The Reliable Concrete Compression Strength Assessment by SCHMIDT Hammer for Different Concrete Grades

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Abstract. The evaluation of the existing construction building is one of the urgent problems in the current era, different tests and methodologies can be used to get the required information about the properties of the structure so that the construction industry interests in applying the concrete test with the lowest time and cost. The purpose of this study is to present the combination between Nondestructive test (NDT) and Machine compression Test (MCT) to get the real results for the Schmidt hammer test method. All tests are created for different grade of RC concrete from medium to high grade with classes between Grade 200 to Grade 800, to study the Nondestructive test (NDT) and generate the comparison with the Machine compression Test (MCT), using different composition of the concrete with Varity in the proportion mix between ingredients of cement, water content, aggregate, all results have been represented tabular and graphically to notice any deviation between Destructive test (DT) and MCT test, Regression analysis was been used as a statistical method to get the variation between tests and establish as a linear mathematical relationship between compressive strength and rebound number and it can be illustrated that the variances between them in case of Low, the medium and semi-high grade is very low which means the null hypothesis is accepted according to the statistical analysis, and on another side, there are variances in case of very high grade according to statistical analysis.

1. Introduction

In the reinforced concrete structure, Several parameters such as the aggregate Type, cement types, RC design, admixture design, and production methodologies can affect the reliability of RC construction building on resisting natural disasters (Yılmaz & Avsar, 2013)[1]. The lowest quality of concrete has always been one of the critical problems for the civil Engineers so that it is crucial to take all required precaution in the structure design, on the another hand the constructors always search the save way for evaluation the RC structure building with lowest time and cost, it can be obtained by using NDS (Nondestructive test), Schmidt hammer and Ultrasonic Pulse Velocity (UPV) which can be consider the famous test to save energy and cost.

The objective of studying is to study Nondestructive test reliability for the concrete compression strength by creating the relationship between NDT and MCT which means calibration curve for improving the estimation of the scores, to obtain these results, using two groups for the calibration curve, the first group of specimens was gotten from Schmidt Hammer curve, and the other group was created from the MCT test.
The study investigates the creation of correlation curve and the difference between the rebound curve results and the actual reading from MCT and applies all tests for the different grade cases to get full comprehensive description about the deviation between them.

2. Literature Review
The concrete can be considered as a composite material with a combination of aggregate, water, and cement with different proportion, one of the important advantages of concrete is the ability to create with the desired size and shape with different concrete compressive strength, civil engineers take care about the ability of the concrete element to resist all anticipated load, therefore the compressive strength test should be checked to ensure the suitability of the building for living during the life cycle of the building, furthermore, the increase of the concrete age around the world led to numerous requirements for growing up the assessment of the concrete strength, so the concrete compressive strength is the most important characteristic to determine the quality of concrete (Abrams, 1927)[2].

In most cases, the concrete compressive strength should be determined with the samples during the pouring, but the advancement in the construction industry requires to develop of different tests to identify the strength of concrete elements quickly and applied these in place which became more urgent, and application of the tests on the concrete compressive strength became more important especially in the countries located in the seismic zone (Yon et al., 2015) [3]. However, a lot of existing building in the current era needs to determine the strength of concrete in a short time, So there are exigent needs for measuring the strength of the concrete in the site, which is based on the quality assurance for assessment of the concrete elements, NDT is the best economical and practical test to use and very popular due to permit the testing in place and evaluate these with short time (Alyamac, 2017)[4].

Although the simplicity of the Schmidt hammer test, there are various factors that can lead to the deviation results, such as Age of concrete, Roughness of concrete surface, and the properties of aggregate and cement have harmful effects on the results of the testing (Malhotra,2004)[5], so the testing the cleaning of RC surface should be applied, and for test recommendation, Ilhan suggested a recommendation for Schmidt test by ten readings should be done with distance not more than 20 mm and 40 -50 mm from the edge of the samples (Ilhan, 2000)[6].

The rehabilitation of the concrete building is related to the properties such as strength and durability (Hobbs et al., 2007)[7] so civil engineers interest to apply different tests to get the full information, in general, the determination of these properties needs two main types of test DT which can be executed by the drilling core test and another type is NDT on-site, the rebound hammer is one of type of NDT and it is a popular using by civil engineer due to simplicity and faster test.

