INVESTIGATION OF THE EFFECT OF IMPACT DIRECTIONS AND DIFFERENT ENVIRONMENT CONDITIONS ON REBOUND NUMBER

H.A.M. Hasanthi, I.M.S.M. Sandakelum and L.S.S Wijewardena*

Department of Civil Engineering, The Open University of Sri Lanka, Sri Lanka

The Schmidt hammer test has been used for estimating concrete strength for a long time. It is assumed that in the case of an undamaged concrete structure, the concrete is a homogenous mixture with equal strength at all depths. Hence the rebound hammer test may give a pretty accurate value when compared to the compressive tests performed in the laboratory. In the case of a structure, which has been damaged by elevated temperature, and an aggressive environment the concrete may no longer be homogenous at all depths and there might be considerable changes in its internal structure. Hence, this study is an attempt to carry out non-destructive tests on such concrete samples and then find out the accuracy of the results when compared to the compressive strength test performed in the laboratory. The rebound hammer strength from vertical downward shows over-estimated results due to the gravitational force applied when testing and the rebound hammer strength from the horizontal direction shows approximately equal strength value compared with the actual compressive strength value taken from the cube test at normal conditions. The $Y = 1.3222X - 14.352$ and $R^2 = 0.9326$ equation recommended to normalize the gravitational effect on the vertical rebound number. The average rebound number of vertical downward direction and horizontal direction is higher when the concrete surface is exposed to a temperature of 150°C to 350°C beyond that, it decreased. $Y = 2.8542e^{0.0663X}$, $R^2 = 0.8261$, and, $Y = 3.3511e^{0.06617X}$ with $R^2 = 0.9307$, equations are recommended to normalize temperature effect on rebound number in vertical downward and horizontal directions respectively. The rebound hammer shows higher values under seawater curing conditions compared with fresh water curing at 7 days, 14 days, and 28 days, Hence, there is a 28.59% over-estimated error in hammer strength compared with the actual cube strength of concrete in seawater conditions within the first 28 days. Beyond that. There is a 24.7% under-estimated error in hammer strength compared with the actual cube strength of concrete in seawater conditions after 28 days. There is no considerable variation in rebound number under normal water from 28 days to 112 days. Modified correlation equations, $Y = 1.0631X - 11.714$ with $R^2 = 0.9587$ and $Y = 0.7141x + 5.3756$ with $R^2 = 0.9338$ to normalize the seawater effect on the rebound number within the first 28 days and from 28 days to 112 days respectively in the horizontal direction (Y- Actual Cube Strength, X- Rebound Number)

Keywords: Rebound Number, Hammer Strength, Compressive strength, Bond strength, Elevated temperatures, Marine Environments.

**Corresponding author: lswij@ou.ac.lk*

INVESTIGATION OF THE EFFECT OF IMPACT DIRECTIONS AND DIFFERENT ENVIRONMENT CONDITIONS ON REBOUND NUMBER

H.A.M. Hasanthi, I.M.S.M. Sandakelum and L.S.S Wijewardena*
Department of Civil Engineering, The Open University of Sri Lanka, Sri Lanka

INTRODUCTION

There are various destructive (DT) and non-destructive (NDT) testing methods available for estimating compressive strength. Estimating the compressive strength of concrete exposed to different environmental conditions is an essential parameter in evaluating the quality of concrete and proving its ability to perform as designed. The Schmidt hammer test has been used for estimating concrete strength for a long time. It is assumed that in the case of an undamaged concrete structure, concrete is a homogenous mixture with equal strength at all depths. Hence, the rebound hammer test may give a pretty accurate value when compared to the compressive tests performed in the laboratory. The calibration of Rebound Hammer is still based on the original Schmidt curve from the 1950s, (Brencichet al., 2020). It has not been calibrated for specific tested environments. Because of this, the Rebound Hammer test is limited to some specifications. However, in the case of marine environments, concrete structures can be found both within marine environments or near marine environments **(**Sakthivel et al., 2018). Hence, modified correlation is essential to determine between rebound number and compressive strength of concrete in the marine environment. Other than that, concrete, when exposed to high temperatures, undergoes significant deterioration. Its mechanical and physical properties can be affected. Elements can become distorted and displaced due to heat-induced dimensional changes. There is a likelihood of a decrease in strength and stiffness at elevated temperatures. Brozovskyet al. (2016), in their research, concluded that there is an increase in rebound numbers at elevated temperatures. But still, there are no relationships found between the actual compressive strength with increased rebound numbers. Karakul, (2020), concluded that the changes in rebound numbers can be observed due to gravitational forces. Also, the variation of hammer strength on the same concrete surface in different impact directions has not yet been proven. The relationships between cube strength and hammer strength for different impact directions at different environmental conditions also have to be established. Hence, developing correlations for varying impact directions is useful.

