and the maximum pull-out load was recorded using a 100 kN load cell placed at the top of center hole jack as shown in Figure (3), which shows the pull-out experimental test setup used in the presented research.

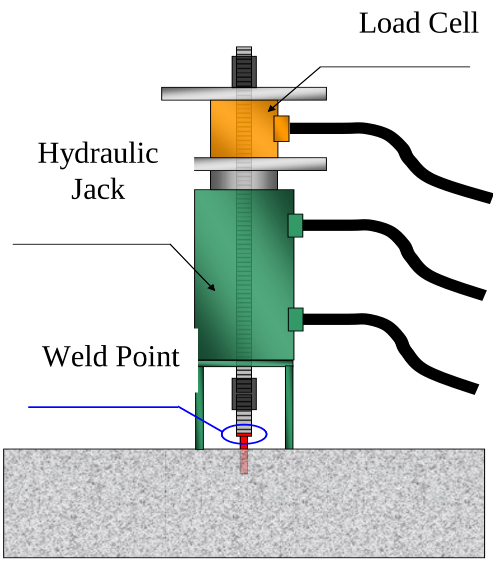

Fig. (3). Pull-out assembly

The flow of methodology adopted is as illustrated in Figure (4), where first concrete casting was done and upon achieving the desired strength, anchor installation was carried-out, once the misaligned nails were identified rebound hammer readings were taken and recorded. Afterwards the pull-out load capacity was recorded by physically pulling out the anchor nail using a hydraulic jack apparatus, as shown in Figure (3). A detailed analysis of the results produced by the experimentation was carried-out to identify the misaligned readings and to eradicate any errors. Several problems were also identified while recording the readings of the rebound hammer. It is challenging to record repeated reading on top of nail head. Initial rebound hammer blow on the nail head can result in slight indentation of top of the nail, which upon second and third attempt can become slippery and lead to errors. Several reading were missed as a result of the mentioned phenomenon, see Table (2, 3 and 4). However this difficulty in taking rebound hammer readings can be eliminated by using an alignment tube to align the nail head with the rebound hammer shaft.

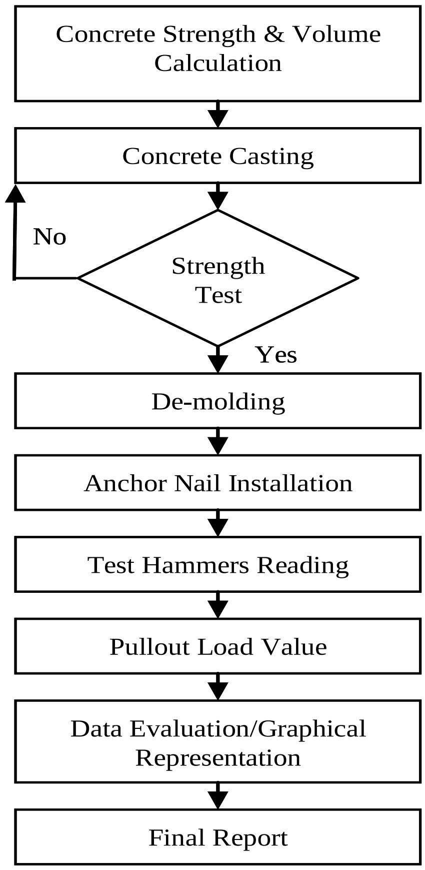

Fig. (4). Flow chart of experimental procedure

3. Factors Influencing the Pull-Out Load Carrying Capacity of Anchor Nails

Figure (5) represents the conceptual schematic diagram showing the internal stress distribution and cracking pattern of the test specimen. Traditional anchor pull-out test result in cone type failure of concrete, however owing to the nature of the bond between the surrounding concrete and anchor nail, slippage and eventual extraction of the anchor nail was expected. During experimentation it was observed that the rebound value of the anchor nail is deeply affected by the embedment length, anchor nail diameter, concrete strength and the interfacial bond between the anchor nail and the surrounding concrete.