The destructive test method (DT ) can be executed by crushing the cast specimen until failure point, on the other side the Nondestructive test has an advantage in an application, it is carried out without destructive of the structural element with the lowest cost and time but it suffers from the approximation results which may be not valid for all circumstances so there are needs to modify the correlation between the rebound number and the concrete compressive strength under different conditions . Furthermore, the correlation curve can be created between the concrete compressive strength of standard cubes and the rebound number, nevertheless, the correlation can be different from testing to another according to ambient conditions , so that there is an urgent need to modify the correlation curve with different circumstances, such as different types of concrete or conditions can cause various characteristics, Kim also demonstrated that the increase in the surface hardness of the aggregate and carbonation degree also can effect on the Schmidt rebound number (Kim et al,2009)[8].

NDT is not required only for determining the strength of the structural elements with low resistance versus seismic load but also for quality control, curing time, and diagnosis of the defects in the existing concrete elements (Naderi, 2007)[9].

And also the strength information can be emphasized by happening failures in the construction elements that can be prevented by in-place test (Kosmatka S, et al., 2003)[10].

For measuring the concrete compressive strength, the Schmidt Hammer depends upon the rebound number which can be gotten by the spring load mass impact on the surface of concrete, the higher
number of rebound numbers indicates the harder surface on another meaning the higher concrete compressive strength.

The objective of the research is to get the comparison between the results of the concrete cubic compressive strength and NDT. For the NDT: the Rebound Hammer used in the test was Type classic concrete Hammer with energy impact equal to 2.207 Nm. Shown in Figure 1, Figure 2 shows the Compression Testing Machine used in the test. By using the linear regression analysis we can get the correlation between them, although the rebound number is not related to the concrete compressive strength directly, the regression analysis can be used to get the relationship between the dependent (Rebound number) and independent variables (concrete compressive strength), and SPSS software program is one of the popular programs can be used in the regression analysis.

![Figure 1. Schmidt Hammer](image1.png)

![Figure 2. Compression machine test](image2.png)

The test of NDT has been done by the rebound of the elastic mass which depends on the hardness of the surface, in our testing the weight of the rebound hammer is 1.200 kg which is suitable to apply the test on the site, and the time of applied testing is at the end of curing after 28 days, the EN12504-02 determines the specification of the Schmidt test and number of reading for each specimen, furthermore, test of concrete cubic compressive strength can be carried out by the compression machine, the machine (Matest 1000 kN) was used in the experimental research, and a number of reading for each specimen is ten for different concrete grade for ordinary (200-299) Kg/cm², medium (300-399) Kg/cm², Simi high (400-499) Kg/cm² and high (over 50) Kg/cm² all tests have been carried after the duration of curing 28 days.

Different NDT can be used in place or on-site to determine not only the strength of concrete but also the cracks of the materials, voids behind the surface, the percentage of carbonation, or chloride et al (Breysse, 2012)[11].

The main standard for NDT methods is the surface hardness, ultrasonic pulse velocity, and penetration resistance methods (Malhotra et al., 2004). However, the purpose of the procedure of standard is to get the properties of the concrete on site.

The Schmidt Hammer test is considered as hardness test methods with indirect methods to determine the strength of concrete, there are different factors that can affect the values of rebound number such as the test area treatment, the component of the concrete element, type of cement, and aggregate, the position of the hammer, the humidity of the concrete, age of concrete and mix proportions (Jiri Brozovsky, 2011)[12]. And the results of the device is based on the impact of the hammer on the concrete by a spring, the results of testing depends on the hardness of concrete surface affected with a
Hammer and from these the concrete compressive strength is estimated via the surface rebound number.

Furthermore, the reliability of the nondestructive test has been investigated in various research (13),(14),(15) All results of the research need to be careful in your recommendation which is based on the interpretation so, in our research, there are caring about the quality of instruments, the sample, and the statistical tool to get high accuracy and reliability.

3. Experimental

3.1. Materials
The characteristic of materials were used in the experimental to create concrete mixes as followings:

- **Aggregate**
The aggregate used in the experimental crushed basalt, crushed limestone and natural gravel (as a coarse aggregate), sand (as a fine aggregate) with properties as following in Tables 1 and Figure 3.

| Property                  | Sand | Gravel | Limestone | Basalt |
|---------------------------|------|--------|-----------|--------|
| Volume weight (t/m³)      | 2.5  | 2.5    | 2.6       | 2.6    |
| Specific gravity          | 1.6  | 1.5    | 1.6       | 1.7    |

![Figure 3. Aggregate Sieve Analysis](image)