METHODOLOGY

Concrete cube specimens of 150×150×150mm of 1:1.5:3 ratio (Grade 25) were prepared. The values obtained from the Schmidt hammer test can vary due to different impact directions, (Karakul, 2020). Therefore, this study evaluated the accuracy of impact directions and established a correlation between the rebound number and actual cube strength to normalize the gravitational effect on the rebound number.

Brozovsky et al. (2016), concluded, that a certain increase in rebound numbers was recorded at temperatures of up to 400°C when compared to the rebound numbers determined for concrete placed in a standard environment (room temperature). Therefore, after 28 days of curing, cubes were placed in the oven at temperatures 150°C, 250°C, 350°C, 450°C, 550°C, 650°C, and 750°C. After 1 hour, specimens were taken out from the oven, and the rebound hammer test and compressive strength test were performed. Three test specimens were tested for duration along with the temperature. Correlations were developed between rebound number and actual cube strength.

Sakthivel et al. (2018) through their study concluded that the surface hardness of concrete is increased in both normal and seawater curing of concrete. Therefore, in this study, the rebound hammer test, and compressive strength test were conducted on the 7th, 14th, 28th, 56th, 84th and 112th days for both curing conditions. All concrete cube samples were air-dried for twenty-four (24) hours before they were tested, and three test specimens were tested for each day. Correlations were developed between the rebound number and the actual cube strength of concrete in the marine environment.

RESULTS AND DISCUSSION

Effect of impact directions on rebound number

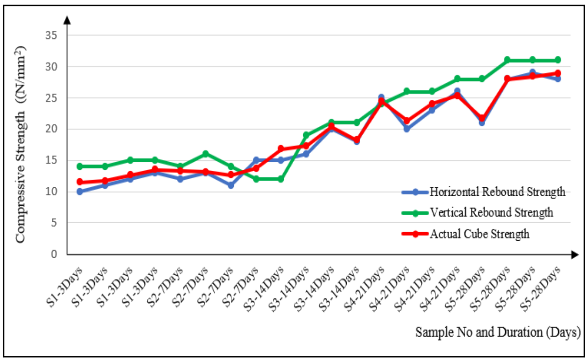


Figure 1: Rebound strength and cube strength

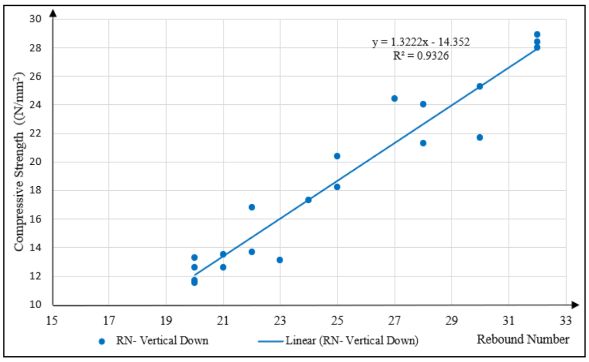
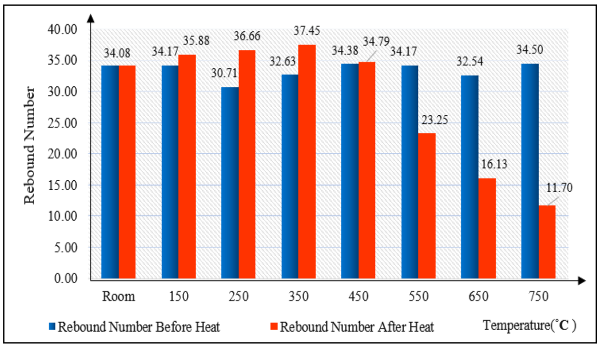


