STUDY ON REBOUND VALUES ON INCLINED PLANES

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Abstract: Non-Destructive Testing (NDT) methods are widely used in the industry to assess the parameters like strength and durability of an existing structure. They offer significant advantages of speed, cost and lack of damage in comparison with test methods which require the removal of a sample. But they incorporate various limitations in practical use.

This study is focused on the 'Rebound Hammer Test' which is used to assess the compressive strength by surface hardness. The rebound hammer concernedin this case, has been calibrated and charts have been developed to get the readings on vertical and horizontal surfaces only. When the structure to be investigated is consisted of an inclined surface, direct use of these charts may not be possible. During this study, basic formulation to calculate the corresponding horizontal rebound number to represent a rebound value obtained on an inclined plane was derived and verified. Taking readings on inclined surfaces of the cubes placed at different angles was done in order to observe the deviations and then the results were interpreted and analysed to obtain a suitable relationship by applying the derived formula.

Keywords: Rebound number, inclined plane/surface, formulation, verification

1. Introduction

In-situ testing of concrete plays a very important role in many fields such as quality assurance program or as part of a diagnostic evaluation of the causesof concrete problems with regard to durability, cracking and compliance toprescribed specifications. In-situ testing is also required to assess the final product of the construction work.In-situ testing can virtually be divided into three groups, depending on theamount of destruction that will happen to the concerned structure whenperforming a specific in-situ test. These groups are:

1. Non-destructive tests (NDT)
2. Semi-destructive tests
3. Destructive tests

Because NDT does not permanently alter the article being inspected, it is a highly-valuable technique that can save both money and time in product evaluation, troubleshooting, and research.

The rebound hammer, commonly referred to as a Schmidt hammer, is a mechanical device used to measure the compressive strength of in-situ concrete non-destructively. In 1948, Ernst Schmidt, a Swiss engineer, developed the device for testing concrete based upon the Rebound principle. The device consists of a plunger and aspring-loaded hammer. When triggered, the hammer strikes the free end of the plunger that is in contactwith the concrete, which in turn causes the plunger to rebound. Schmidt standardized the hammer blow by developinga spring-loaded hammer and devised a method to measure the rebound of the hammer (Katalin 2011,Nicholas 1997)

With the advancement of technology, the rebound hammer has also been developed to much accurate and easy to use equipment. Different versions of the rebound hammer produced by the company Proceq have different distinctive features. Some of the late developments are the integration of computers with the equipment and high level of accuracy.

The original Schmidt hammer can archive an accuracy of ±15% to ±20% only for specimens cast, cured and tested under controlled conditions (Demirdag 2009). Thus the use of it under site conditions other than the specified is erroneous. In site conditions, the structures that need to be tested are not always horizontal or vertical. Measuring the compressive strengths of structures with inclined surfaces such as intz-type and conical water tanks without harming the structure is virtually impossible with the generally used Rebound Hammer, since its accuracy in inclined planes is off the actual mark. New advanced rebound hammers with high accuracy in measuring inclined rebound values are relatively expensive and are not used in the local industry. Thus in our research we tend to calibrate the generally used Rebound Hammer to be able to take angled measurements of hardness of in-situ concrete.

2. Calibrating the Existing Conversion charts for Horizontal and Vertical Surfaces

The N type rebound hammer has conversion charts for horizontal and vertical surface provided by the manufacturers. Since the hammer is used frequently and not being calibrated recently, charts were checked for accuracy using test cube results.

2.1 Testing Procedure

Concrete test cubes were cast using mixes of different gradesand tested using the rebound hammer and actual strength.

Sixty three cubes comprising of strength grades G15, G30, G40 and G50 tested using the rebound hammer on vertical and horizontal surfaces in accordance with the BS1881: part-202 : 1986. Then the crushing loads of cubes were obtained via testing them inAmsler testing machine. The rebound number (R_n) was plotted against the actual cube strength and compared with existing graphs of the hammer (Proceq). The obtained results are given in the figures 1 and 2.

2.2 Results and Analysis

According to the obtained results the equations for the conversion of rebound value into corresponding compressive strength are as follows.