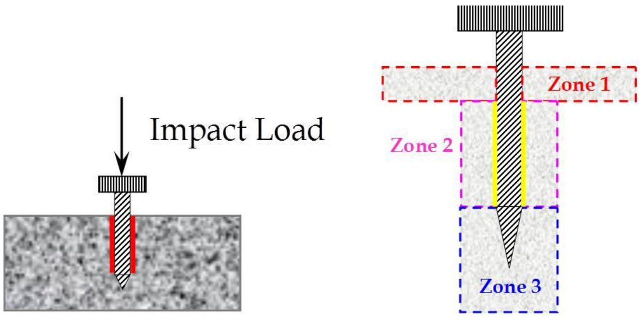

Fig. (5). Conceptual diagram of damage zone along the amendment length of anchor nail

4. Effect of Impact Loading on Surrounding Concrete

During anchor nail installation in concrete by impact loading some damage was observed on the surface of concrete. The damaged zone of the concrete has been divided into three distinct zones as shown in Figure (5). The first being the top cover layer which can get damaged during the installation of the anchor nails, followed by the intermediate zone where interfacial cracks can be observed as shown in Figure(6) and Figure (7). These interfacial cracks occur owing to the penetration of nail in concrete. The bottom zone is the energy transfer zone where the impact energy is transferred to the surrounding concrete. It can be noted that friction nails owe most of the load carrying capacity to the intermediate zone and bottom zone. Ink injection method was employed to study the interfacial cracking, it was observed during microscopic evaluation that the denser intermediate zone resulted in a higher load carrying capacity while the cracked interfacial zone lead to a reduced load carrying capacity. The main reason being the ability to transfer frictional force to the surrounding concrete, thin and long cracking inside the concrete was observed in high damage conditions. Furthermore, it was also observed during experimentation that the presence of sub-surface aggregate below the tip of the nail resulted in bending of the nail inside the concrete which lead to poor pull-out strength and large damage to the surrounding concrete. Such nails are categorized as Bent Inside concrete nails (*BI*) in the presented research work.