Figure 2: Modified Correlation chart for RN

Figure 1 shows the variation of rebound hammer strength and actual cube strength. The rebound hammer strength from vertical downward shows over-estimated results due to the gravitational force applied when testing and the rebound hammer strength from the horizontal direction shows approximately equal strength value compared with the actual compressive strength value taken from the cube test at normal conditions. Based on the results shown in Figure 2, The Modified Correlation equation between the vertical downward rebound number and actual cube strength is Y = 1.3222x - 14.352 and R^2 = 0.9326. (Y- Actual Cube Strength, X- Rebound Number) This equation is recommended to normalize the gravitational effect on the rebound number.

Effect of elevated temperature on rebound number in vertical and horizontal direction



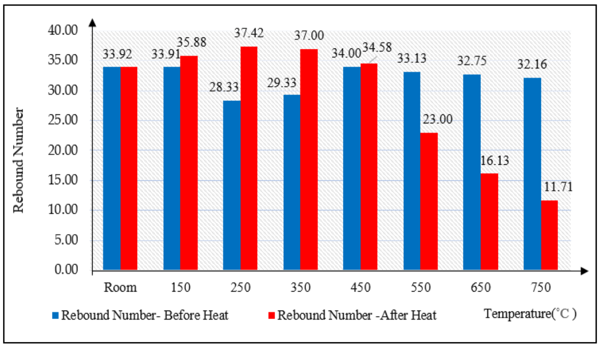


Figure 3: Vertical RN before and after heat

Figure 4: Horizontal RN before and after heat

Figure 3 shows that the rebound number increased up to 350 °C and beyond that it decreased. The rebound number is higher when the concrete surface is exposed to a temperature of 150°C to 350°C due to the hardening of the concrete surface of the sample at a higher temperature than that of the normal condition. Also, Micro-cracks appeared on the surface after 450°C temperature, which is the reason for the reduction of the rebound number.

Correlation equations between RN and actual cube strength at elevated temperature