- **Cement**
Ordinary Portland Cement (OPC) was used as received. The chemical and physical properties of the cement are shown in Table 2

| Property                  | 2 day | 28 day | Initial | Final |
|---------------------------|-------|--------|---------|-------|
| Strength of cement        | 248 Kg/cm² | 425 Kg/cm² | 2:12 h  | 4:45 h |
| Setting time              | ≥ 100Kg/cm² | ≥325 Kg/cm² | ≥75 min |       |

- **Water**
The water used in the concrete mixtures is drinking water.
Concrete mixtures
The test for studying the concrete strength after 28 days. Concrete mix trails proportion is shown in Table 3.

| Type of Agg. | Mix No. | Cement (Kg/m³) | Coarse Agg. (Kg/m³) | Sand (Kg/m³) | Water (Liter/m³) | Admixtures (Liters/m³) |
|-------------|---------|----------------|---------------------|--------------|------------------|------------------------|
| Gravel      | 1       | 350            | 1266                | 590          | 175              | 0.50                   |
| Basalt      | 2       | 400            | 1334                | 614          | 137              | 0.34                   |
| Gravel      | 3       | 425            | 1198                | 539          | 213              | 0.50                   |
| Gravel      | 1       | 400            | 1194                | 556          | 200              | 0.50                   |
| Gravel      | 2       | 325            | 1697                | 799          | 166              | 0.51                   |
| Gravel      | 3       | 250            | 1411                | 657          | 125              | 0.50                   |
| Gravel      | 4       | 350            | 1379                | 919          | 165              | 0.47                   |
| Basalt      | 5       | 400            | 1334                | 621          | 132              | 0.33                   |
| Basalt      | 6       | 450            | 1273                | 593          | 136              | 0.30                   |
| Gravel      | 7       | 275            | 1374                | 640          | 135              | 0.49                   |
| Gravel      | 8       | 450            | 1120                | 524          | 225              | 0.50                   |
| Gravel      | 9       | 300            | 1702                | 783          | 167              | 0.56                   |
| Gravel      | 10      | 375            | 1229                | 572          | 187              | 0.50                   |
| Lime st.    | 11      | 400            | 1216                | 590          | 137              | 0.34                   |
| Basalt      | 12      | 400            | 1224                | 570          | 200              | 0.50                   |
| Basalt      | 13      | 400            | 1261                | 588          | 180              | 0.45                   |
| Lime st.    | 14      | 400            | 1216                | 590          | 133              | 0.33                   |
| Lime st.    | 15      | 450            | 1060                | 866          | 170              | 0.38                   |
| Lime st.    | 16      | 400            | 1216                | 590          | 135              | 0.34                   |
| Lime st.    | 17      | 450            | 1208                | 588          | 152              | 0.34                   |
| Basalt      | 18      | 500            | 1050                | 790          | 170              | 0.34                   |
| Basalt      | 19      | 400            | 1296                | 604          | 160              | 0.40                   |
| Lime st.    | 20      | 400            | 1160                | 540          | 200              | 0.50                   |
| Basalt      | 21      | 450            | 1273                | 593          | 152              | 0.34                   |
| Basalt      | 22      | 400            | 1334                | 621          | 140              | 0.35                   |
| Lime st.    | 23      | 400            | 1216                | 590          | 132              | 0.33                   |
| Basalt      | 24      | 450            | 1273                | 593          | 150              | 0.33                   |
| Lime st.    | 25      | 450            | 1208                | 588          | 150              | 0.33                   |
| Basalt      | 26      | 400            | 1334                | 614          | 135              | 0.34                   |
| Lime st.    | 27      | 450            | 1208                | 588          | 148              | 0.33                   |
| Gravel      | 28      | 350            | 1266                | 590          | 175              | 0.50                   |
| Basalt      | 29      | 400            | 1334                | 614          | 137              | 0.34                   |
| Gravel      | 30      | 425            | 1198                | 539          | 213              | 0.50                   |

A super plasticizer was used (Sikament R2008, Sikament NN). Three standard cubes 15 cm x 15 cm x 15 cm were cast from each mix and cured in laboratory.

3.2. Fabrication of tested samples
Using mixture of 0.1 m³ capacity to compose the constituent materials. In the beginning, mix the dry aggregates, cement and aggregate for a one minute and then add the water which mixed with admixtures to create continuity mixing of the component until reaching to the homogenous constituent, this process will take two minutes to finish.