Table 1 – Conversion curves data

	Vertical	Horizontal
Actual Results	y (A) = 1.7126x - 21.865	y(A) = 1.759x - 13.977
	R^2 = 0.7509	R^2 = 0.5031
Existing Curve	y (R) = 1.7241x - 26.361	y(R) = 1.6697x - 19.763
	R^2 = 1	R^2 = 1

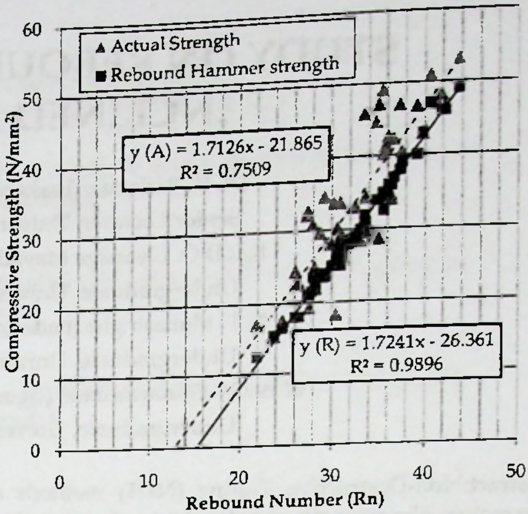

Figure 1 – Calibratedcurve and existing curve for vertical surface

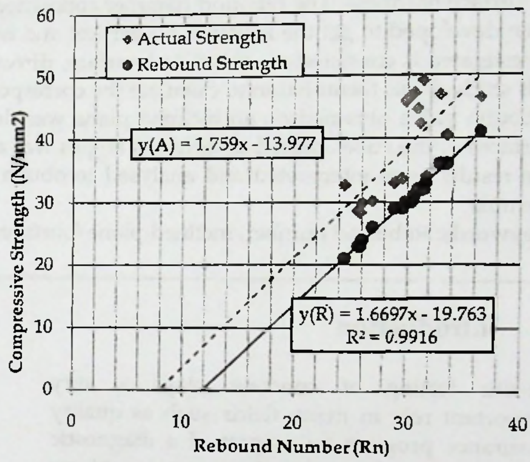

Figure 2- Calibrated curve and existing curve for horizontal surface

3. Theoretical Formulation for Inclined Surfaces

The hammer should be perpendicular to the concrete surface when the pressure is applied on the body and it is pushed towards the surface. Then the hammer is released on to the plunger and due to the hardness of the surface it rebounds.Hence rebound height can be used as a measurement of surface hardness (ASTM). The mechanism is explained through operation the components of the hammer as given in the figure 3. Then the equations are being constructed accordingly.

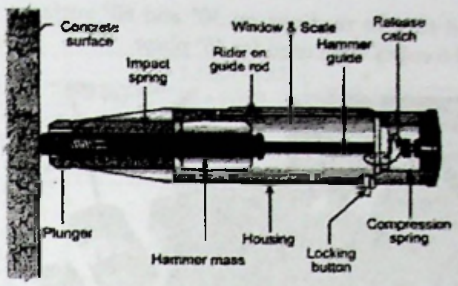

Figure 3 – Components of Rebound Hammer

By considering the energy conservation in horizontal direction,
When the hammer mass touches the plunger,
The energy released by the impact spring is equal to the kinetic energy of the hammer mass when it is released on to the plunger (Basu 2004).

$$0.5\,kx_1^2 = 0.5MV_1^2 \text{.................(1)}$$

Where, k - spring constant

x_1- maximum contraction of the spring (when it is fully loaded)

V_1- the velocity of the piston when it touches the plunger (while firing)

M – mass of the hammer

When the hammer rebounds,
The kinetic energy of the hammer massat the initial rebound position is equal to the energy released by the spring at maximum rebound position.

$$0.5\,kx_2^2 = 0.5MV_2^2 \text{...................(2)}$$

Where, x_2- length of stretch of the spring at the maximum rebound position

V_2 -initial rebound velocity of the hammer

By combining equation (1) and (2),

$$\frac{X_1}{X_2} = \frac{V_1}{V_2} \quad \text{..........................(3)}$$

When this ratio is taken as a percentage it is called the rebound number.

$$R_n = \frac{X_1}{X_2} \text{x } 100 \text{.................(4)}$$

But if the surface is not vertical (or hammer is not horizontal), the weight of the apparatus affects the pressure applied on the surface. As shown in the figure4, when the surface is inclined by an angle of θ degrees, above equations must change accordingly.
In that case energy balance equation when hammer touched the plunger should be modified as follows. Here, $V_{1\theta}$and $V_{2\theta}$replace V_1 and V_2 as the surface is inclined by θ angle.