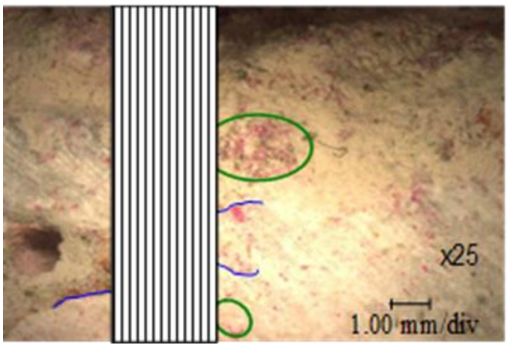

Fig. (6). Damage to the concrete

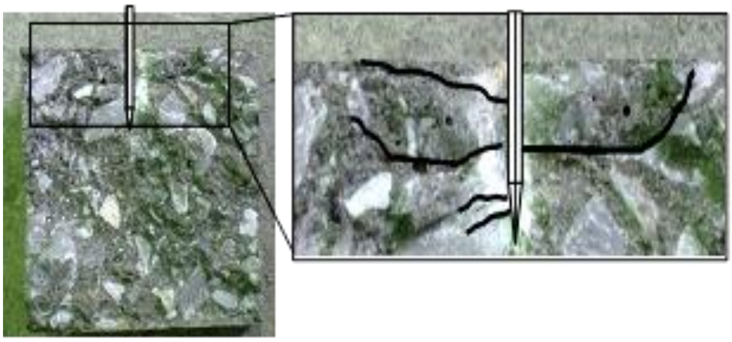

Fig. (7). Microscopic evaluation of damage inside concrete

5. Bond Evaluation

The interfacial bond between the anchor nail and the surrounding concrete can be categorized as a frictional bond. Saleem et. al. [12-14] developed a constitutive relationship describing the de-bonding behavior and pull-out of the anchor rods as shown in Figure (8). The constitutive relationship is expressed by Equations (1) and (2), where q is the force per unit length acting on the interface, q_f is the frictional force per unit length, and $U(x)$ is the pull-out displacement. The constitutive relationship can be explained as a linear branch up to the shear strength followed by de-bonding at the interface and a sudden drop Dq_y in the shear stress followed by constant stress acting along the de-bonded interface. In an actual case the stress after de-bonding is not constant because the frictional stress becomes variable at large interfacial slip. However the model is valid for the presented as it explains the complete detaching of the anchor nail from the surrounding concrete. It is seen that prior to cracking the frictional bond offers sufficient strength to carry the load, however upon the commencement of micro-cracking the frictional bond diminishes and a constant frictional force becomes active owing to the contact surface between the nail and the surrounding concrete. This explanation is also useful to explain the cracking pattern as shown in Figure (6), where upon commencement of slipping a constant frictional force which is dependent upon the contact surface area becomes dominant.

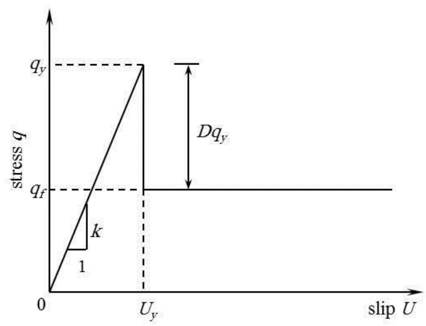

Fig. (8). Constitutive relationship of bond between anchor nail and surrounding concrete

$$q = k\,U(x) \qquad 0 < x < (L - a) \tag{1}$$

$$q = q_f \qquad (L - a) < x < L \tag{2}$$

6. Evaluation of Pull-out Strength

During experimentation it was observed that the rebound value of test hammer was effected by various factors such as hardness of the nail head, damage caused inside the concrete, interfacial frictional bond, anchor nail alignment, diameter and embedment length. The anchor nail alignment plays a significant role in the overall load carrying capacity. The verticality of the anchor nails was monitored visually with a margin of $\pm$ 5°. It was observed that vertical anchor nails were able to sustain a larger pull-out load carrying capacity as compared to the non-vertical anchor nails. Different nail configurations were observed during the pull-out experiment are shown in Figure (9). These are categorized as bent inside concrete (*BI*), inclined pull-out (*NV*) and straight pull-out (vertical *V*). It was also recorded that the alignment and stability of the impact installation device affected the anchor nails indentation and the eventual pull-out failure. Ill-aligned impact device lead to a *NV* penetration and unstable and uncontrollably recoiled indentation lead to *BI* penetration. This condition is also indicative of the presence of course aggregate under the impact penetration location. However these issues can be rectified in the practical work situation by educating the work force and hence a good load carrying capacity can be achieved. Table (2 and 3) shows the pull-out capacity *P* and rebound value *R* of the 38mm anchor nail length with the embedment length of 10 and 20mm, respectively. $R_{1,2,3}$ represent the set of three rebound readings as recorded on the nail head and R_{avg} represent the average value of rebound number. From the tables it can be seen that several values of test hammer readings are missing. This can be attributed to the explanation that attempts to take repeated readings on top of the anchor nail lead to a slippery top surface which resulted in errors.

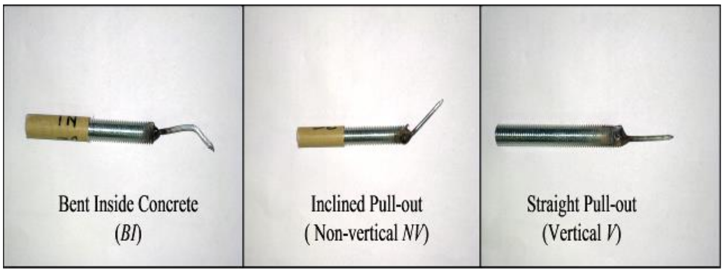

Fig. (9). Nail configurations after pull-out

Table (2). Test hammer reading and pull-out load for 38mm length nail with 10 mm embedment