3.3. Instrumentation (Description of the testing machine)
Using the testing machine (MATEST to 100 tons up) to execute the static load which loaded from zero until failure.
4. Results and discussion

In the Experimental study, the cases of investigation were divided into four groups of concrete grades from ordinary, medium, Simi high to high grade, the total number of samples are 90s with different concrete mixtures design which sorting into four categories, the first group can be obtained with concrete compressive strength (200-299) Kg/cm², which had been done through 24 samples, the second groups can created with concrete compressive strength from (300-399) Kg/cm² with 18 samples, third group contains the samples with concrete compressive strength from (400-499) Kg/cm² with 24 samples and also the final group contains high grade of concrete compressive strength (over 500) Kg/cm² with 24 samples. Average of three cubes strength of each mix were calculated. Average of ten point of rebound Hammer test at each cube which subjected to 50% of Fcu failure were calculated. So that all samples contain nearly different types of grade to create comprehensive comparison between results from rebound number Schmidt Hammer test NDT and Machine compression Test MCT, Tables (4,5,6,7) illustrate the values of the concrete compressive strength from manufacture curve of Rebound Hammer (RH) and average of three cubes values of the actual concrete compressive strength from MCT (Machine compression test).

Table 4. Compressive strength and rebound number for ordinary concrete grade (200-299) Kg/cm²

| Rebound Number | 26.0  | 29.2  | 29.8  | 31.4  | 31.7  | 32.6  | 33.0  | 35.0  |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Fcu from Manufacturer’s curve of R.H Kg/cm² | 175   | 225   | 230   | 245   | 250   | 280   | 280   | 305   |
| Actual Fcu from MCT Kg/cm² | 175   | 223   | 237   | 241   | 248   | 271   | 275   | 298   |

Table 5. Compressive strength and rebound number for medium concrete grade (300-399) Kg/cm²

| Rebound Number | 36.30 | 36.34 | 36.80 | 36.91 | 37.51 | 38.12 |
|----------------|-------|-------|-------|-------|-------|-------|
| Fcu from Manufacturer’s curve of R.H Kg/cm² | 315   | 320   | 340   | 345   | 360   | 370   |
| Actual Fcu from MCT Kg/cm² | 324   | 326   | 339   | 345   | 352   | 363   |

Table 6. Compressive strength and rebound number for Simi high concrete grade (400-499) Kg/cm²

| Rebound Number | 41.2  | 41.5  | 41.5  | 41.6  | 41.7  | 41.7  | 42.0  | 45.0  |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Fcu from Manufacturer’s curve of R.H Kg/cm² | 410   | 425   | 425   | 427   | 430   | 430   | 440   | 490   |
| Actual Fcu from MCT Kg/cm² | 406   | 420   | 420   | 427   | 433   | 433   | 444   | 493   |

Table 7. Compressive strength and rebound number for high concrete grade of (over 500) Kg/cm²

| Rebound Number | 46.0  | 47.1  | 47.3  | 49.0  | 49.0  | 52.6  | 55.4  | 58.1  |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Fcu from Manufacturer’s curve of R.H Kg/cm² | 500   | 520   | 525   | 560   | 560   | 620   | 680   | 780   |
| Actual Fcu from MCT Kg/cm² | 515   | 528   | 530   | 568   | 568   | 623   | 736   | 813   |

Comparing the variations between the results of the concrete compressive strength for cubic compressive strength test MCT and non-destructive test (Schmidt Hammer) NDT.
All samples are cured for 28 days before getting observation of the results, main observation can be noticed that:

- Actual Fcu at until concrete grade 425 Kg/cm² give value lower than the R. H. T. Fcu but by increasing the concrete grade we found that the Actual Fcu give value higher than R. H. T. Fcu.
- The balance Fcu value which Actual Fcu equal R. H. T. Fcu was 427 kg/cm².
- So the using of Schmidt Hammer test need correlation equation for concrete grade until 425 kg/cm² and different correlation equation for concrete grade above of 427 kg/cm².

Tables 8 illustrates the comparison between the results of the average actual concrete compressive strength from Machine compression Test MCT and the average value from the Manufacturer’s curve of R.H ( Rebound Hammer test ) . Statistical T test had been done for analysis of the results, it contains two main hypothesis, the null and alternative hypothesis, the null hypothesis means there are not significant difference between the values of concrete compressive strength from RH (Rebound Hammer) and Machine compression Test MCT, and for the alternative hypothesis there are significant in the results between two investigation, the Paired T test is used to get the difference between the measurements from MCT and NDT for the same samples, the purpose of the statistical analysis is to determine the difference between paired experimental results, in the statistical analysis the acceptance of the null hypothesis depends on the values P to be bigger than 0.05 and if not the alternative hypothesis becomes acceptance. From table 8 it can obviously that:

- In case of ordinary grades: There aren't significant difference between the results from MCT and NDT.
- In case of Medium grades: There aren't significant difference between the results from MCT and NDT.
- In case of Semi High grades: There aren't significant difference between the results from MCT and NDT.
- In case of High grades: There are significant difference between the results from MCT and NDT.