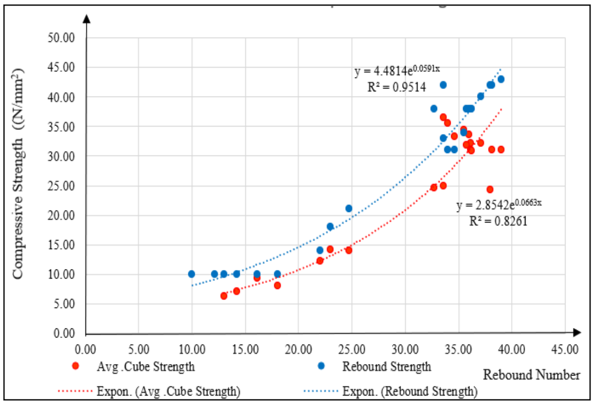


Figure 5: Correlation chart for vertical RN

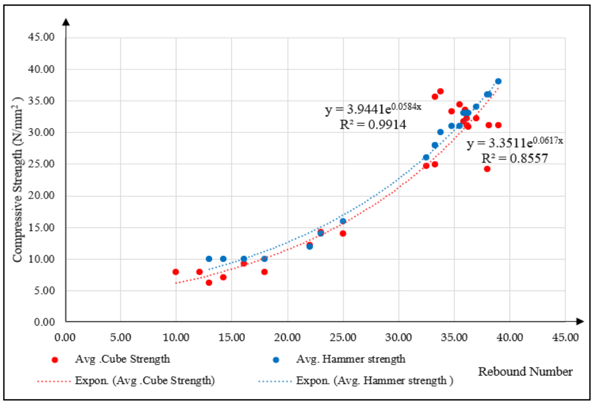


Figure 6: Correlation chart for horizontal RN

According to Figure 5, the correlation equation of the rebound number of the vertically downward direction and rebound strength is, $Y = 4.4814e^{0.0591x}$ and, $R^2 = 0.9514$. The correlation equation of rebound number of vertical downward direction and actual cube strength is, $Y = 2.8542e^{0.0663x}$ and, $R^2 = 0.8261$. According to Figure 6, the correlation equation of the rebound number of horizontal direction and rebound strength is, $Y = 3.9441e^{0.0584x}$ and, $R^2 = 0.9914$. The correlation equation of the rebound number of horizontal direction and actual cube strength is $Y = 3.3511e^{0.06617x}$ and, $R^2 = 0.8557$. As seen in Figures 5 and 6, the rebound strength is higher than the actual strength. The reason is, in the case of a structure, which has been damaged by elevated temperature, the concrete may no longer be homogenous at all depths and there might be considerable changes in its internal structure.

Based on the results shown in Figures 5 and 6, the modified correlation equations are $Y = 2.8542e^{0.0663X}$ with $R^2 = 0.8261$ and $Y = 3.3511e^{0.06617x}$ with $R^2 = 0.8557$ for vertical downward RN and horizontal RN with actual cube strength respectively.

Effect of seawater and normal water curing conditions on rebound number

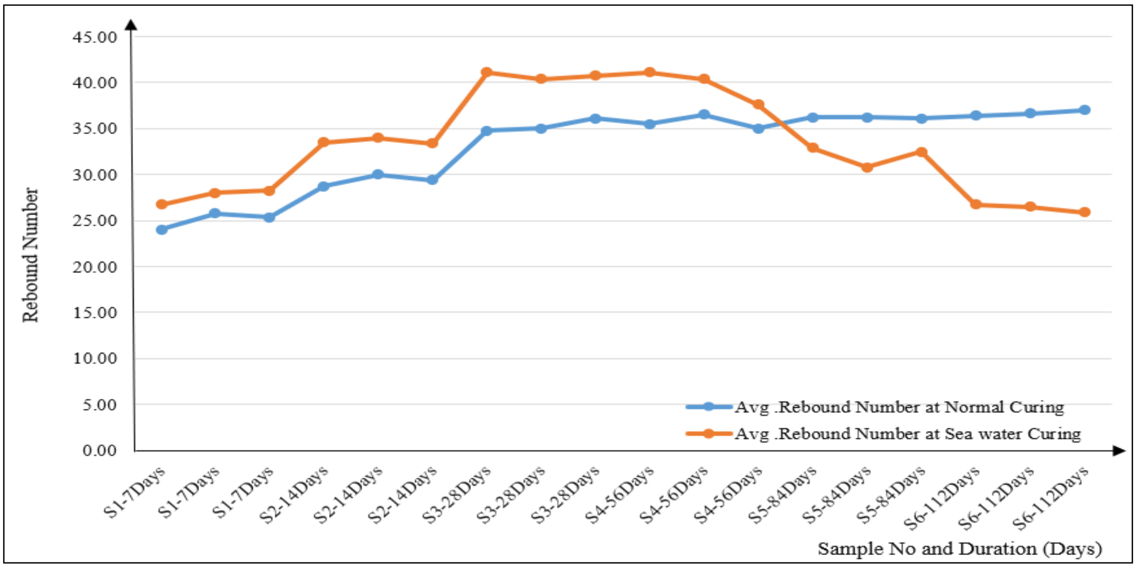


Figure 7: Variation of RN from 7 days to 112 days of curing

According to the results shown in Figure 7, the rebound hammer shows higher values under seawater curing conditions compared with normal water curing at 7 days, 14 days, 28 days and 56 days, The reason is the hardening of the concrete surface of the sample curing at seawater than that of the normal water curing condition. Beyond that, the rebound number decreased from 37 to 25 at 84 days and 112 days respectively. It shows that surface exposure to seawater can lead to the deterioration of concrete through processes like Sulfate attack and Chloride ions penetration to the concrete surface. There is no considerable variation in rebound number under normal water from 56 days to 112 days.