Nail No.	R_1	R_2	R_3	R_{ave}	P (N)	**Comments**
1	19	-	13	16.0	4.50	V
2	18	14	21	17.7	7.54	V
3	11	15	-	13.0	7.24	NV
4	21	22	19	20.7	15.00	V
5	22	27	32	27.0	38.12	V

Table (3).Test hammer reading and pull-out load for 38mm length nail with 20 mm embedment

Nail No.	R_1	R_2	R_3	R_{ave}	P (N)	Comments
1	22	14	27	21.0	79.54	V
2	10	17	-	13.5	49.76	NV
3	27	27	27	27.0	106.01	V
4	11	-	23	17.0	76.45	V
5	13	11	18.5	14.2	65.00	V
6	-	10	18	14.0	51.41	NV
7	21	15	18	18.0	93.78	NV

Table (3). continued

Nail No.	R1	R2	R3	Rave	P (N)	Comments
8	13	17	-	15.0	58.10	V
9	20.5	21.5	23	21.7	81.25	NV
10	-	17	21	19.0	95.00	V
11	13	19	16	16.0	71.57	V
12	29	21	25	25.0	101.94	V
13	21	18	24	21.0	101.22	V
14	25	-	27	26.5	112.13	V
15	18	20	19	19.0	86.65	V
16	10	17.5	24	17.2	71.11	V
17	19	25	13	19.0	84.21	V
18	30	18	24	24.0	99.72	V
19	21	-	26	23.5	101.22	V
20	20.5	21.5	23	21.7	93.41	NV

However, erroneous readings were ignored and did not affect the presented results. The evaluation method for the pull-out load capacity was derived keeping in reference the 3mm diameter anchor nails which require drilling. The mean pull-out strength for these types of nails ranges between 80 to 250 N. It can be seen from Figure (10, 11 and 12) that for vertical (*V*) anchor nails, for all the embedment length and diameter, showed the rebound value between 10 and 30 with larger rebound values resulting in larger pull-out loads. However, as the embedment length increased the load carrying capacity also increased. The presented result in the Figure (10) is to communicate to the readers as a proof of concept that the impact loading can be used to judge the quality of the bond between nail and surrounding concrete. However, it is highlighted that in real world situation small penetration depth such as 10 mm will not require impact load inspection as such small penetration depths are rarely used. So the sole objective of the presented figure is to communicate the existence of a clear relationship between rebound number R and pull-out strength P. It can be seen from the results presented in Figure (11 and 12) that as the diameter of the anchor nail increased the load carrying capacity also increased for the same embedment length. From the Figures (11 and 12) it is evident that same diameter of the anchor nails, load carrying capacity increases for an increased embedment length. The phenomenon can be attributed to the presence of larger surface area available to transfer the pull-out force to the surrounding concrete which leads to an increased load carrying capacity. Furthermore it can be seen that as the diameter of the anchor nail increases the load carrying capacity also increases. In addition it can be seen from the figures that the *NV* and *BI* anchor nails can be easily identified from the results as their values either lie outside the prescribed range or they show lower load capacity. Figure (13) depicts the average rebound value and pull-out strength observed for 38 mm and 50 mm diameter anchor nails that were aligned exactly vertically. The average rebound values of 38 and 50 mm diameter anchor nails were almost at the same level at about 20 which is 16.4 % greater than that in the 38 mm diameter nails. However the maximum pull-out strength was noticed in 50 mm diameter nail followed by 38 mm nail respectively. The maximum average pull-out strength was 152.57 N which was 74% greater than 38 mm nail. While the difference in strength among 38 mm nails with 10 mm embedment length and 20 mm embedment length was almost 4.5 times.