Table 8. Statistical T test analysis and results.

| Sample Grade  | P-value vs. Level of Significance, α | conclusion |
|---------------|------------------------------------|-------------|
| Ordinary grade (200-299) Kg/cm² | P-value = 0.156 α = 0.05 | P-value > α; The null hypothesis is accepted and fail to replace by alternative hypothesis | There aren't significant difference between the results from MCT and NDT and the average strength generated from the Manufacturer’s curve of R.H underestimates by 1.12% the average actual concrete compressive strength from MCT. |
| Medium grade (300-399) Kg/cm² | P-value = 0.954 α = 0.05 | P-value > α; The null hypothesis is accepted and fail to replace by alternative hypothesis | There aren't significant difference between the results from MCT and NDT and the average strength generated from the Manufacturer’s curve of R.H underestimates by 0.05% the average actual concrete compressive strength from MCT. |
| Semi high grade (400-499) Kg/cm² | P-value = 0.931 α = 0.05 | P-value > α; The null hypothesis is accepted and fail to replace by alternative hypothesis | There aren't significant difference between the results from MCT and NDT and there aren't nearly difference between average strength generated from the Manufacturer’s curve of R.H and the average actual concrete compressive strength from MCT. |
| High grade of (over500) Kg/cm² | P-value = 0.035 α = 0.05 | P-value < α; The null hypothesis is rejected, and the hypothesis will be in favor of alternative hypothesis | There are significant difference between the results from MCT and NDT and the average strength generated actual concrete compressive strength from MCT by 2.87% the Manufacturer’s curve of R.H. |
4.1. The relationship between Schmidt Hammer Rebound Number and Actual concrete Compressive Strength:

Linear regression analysis can be used to get the correlation curve between the variable values of the rebound number and the actual concrete compressive strength, the correlation coefficient $R^2$ for testing samples, the regression analysis is a series of statistical processes for creation the relationship, for the study analysis the correlation curves for the different cases of grades can be illustrated by Figures (4&5&6&7).

In Figure 4 (Ordinary Grade Case): it is observed that the correlation curve is very close to the variables data of RN and $F_{cu}$ from MCT, the high value of $R^2$ ($R^2 = 0.976$) is the prove for the correlation.

![Figure 4](image4.png)

**Figure 4.** Actual Concrete Compressive strength From MCT vs. Rebound hammer in case of Low Grade

In Figure 5 (Medium Grade Case): it is observed that the correlation curve is very close to the variables data of RN and $F_{cu}$ from MCT, the high value of $R^2$ ($R^2 = 0.970$) is the prove for the correlation.

![Figure 5](image5.png)

**Figure 5.** Actual Concrete Compressive strength From MCT vs. Rebound hammer in case of Medium Grade
In Figure 6 (Semi High Grade Case): it is observed that the correlation curve is very close to the variables data of RN and F_{cu} from MCT, the high value of R square (R^2 = 0.933) is the prove for the correlation.

**Figure 6.** Actual Concrete Compressive strength From MCT vs. Rebound hammer in case of Semi High Grade

In the final Figure 7 (High Grade Case): it is observed that the correlation curve is very close to the variables data of RN and F_{cu} from MCT, the high value of R square (R^2 = 0.974) is the prove for the correlation.

**Figure 7.** Actual Concrete Compressive strength From MCT vs. Rebound hammer in case of Very High Grade
4.2. The comparison in the relationship between values of concrete compressive strength from Schmidt Hammer and the Machine compression test

Figure 8 illustrates the relationship between the values of concrete compressive strength which gotten from the Schmidt Hammer and the machine compression test.

5. Conclusion

In the final conclusion, using the statistical analysis to get the full relationship between the manufacturing curve of NDT and the actual concrete compressive strength from the machine compression test, using Paired T-test can help to get the variances between values from RH and MCT, and from the analysis, the variances between them in case of Ordinary, the medium and semi-high grade is very low which means the null hypothesis is accepted according to the statistical analysis and on another side, there are variances in case of high grade according to statistical analysis.

The study results notice that the relationship between values of Cubic compressive strength from Rebound Hammer No. and the Machine compression test can achieved by using relation formula as shown in Figure (4,5,6&7) for each grade.

The study also interested to get from results; it is obviously the closing in the values in high accuracy level with extreme confidence.
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