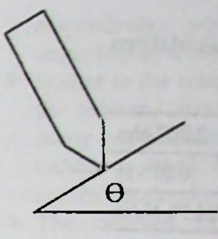

Figure 4 – Inclined Surface

$$0.5\,kx_1^2 + Mgx_1\text{Cos}(\theta) = 0.5MV_{1\theta}^2 \text{....... (5)}$$

Similarly, for the point of maximum rebound the equation can be written as,

$$0.5\,kx_2^2 + Mgx_2\text{Cos}(\theta) = 0.5MV_{2\theta}^2 \text{...........(6)}$$

As k, x_1, M and θ are known and x_2 is calculated,the square of initial rebound velocity $V_{2\theta}$ can beobtained from Eq. (6). As this velocity is produced by the impact energy (Eq. (5)), its equivalent in thehorizontal direction (Eq. (1)) would be

$$V_2^2 = \frac{V_{2\theta}^2(0.5\,kx_1^2)}{0.5\,kx_1^2 + Mgx_1Cos(\theta)} \text{.........(7)}$$

So, from equations (3) and (4), the corrected rebound number for vertical surface would be,

$$R_n = 100X\sqrt{V_2^2/V_1^2} \text{..............(8)}$$

4. Verification of Formula

4.1 Verification of Formula Using Horizontal and Vertical Surfaces

The derived formula was verified using cube samples of different grades, tested on vertical plane (90°) and horizontal plane (0°). Here the N type Proceq hammer used in the laboratory has constant impact energy (E) of 2.207Nm(Proceq) The maximum stretch of the key-spring at fully loaded condition (x_1) and the maximum compression of the spring due the weight of the hammer (x) are constants in these calculations. The spring constant (k) and the square of the impact velocity(V_1^2), when it hits the plunger are calculated using the energy equations. The mass (M) of the hammer was obtained by the equilibrium of forces exerted on the spring (Basu 2004). The values used for E, x, K, x_1, M and V_1^2 are given in the table 2.

Table 2 - Constants used in calculations

E	2.207 Nm
x_1	0.075 m
$k^{(1)}$	784.71 N/m
x	0.005 m
$M^{(2)}$	0.4 kg
$(V_1^2)^{(3)}$	$11.035 (m/s)^2$

(1)from $E = 0.5kx_1^2$,
(2) from$Mg = kx$,
(3) from $E = 0.5MV_1^2$

The rebound hammer numbers obtained on the vertical surface were compared with the corresponding corrected rebound values using the formulae (4), (6), (7) and (8). The formulation was verified as the two rebound values coincided with each other. Graphical results are displayed in figure-5.

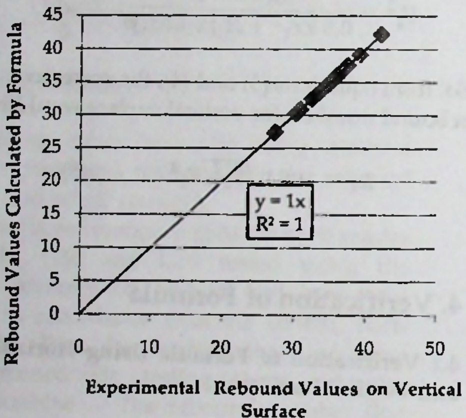

Figure 5-Verification of the formula for vertical surface

5. Derivation of Relationships for Inclined Surfaces

5.1 Test Procedure

The concrete cubes having two strength grades were used for testing on inclined planes. A total of 18 cubes which comprised of 9 from G30 and 9 from G15 were tested.The rebound hammer readings were taken at three inclined angles. The arrangement in the figure 6 was used to place the cubes in desired angle and to load the vertical surface. Rebound readings were taken on inclined surfaces. A total of 12 cubes were used to take readings on 30° and 60° surfaces and 6 cubes were used for 45° plane.

Figure 6 - Taking rebound readings on inclined cubes

5.2Results

Obtained rebound numbers (Rn) were converted into the corresponding vertical-surface-Rnvalues usingformulae (4) to (8). Then the corresponding strengths indicated by the existing rebound hammer curve for vertical surfaces (where the hammer is horizontal)were compared against the actual cube strength obtained at the laboratory.

The relationships between the derived rebound hammer strength and the actual strength of cubes were obtained for each angle of inclination. The figures 7 to 9 contain the derived relationships.