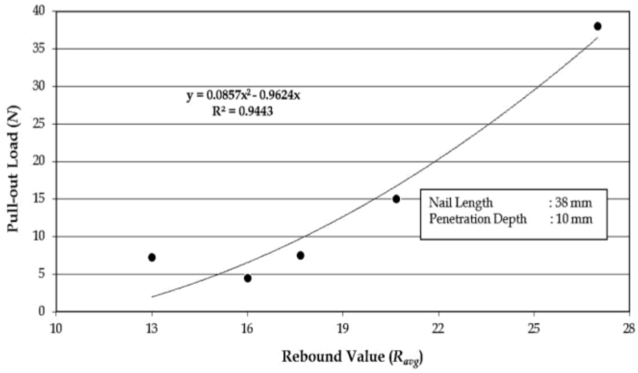

Fig. (10). Pull-out load and rebound value relationships for 38 mm nail length with 10 mm embedment

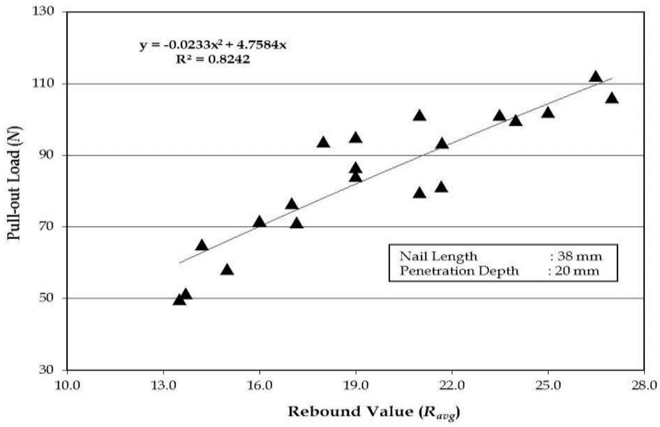

Fig. (11). Pull-out load and rebound value relationships for 38 mm nail length with 20 mm embedment

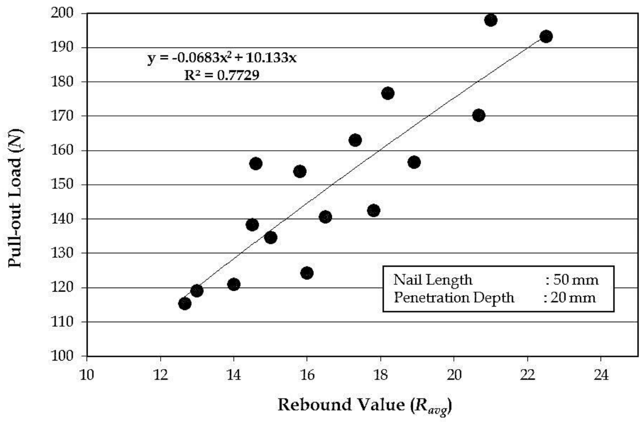

Fig. (12). Pull-out load and rebound value relationships for 50mm nail length with 20 mm embedment

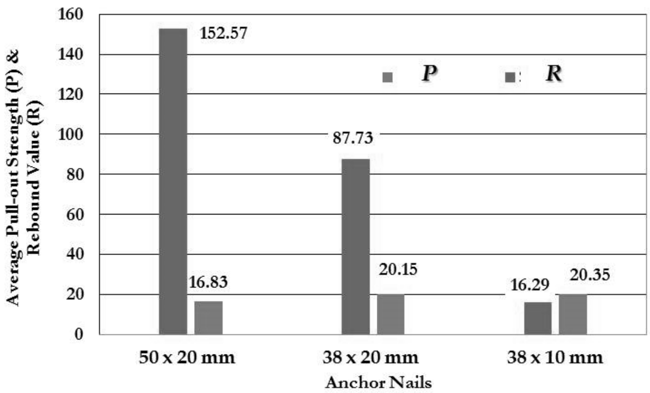

Fig. (13). Average rebound value and pull-out strength comparison

It can be seen from the result that even for same rebound value the pull-out value for larger diameter nail is greater which is in sequence with the above explanation regarding bond performance. Figure (14) depicts the combined response of the 50 and 38 mm anchor nails with 10mm and 20 mm embedment lengths. It can be seen that as the diameter increases the load carrying capacity also increases. This phenomenon can be attributed to the larger surface area available for the 50 mm anchor nail, which is better able to transmit energy to the surrounding concrete. Also it can be said that the maximum pull-out load was governed by the interfacial frictional bond of the anchor nail and surrounding concrete and if the damage increased inside the concrete due to non-verticality the resulting pull-out load carrying capacity reduced. Similar trend was seen for 38mm nail length.