Effect of seawater and normal water curing conditions on compressive strength of concrete

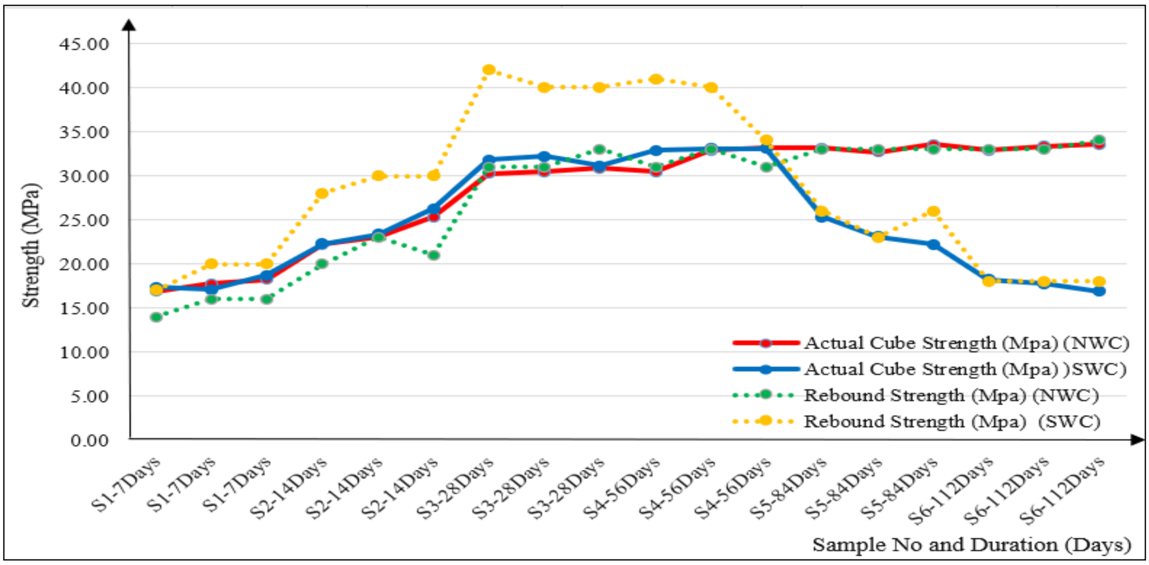


Figure 8: Variation of actual cube strength and rebound strength at normal and seawater curing

According to Figure 8, the actual compressive strength indicates the same variation in both NWC and SWC up to 28 days. The rebound hammer shows higher values under seawater curing conditions (SWC) compared with normal water curing conditions (NWC) at 7 days, 14 days and 28 days. The rebound hammer strength at SWC is higher than the actual compressive strength. and the variation of cube strength and rebound strength of concrete cured with normal water are very close to each other with no reduction. However, there is a reduction of both the cube strength and rebound strength of concrete cured with seawater from 56 days to 112 days.

Correlation equations between RN and actual cube strength of concrete under seawater

