Scientific Research and Essays Vol. 5(13), pp. 1644-1648, 4 July, 2010
Available online at http://www.academicjournals.org/SRE
ISSN 1992-2248 ©2010 Academic Journals

Full Length Research Paper

Correlation between Schmidt Hammer and destructive compressions testing for concretes in existing buildings

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Accepted 4 June, 2010

In this study, a relationship is determined and correlated between non-destructive testing (NDT) named as Schmidt rebound hammer test and concrete destructive compression test. The Schmidt rebound hammer is principally a surface hardness tester with an apparent theoretical relationship between the strength of concrete and the rebound number of the hammer. In order to calibrate the Schmidt Hammer with the various-aged concretes, cube specimens of 28 - 90 days and a number of core samples from different reinforced concrete structures have been tested. This calibration has been done to get the related constant obtained from Schmidt and compression tests. The best fit correction factors for the concrete compressive strength-Schmidt rebound hammer relationship are obtained through processing correlation among the data sets. The correction factors can be easily applied to in situ concrete strength as well as existing concrete structures.

Key words: Concrete quality, compressive strength, non-destructive tests, Schmidt.

INTRODUCTION

Concrete is the most commonly used construction material in structures. Determination of compressive strength has become the most important concern of researchers since its usage and usually regarded as the main criteria to judge the quality of concrete. Various destructive and non-destructive test (NDT) methods have been developed for determining the compressive strength.

The aim of these tests is to control concrete production and determine under service loads deteriorations in buildings on time. Nevertheless, the destructive methods are expensive and time consuming. In addition, cube and cylinder concrete specimens prepared in laboratory are not represented in situ concrete. Furthermore, getting core specimens from structural element reduces the load carrying capacity of construction elements.

The NDT is a direct method to find in situ compressive strength of concrete (Yüksel, 1995). Advantages of the NDT test were summarized by Leshchinsky (1991) as compared to core testing as:

1. A reduction in the labor consumption of testing.
2. A decrease in labor consumption of preparatory work (such as tedious work associated with determining location and diameters of reinforcement bars).
3. A smaller amount of structure damage in testing.
4. A lower probability of such structural damage which may cause the need for reinforcement.
5. A possibility of testing concrete strength in structures where cores cannot be drilled (thin-walled, densely reinforced, etc. . .).
6. An application of less expensive testing equipment.

However, these advantages are of no value if the results are not reliable, representative and as close as possible to the actual strength of the tested part of the structure (Turgut, 2004). The main limitations related to the NDT testing method are anisotropy and heterogeneity of materials, small test conduction area, roughness on the surfaces where the test is applied, test direction, and there have been a number of different empirical equations proposed for different types of materials

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(Yılmaz and Sendir, 2002; Yılmaz, 2009). In order to overcome these limitations, the test results have to be correlated with the outcomes of destructive tests. In reality, the correlation of strength calibration curves is provided and recommended NDT equipment manufacturers for users. Nevertheless, the curves have been made up using 14 - 56 days concrete specimens (written on Schmidt Hammer). However, an existing construction to be investigated in situ for its construction quality may be quite old. Estimation of compressive strength in an existing structure is established through correlating rebound numbers of structure with the strengths of the cores.

Therefore, when the NDT was used to evaluate the concrete strength in many countries, experimental studies have been investigated to define the method more reliable and practical. The concrete strength is estimated using curves which correlate the NDT measurements with the compressive strength of concrete established by a laboratory testing program. Usually the parameters affecting these curves are the water/cement ratio, aggregate type, maximum aggregate size and cement type of the concrete. This work presents a study on the calibration of Schmidt rebound Hammer with various-aged concretes. Data were obtained from cube specimens in 28-90 days and many core specimens taken from the different existing structures.

NDT testing of concrete using Schmidt Hammer

Among the available non-destructive methods, the Schmidt Hammer test is the most commonly used one in practice. It has been used world-wide as an index test for a testing equipment to estimate strength of concrete due to its rapidity and easiness in execution, simplicity, portability, low cost and non-destructiveness.

The rebound hammer test is described in ASTM C805 (1993), BS 1881: Part 202 (1986) and TS 3260 (1978). The test is classified as a hardness test and based on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. The energy absorbed by the concrete is related to its strength (ACI, 1994). Despite its apparent simplicity, the rebound hammer test involves complex problems of impact and the associated stress-wave propagation (Akashi and Amasaki, 1984). The test method starts by the careful selection and preparation of the concrete surface to be tested and a fixed amount of energy is applied by pushing the hammer against the test surface. The plunger must be allowed to strike perpendicularly to the surface, as the angle of inclination of the hammer affects the results. After impact, the rebound number should be recorded by taking at least 10 readings from each tested area (TS 3260, 1978). Although there is no unique relation between hardness and strength of concrete, experimental data relationships can be obtained from given specimens.