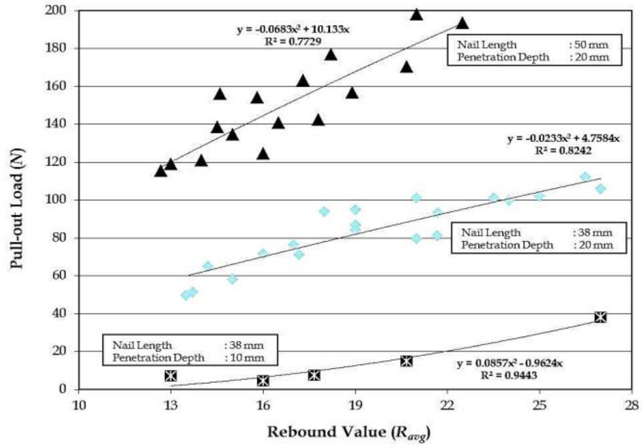

Fig. (14). Combined pull-out load and rebound value relationships

Table (4) shows the pull-out load and rebound value *R* for the 50mm anchor nail length. Furthermore it can be seen that exist clear boundaries depending upon the diameter of the anchor nail. Larger diameter nail is able to carry the larger pull-out load, however it is important to note that for 38 mm and 50 mm anchor nails the range of rebound value *R* begins and ends at same level. Also it is evident that inclined anchor nail, nails embedded in porous concrete and nails with improper embedment length can be identified using the relationship as they depict lower pull-out load capacities and their rebound values lie outside the specified zone for the particular diameter anchor nails.

Table (4). Test hammer reading and pull-out load for 50mm length nail with 20 mm embedment

Nail No.	R_1	R_2	R_3	R_{ave}	P (N)	Comments
1	11	16	12	13.00	119.12	V
2	10	25.5	-	17.80	142.43	BI
3	16.5	13	27	18.90	156.65	NV
4	-	15	18	16.50	140.65	V
5	13	15	-	14.00	120.99	V
6	22	18	22	20.67	170.29	V
7	18	16	18	17.30	163.10	V
8	12	13.5	18	14.50	138.39	V
9	25	10	9	14.60	156.16	V

Table (4).continued

Nail No.	R1	R2	R3	Rave	P (N)	Comments
10	-	21	11	16.00	124.36	NV
11	-	14.5	22	18.20	176.74	V
12	21.5	-	10	15.80	153.92	NV
13	28	-	17	22.50	193.29	V
14	-	28	14	21.00	198.09	V
15	15	-	15	15.00	134.56	V
16	12	14	12	12.67	115.44	V

7. Conclusions

An experimental study to develop a non-destructive load carrying capacity evaluation test for the concrete anchor nails installed using impact loading is presented. The focus of the presented work was to investigate the existence of relationship between the rebound hammer number and the pull-out strength capacity of nails. The influence of impact force on the concrete was also observed. Following conclusions can be drawn from the presented research work:

1. It is observed during experimental testing that cracks formed during the penetration of nail in the concrete. These cracks originated from the interface of the nail and surrounding concrete. The damage to the surrounding concrete was affected by the impact load and penetration condition of the nail. Most damage was observed in the case of Bent Inside (*BI*) nails which resulted due to the presence of sub-surface aggregate, followed by non-vertical nail (*NV*). Anchor nails with vertical (*V*) penetration showed least damage to the surrounding concrete. Furthermore, interfacial cracking at the coarse aggregate and matrix also recorded as a result of impact loading.