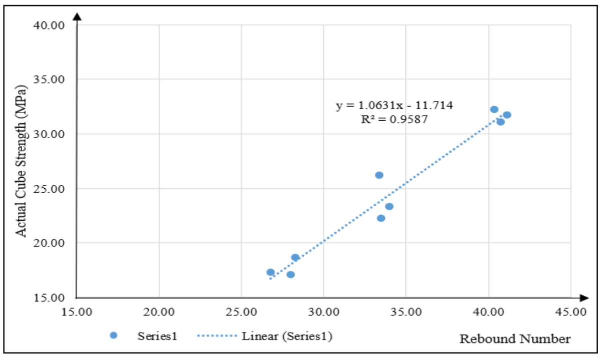


Figure 09: Correlation for RN within 28 days

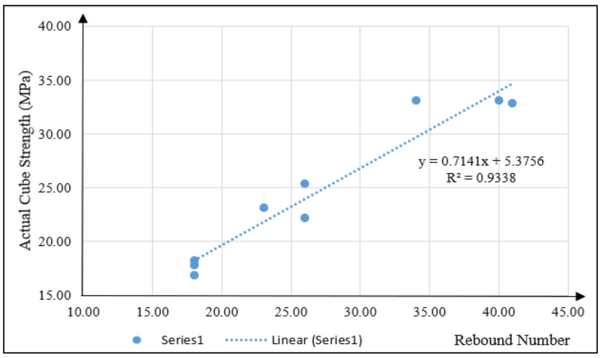


Figure 10: Correlation for RN from 56 to 112 days

It is recommended to use the modified correlation equations, Y = 1.0631x -11.714 with R^2 = 0.9587 and Y = 0.7141x + 5.3756 with R^2 = 0.9338 to normalize the seawater effect on the rebound number within the first 28 days and from 28 days to 112 days respectively in the horizontal direction (Y- Actual Cube Strength, X- Rebound Number)

CONCLUSIONS/RECOMMENDATIONS

According to the results, the accuracy of estimated compressive strength in the horizontal direction (94.42%) is higher than that in the vertical downward direction (86.45%). The rebound number is higher when the concrete surface is exposed to a temperature of 150 °C to 350 °C due to the hardening of the concrete surface of the sample at a higher temperature than that of the normal condition. Also, micro-cracks appeared on the surface after 450 °C temperature, which is the reason for the reduction of the rebound number after 450 °C. The average rebound number increased by 40.93% and 47.32% in normal and seawater conditions respectively within 28 days. There is a 28.59% over-estimated error in hammer strength compared to the actual cube strength of concrete in seawater conditions within the first 28 days. The average rebound number increased by 0.027% and decreased by 50.58% in normal water and seawater conditions respectively from 56 days to 112 days.

The Modified Correlation equation between the vertical downward rebound number and actual cube strength is $Y = 1.3222x - 14.352$ and $R^2 = 0.9326$. This equation is recommended to normalize the gravitational effect on the rebound number. It is recommended to use the modified correlation equations, $Y = 2.8542e^{0.0663X}$ $R^2 = 0.8261$. and, $Y = 3.3511e^{0.06617X}$ with $R^2 = 0.9307$, for vertical downward and horizontal directions respectively to normalize the temperature effect on rebound number. It is recommended to use the modified correlation equations, $Y = 1.0631x - 11.714$ with $R^2 = 0.9587$ and $Y = 0.7141x + 5.3756$ with $R^2 = 0.9338$ to normalize the seawater effect on the rebound number within the first 28 days and from 28 days to 112 days respectively in the horizontal direction (Y- Actual Cube Strength, x- Rebound Number)

REFERENCES

1. Brozovsky. J, et.al. (2016*). Contribution to the issue of evaluating the compressive strength of concrete exposed to high temperatures using the Schmidt rebound hammer. Russian Journal of Nondestructive Testing. 52*. 44-52. 10.1134/S1061830916010046.
2. Karakul, H. (2020). *Investigation of the effect of impact direction on Schmidt rebound values by multivariate regression and neuro-fuzzy model. SN Applied Sciences*, 2(11). doi:https://doi.org/10.1007/s42452-020-03600-6.
3. Sakthivel, M.R., et al. (2018). *Studies on the effect of seawater & normal water intrusion in sea sand on concrete cubes*. *International Journal of Scientific & Engineering Research, Volume 9 (Issue 12)*.
4. Brencich, A. et al. (2020) *'Rebound hammer test: An investigation into its reliability in applications on concrete structures'*, *Advances in Materials Science and Engineering, 2020,* pp. 1–11. doi:10.1155/2020/6450183.