The Effect of Different Equations and Methods on R-Square Values of Ndt Correlations

Hadi Abbaszadeh^{1, *}, Serkan Karatosun² and Servan Baran³

^{1, 2, 3} MS.C. Student, Faculty of civil engineering, Istanbul Technical University, Istanbul, Turkey

*Corresponding author

Abstract. The assessment of compressive strength of RC building to find out their current condition is essential for condition assessment of these building and taking out too much cores for reaching valid results be an expensive method. Non-destructive methods are the way to reduce the amount of charges and to increase the speed of work. However, there is lack of knowledge in literature about using Rebound hammer-Q (Silver Schmidt) and it's R-square values either in single correlation or in SonReb method. A fifteen-story building that was left half-made around thirty years ago at Istanbul, Turkey was evaluated by Rebound hammer type R and Q, Ultrasonic Pulse Velocity (UPV), and combined SonReb method by both R and Q type Rebounds, and three cores were pulled out in each story in same locations for all buildings. The R-square value was find out in this research for different equations based on EN 13791 standard with three cores in each story of all four building and comparison was made based on R-square values of various correlations among equation types, also. In addition, the effect of using Rebound hammer type Q was illustrated in this paper in single correlation with compressive strength results and combined SonReb method with UPV results.

Keywords: NDT, RC building, Rebound number, R-square, UPV

1. Introduction

The assessment of current condition of existing buildings is an essential issue that researchers and engineers in worldwide deal with it. The assessment of in situ compressive strength of a RC building plays a key role in the evaluation of its safety (Pucinotti, 2015). The testing of old concrete needs was noticed some decades ago. For evaluating the integrity of concrete and reinforcement, Non-destructive testing methods is one of the most powerful and reliable tools. The needs for manipulating non-destructive test for condition assessment of the RC buildings has merged significantly in recent years, as their area great increase in number of old and unreliable structures, showing signs of dangerous conditions. The standard service life of RC frame structure is considered to be 60 - 80 years. However, it has been reported that, many of the buildings completing just 20 - 25 years of their life, if one visits the chemical plant buildings, the RC buildings are in distressed condition within a service life of only 7 to 10 years. The severe exposure condition is the main reason for this deterioration (Kumavat et al., 2014).

The standard methods that were used to evaluate the quality of concrete in RC buildings on specimens cannot be considered, as the results are not immediately available, the number of specimens or samples that was taken is not sufficient because of high cost, still results do not demonstrate the reality of the structure (International Atomic Energy Agency, 2001).

The main advantage of nondestructive testing (NDT) method is to reduce the concrete damage on the performance of building structural components. Furthermore, their usage is simple, quick and cheaper. In addition, test results are available on site while test was done.

Concrete testing in a case is required in which the cores cannot be pulled out, where the use of less expensive equipment is needed (Hobbs and Tchoketch, 2007)

The Non Destructive Testing is being fast, easy to use at site and relatively less expensive that can be used for (a) Test could be done at any location or point in any number, (b) Evaluate the overall stability of building, (c) Figure out the voids, cracks, honeycombs, fractures, and weak locations, (d) Test actual structure instead of representative sample, (e) Assess the structure for different weak or distressed conditions, (f) Scanning for demonstrating the location of reinforcement and stress, (g) Damage assessment made by chemical attack, fire, environmental impact, age of structure etc., (f) Monitor progressive changes in the properties of concrete elements, reinforcement etc. (Kumavat et al., 2014).

Based on the fact that some physical properties of concrete can be related to the compressive strength of concrete, some NDT methods have been submitted and developed. Non-destructive tests associated with destructive tests (DT) results to an improved alternative for concrete strength estimation in existing structures (Vona and Nigro, 2013), and (Fiore et al., 2013).

An experimental relationship must be identified between strength measured from cores that was pulled out and NDT results from the same locations. For the non-destructive evaluation of strength, the European standard EN 13791 suggested at least 18 pairs of data; however, ACI 228.1R standard suggested six to nine areas of test measurement with two cores in each area. On the other hand, the actual practice is usually based on lower number of cores, thus the reliability of this estimation is disputable and rarely discussed (Breyse and Martinez-Fernandez, 2014), and (Alwash et al., 2015).

The compressive strength of concrete is usually the most sought after property. This leads to the development of a method that combines index rebound hammer and the ultrasonic pulse velocity UPV (Breyse, 2009).

The combination of some techniques of nondestructive testing is often provided empirically, combining two techniques most often used to increase the reliability of the estimate compressive strength of concrete; the principle is based on correlations between observed measurements and the desired property. The standardized combined method that was most widely used is SonReb method developed by RILEM 1983, first born and established in Romania then propagated in Australia and in Europe. The development in the reliability of the measures is demonstrated by taking into account the contradictory effect of variability factors of some properties for either Rebound hammer or UPV (Breyse, 2008).

It seems that combined Rebound Hammer and Ultrasonic Pulse Velocity (UPV) method does not have any important effectiveness in certain conditions which have not been really clarified. In addition, if one of these techniques is significantly less accurate than the other one, combining poor quality results could lead to unreliable outcomes (Breyse, 2012), (Knaze and Beno, 1984), and (Malhotra and Carino, 2004). This is also the case when the dataset is heterogeneous, for example carelessly mixing measurements on carbonated and un-carbonated concrete. Furthermore, few works deal with the effect of the number of data on the combined method effectiveness (Rilem, 1983) and (Breyse, 2012).