2. In case of non-vertical nails high pullout load capacity cannot be achieved, hence the verticality of the nails plays a significant role in the strength performance of the concrete nails.

3. Based on experimental observations it is suggested that a relationship between the rebound value R and the pull-out strength P of the anchor nail exists. Furthermore, factors such as anchor nail diameter, embedment length, nail alignment and quality of concrete surrounding the anchor nail are the influencing factors.

4. For anchor nail diameters 38 and 50 mm, a rebound value R of 15 and above can be treated as an indicator of proper installation, verticality and load carrying capacity. The rebound value R below 15 can indicate in-proper installation, non-verticality and poor load carrying capacity.

The presented work serves as the first of its kind in the development of a non-destructive field pull-out capacity evaluation test for the impact indented installed concrete anchor nails. The proposed method can be utilized by practicing engineers to evaluate the bond performance of concrete nails using impact loading by Schmidt hammer.

8. Range of Application and Recommendations

The results presented in the research work provide a correlating equation between the Schmidt hammer rebound number R and pull-out load carrying capacity P for concrete nails. The proposed correlation is for 38 mm, 50 mm diameter nails embedment length of 10 mm and 20 mm embedded into the normal strength concrete with average compressive strength of 28.5 MPa. Several factors which influence the pull-out load carrying capacity for nails were also identified through the experimentation. These can be categorized as nail diameter, nail head diameter, embedment length, quality of surrounding concrete and nail alignment.

For future research it is recommended to consider detailed experimental investigation regarding the effect of concrete strength, nail diameter and nail embedment length. Furthermore, it is suggested to develop an analytical model considering the frictional bond behavior of nail and compare it to the pull-out displacement response recorded from experimentation. The development of such model can be useful for practicing engineers as they can utilize the model to predict the peak pull-out displacement response for nail in field conditions.

9. Precautions

Following precautions are necessary to achieve consistency and accuracy of the recorded readings. The main precautions are as detailed below;

1. Prior to rebound testing the nail alignment should be assessed and ill-alignment should be carefully recorded.

2. The concrete surrounding the nail should be carefully examined. Any bumps in the concrete surrounding the nail are indicative of sub-surface aggregate. Such observations should be carefully recorded prior to rebound testing.

3. The Schmidt hammer should be kept exactly vertical on the head of nail.

4. The plunger of the Schmidt hammer should be kept in contact with the nail head and should not be allowed to slip.

5. Rebound reading should be repeated in-case the plunger slipped upon impact

10. Acknowledgement

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طريقة اختبار غير مدمر لتقييم تحميل الطاقة الاستيعابية لمسامير الاحتكاك

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ملخص البحث. تستخدم مسامير المراسى عادة في صناعة البناء والتشييد. وتصنف على كونها تثبت بالايبوكسي والاحتكاك. تعتبر مسامير المراسي الايبوكسي أقوى لكنها تتطلب عمالة ماهرة لتركيب وغالية الثمن للتطبيقات العامة ويفضل استخدام مسامير المرساه المثبتة ميكانيكيا بالاحتكاك. حتى الآن لا توجد اي طريقة للاختبارات غير المتلفة لتقدير قدرة التحمل لهذه المسامير. تقدم هذه الدراسة طريقة الاختبارات غير المتلفة وضعت حديثا لتقدير حمولة القدرة على التحمل من خلال ربط نتيجة اختبار مطرقة شميدت للتحميل وانعكاسها على القدرة الاستيعابية للمسامير المرساة. يتم التحقيق في العوامل التي تؤثر على مطرقة شميدت مثل صلابة الرأس، طول الغرز، القطر، قوة الخرسانة، والأضرار الناجمة داخل الخرسانة، وميل المسمار، والاحتكاك الداخلي. يقدم البحث علاقة بين قوة شد المسامير ورد فعل مطرقة شميدت للمسامير بقطر ٣٨، ٥٠ ملم مع أطوال الغرز ١٠، ٢٠ ملم.