However, this relationship is dependent upon the concrete surface effecting factors, such as degree of saturation, carbonation, temperature, surface preparation, and type of surface finish. The result is also affected by type of aggregate, mix proportions, hammer type and inclination. Areas exhibiting honey-combing, scaling, rough texture or high porosity must be avoided. Amasaki (1991) presented the effect of carbonation on rebound number. Grieb (1958) showed the effect of type of aggregates on rebound number and hence estimated strength.

Earlier researches (8 - 10) on finding the correlation between concrete strengths and NDT were generally limited to the specimens prepared in laboratory conditions. This research yields different correction factors for various concrete classifications in suit structures. The correction factors are obtained by comparing compressive strength with Schmidt hammer test. The specimens used for getting correction factors are taken from existing reinforced structures and laboratory.

EXPERIMENTAL STUDIES

The research aimed to obtain a simple correlation plot used by engineers who work on-site. Samples were made from ordinary Portland Cement and aggregate of local natural sources or crushed hard limestone. Various concrete mixes were used to prepare the standard cube specimens (15 × 15 × 15 cm^3) in the laboratory to compare with Schmidt Hammer manufacturer's calibration curve.

Cube specimens were taken from the water on 28-90 days and rubbed with a dry cloth to obtain a surface dry sample. Two opposite faces of the cubes were prepared for the Schmidt Hammer test when drying was completed. The specimens were placed in the testing machine and slight load (7 NM/m^2) was applied (Figure 1). Afterwards, a fixed amount of energy is applied by pushing the hammer against the test surface according to the ASTM C 805 (1993) and TS 3260 (1978).

Each of the two opposite faces of cubes was impacted to get at least 24 readings to illustrate the sensitiveness of the test to the presence of aggregate and voids immediately underneath the plunger. Average of rebound numbers and standard deviations were calculated using Equations 1 and 2 respectively as:

$$fa = \frac{f1 + f2 + ...fn}{n} \quad (1)$$

$$S = \sqrt{\frac{(f_1 - fa)^2 + (f_2 - fa)^2 + ... + (f_n - fa)^2}{n}} \quad (2)$$

where fa is the average of rebound numbers, fi is the rebound number, n is the total impact number and S is the standard deviation.

Cores specimens were drilled horizontally through the thickness of the concrete elements to define Schmidt Hammer calibration. The concrete elements were tested using Schmidt Hammer for the calculation of the rebound values before the execution of the cores (Figure 2). TS 10465 (1992) procedures were used to determine the destructive compressive strength.

Figure 1. The cube specimen placed in the testing machine.

Figure 2. Schmidt Hammer test before the execution of the cores in an existing building.

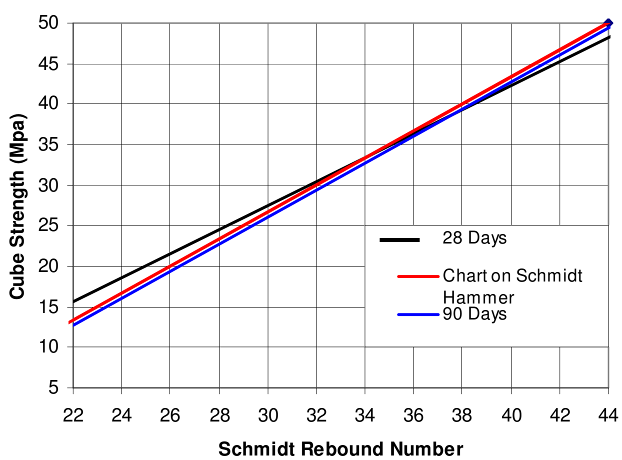

Figure 3. Rebound numbers and strength relation of various ages cube specimens.

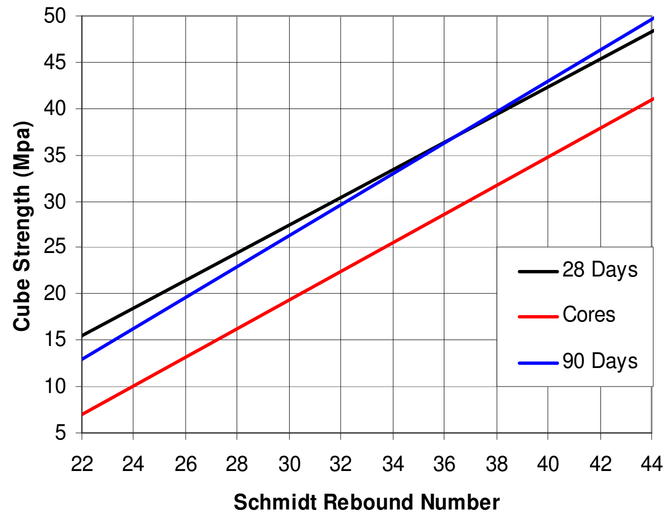

Figure 4. Rebound numbers and strength relation of various ages concrete.