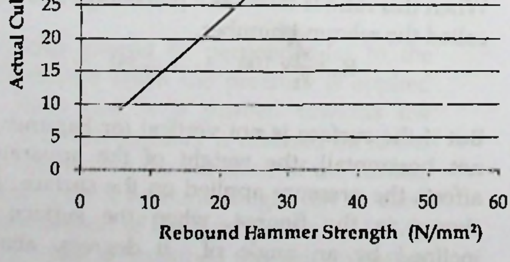

Figure 7 - Results obtained for 30° inclined plane

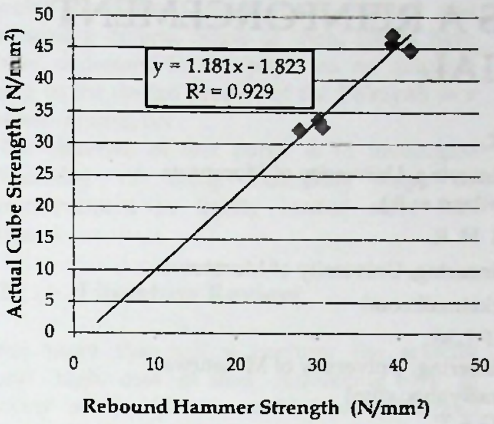

Figure 8 – Results obtained for 45 ° inclined plane

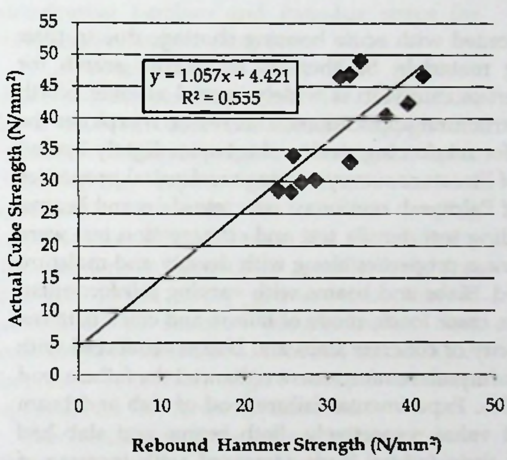

Figure 9 – Results obtained for 60 ° inclined plane

6. Concluding Remarks

- The actual results obtained for the horizontal and vertical surfaces display around 15% to 25% deviations from the existing conversion curves of the rebound hammer. The experimentally derived curves can be recommended to use as calibratedcurvesfor this particular hammer with correlation of the results (R^2 value)of 0.75 and 0.5 for vertical and horizontal surfaces respectively.
- The derived formula can be used to calculate the corresponding vertical surfaces rebound number of any inclined rebound value with 100% accuracy.
- Obtained results for strengths display a significant scatter in values for 30° and 60° of angles with correlations of 0.39 and 0.56 respectively, while the values in 45° angledisplay a correlation of 0.9.
- Scatter in the results can be anticipatedsince the rebound number is largely affected by many external factors. (e.g.-moisture, surface conditions, etc.). Thus, the correlation of the results obtained can be accepted.
- The derived relationships between the rebound hammer strength on inclined planes and their actual cube strength can be used to assess strength of concrete structures with inclined surfaces like Intz-type water tanks, and conical tanks. Accuracy of the results will be similar to the usual accuracy of rebound hammer testing, which is 15% to 20%

References

American Society for Testing and Materials, ASTM C805-02, Standard Test Method for Rebound Number of Hardened Concrete, c805/c805 M

Basu A, Aydin A 2004, 'A method for normalization of Schmidt hammer rebound values', International Journal of Rock Mechanics & Mining Sciences, Volume 41 (2004), pp 1211–1214

British Standard Institute 1986, BS1881-part 202-1986, pg 5.

Demirdag S, Yavuz H, Altindag R 2009, 'The effect of Sample size on Schmidt Rebound hardness value of rocks', International Journal of Rock Mechanics & Mining Sciences, Volume 46, pages 725-730, 2009

KatalinSzilagyi, AdorjanBorosnyoi, IstvanZsigovics 2011, 'Rebound Surface Hardness of Concrete: Introduction of Emperical Constitutive Model', Construction and Building Materials, Volume 25(2011), pp 2480-2487

Nicholas J Carino, 1997, Non-destructive test methods, Concrete Construction Engineering Handbook, Chapter 19 (1997), pg 3

Proceq, Product specifications and instructions manual