RESULTS AND DISCUSSION

A correlation has been set up and illustrated with data obtained from 28, 90 days and in situ core specimens used for concrete strength and Schmidt rebound hammer tests. When Schmidt Hammer test on each cube specimen was completed, the load was applied up to failure. The outcomes were found to be harmonious with the results as plotted in Figure 3. Also, the 28-days specimens' R^2 value is found to be 0.856 and its equation is y = 11.612A–52.033 (where y, compressive strength; A, rebound number). R^2 value of 90-days specimens is found to be 0.9449 and its equation is y = 16.674A–238.31.

Core specimens (75 mm diameter) were extracted to calibrate the old concrete compressive strength. Both the mixture properties of concrete and ages of buildings ranging from 1 to 40 are not known. The samples were tested in the same way and the results were displayed through previous outcomes as shown in Figure 4. The curve obtained from core specimens with R^2 value is found to be 0.8618 and its equation is y = 15.424A–269.53.

The plots demonstrated that compressive strength values of 28 and 90 days specimens showed higher relative values of the cores to the same rebound numbers leading to error for the users of NDT equipment.

The obtained curves from the existing building, which were given by the manufacturers have been compared as shown in Figure 5. It can be seen from the curves that they are nearly parallel. However, the curves have demonstrated different compressive strength to the same rebound number. The advised curve of Production Company showed higher values when compared with the old concrete. Therefore, the correction factors must be used to transform strength intervals obtained from Schmidt Hammer test for old concretes. The factors were

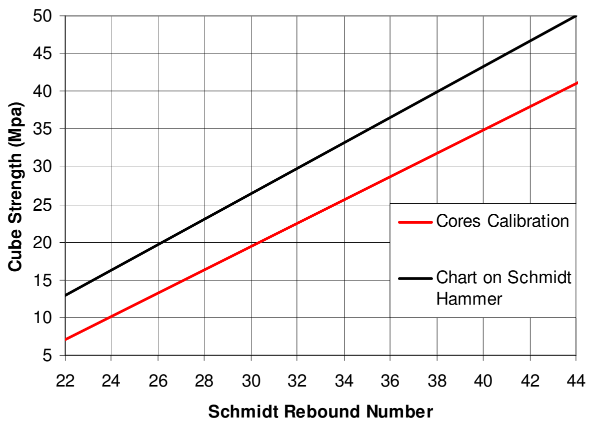

Figure 5. Comparison of curves obtained from existing buildings and manufacturing company.

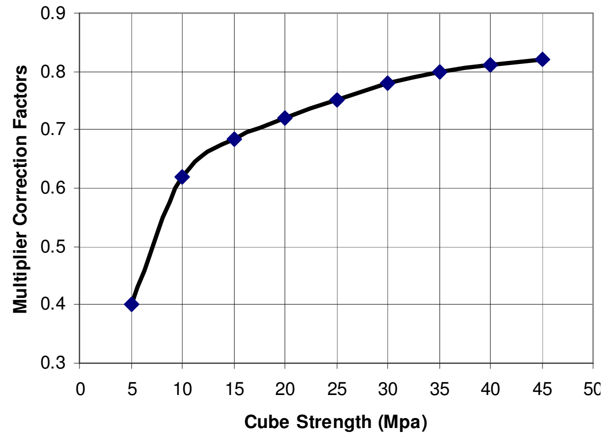

Figure 6. Strength transform (correction) factors for Schmidt Hammer test.

Table 1. Strength transform factors for Schmidt Hammer test used in old concrete.

Strength interval Mpa	Factor number
<10	0.51
10 - 15	0.62
15 - 20	0.67
20 - 25	0.72
25 - 30	0.75
30 - 35	0.78
35 - 40	0.8
40 - 45	0.81
45 – 50	0.82

given in Table 1 for eight strength intervals and for concretes older than 90 days. The factors ranging from 0.50 - 0.80 are suggested to be used for the strength values, as given in Figure 6.

CONCLUSIONS AND RECOMMENDATION

The correlation among the strength values obtained by destructive and NDT test methods on both existing buildings and laboratory-made concrete has been established. Schmidt Hammer test method has been used as a non-destructive test. The following principal conclusions have been drawn:

1. The use of rebound hammer test method on the existing building is not suitable to estimate the strength of old concrete. Direct use of rebound hammer demonstrates high variations, which makes engineering judgment quite difficult. The Schmidt Hammer method could only be used as a reliable instrument to calculate the compressive strength, if the required calibrations are performed.

2. The obtained curves from the existing building, which were given by the manufacturers are nearly parallel. However, the curves have demonstrated different compressive strength to the same rebound number. Therefore, the correction factors ranging from 0.50 - 0.80 are suggested to be used for the strength values of old concrete.

3. Schmidt Hammer test results can be influenced by many factors; such as the characteristics of the mixture, surface carbonation, moisture condition, rate of hardening and curing type. Therefore, the correction factors have to be used to allow this effect for existing concrete.

4. Schmidt Hammer rebound tests can be used to estimate the strength of concrete with calibration curves to reduce the number of cores taken from the structures. As long as this calibration is done properly, there would be even no reason to get the core in situ.

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