This paper presents the correlations and various equations for the tests which was measured for a single half-finished building that is design by just shear walls with no columns. Three different cores were taken in each stories with total of forty-five cores in each building the location that cores were taken was shown at Fig. 1; in addition, it represents the use of Rebound

hammer type Q in single correlation and in SonReb method with UPV results for demonstrating the effect and the differences between this type of hammer and R type hammer in NDT tests.

2. Experimental work

There are some previous real case studies in the literature for the estimation of strength with NDT measurements. However, they are usually use limited number of cores and study was performed on just single building so there is lack of information for comparing the results among similar cases in NDT measurements. Also, some of recent studies were based on laboratory or synthetic data to find out correlations and analyzing the compressive strength behavior by NDT measurements (Benyahia et al., 2017).

The 180 elements (shear walls) in all buildings in this work was examined due to obtaining the DT and NDT results and demonstrating the differences among R-square values while using Rebound hammer type Q. Three cores with diameter of 95 (mm) was taken from each story of all buildings.

After transferring cores to laboratory they were weighted and measured. Then, ultrasonic pulse velocity (UPV) test was done for each core, next the capping procedure begins and after a day (consider for capping hardening) compressive tests was began with compression machine and strains was obtained by LDTV tools of this machine.

Case study building outside view (Fig. 1a) and inside views of half-made building was shown in Fig. 1. The building consist of shear walls with RC beams and deck.

Figure 1: Case study (e.g. Building (A)) with inside views

Figure 1.a demonstrates the studied case overall view and Fig. 1.b-c shows the inside of the intended half-finished building.

3. Results and Analysis

The analysis process was began using Five different equation type (Linear, Polynomial 2nd degree, Polynomial 3rd degree, Power, and Exponential) was selected for evaluating the result of each method and SonReb method both with Rebound R and Q based on R-square values.

Based on EN 13791 standard data was analyzed and curves was provided using the standard equation and it's shifted curve, ploy. 2nd degree curves was shown for all methods also for better comparison.

Table 1: Correlation equations for case study

NDT Method	Equation type	Correlation Equation	r ²	SD
Rebound- R	Linear	$F = 1.234R - 18.38$	0.4920	3.3604
	Poly. 2 nd	$F = 0.0068R^2 + 0.736R - 9.36$	0.4924	
	Poly. 3 rd	$F = -0.0083R^3 + 0.933R^2 - 33.31R + 403.9$	0.5034	
	Power	$F = 0.0602R^{1.693}$	0.4923	
	Expo.	$F = 5.075\exp(0.04517R)$	0.4874	
Rebound-Q	Linear	$F = 0.896Q - 14.79$	0.5062	4.6937
	Poly. 2 nd	$F = -0.00087Q^2 + 0.978Q - 16.71$	0.5062	
	Poly. 3 rd	$F = -0.0013Q^3 + 0.334Q^2 - 14.98Q + 234$	0.5110	
	Power	$F = 0.0731Q^{1.538}$	0.5054	
	Expo.	$F = 6.037\exp(0.318Q)$	0.4995	
UPV	Linear	$F = 9.624V - 12.16$	0.3973	0.3873
	Poly. 2 nd	$F = 3.309V^2 - 17.19V + 41.66$	0.4050	
	Poly. 3 rd	$F = 2.561V^3 - 27.85V^2 + 108.4V - 125.9$	0.4060	
	Power	$F = 3.392V^{1.476}$	0.3996	
	Expo.	$F = 6.095\exp(0.363V)$	0.4034	
SonReb (R)	R 1 st , V 1 st	$F = 0.888R + 4.921V - 25.61$	0.5572	-
	R 2 nd , V 2 nd	$F = 1.7R - 61.22V - 0.06R^2 + 0.934RV + 3.855V^2 + 91.24$	0.5956	
SonReb (Q)	Q 1 st , V 1 st	$F = 0.658Q + 4.423V - 21.64$	0.5545	-
	Q 2 nd , V 2 nd	$F = 0.96Q - 28.72V + 0.016Q^2 - 0.45QV + 6.65V^2 + 37.85$	0.5685	

Table 1 demonstrates the regressions (correlation equation) and their intended R-square value. Based on these results increasing the degree of equation (or complexity) the R-square value increase. In addition, power and exponential correlations significantly depend on data dispersion and based on varies; however, these correlation's R-square values never reach the polynomial 2nd degree correlation.

Combined SonReb method could significantly improve the weak values of UPV and also the Rebound values to reach higher values of R-square in order to have better correlation. These three-dimensional correlations have calculated both using Rebound-R and Rebound-Q values and results was shown in Table 1.

Rebound-R versus Compressive strength correlation was shown in Figure 3. The EN 13791 line was derived using standard suggested equation (1) for Rebound-R hammer and EN 13791 (shifted) line was drawn by shifting the EN 13791 line by delta value ($\Delta = -8.6828$). Polynomial 2nd degree correlation curves was demonstrated in Fig. 3 also for making better comparison between standard suggestion and the one that derived using Matlab software.

$$\begin{cases} F_R = 1.25 \times R - 23 & 20 \leq R \leq 24 \\ F_R = 1.73 \times R - 34.5 & 24 \leq R \leq 50 \end{cases} \quad (1)$$

Figure 2: Correlation: Rebound Number-R vs. Compressive Strength

Correlation for Rebound-R was illustrated in Fig. 2 and the EN 13791 curves and its shifted curves are both close to the fundamental data which was obtained from compressive tests and Rebound measurements. Although, both standard's curves are perfectly close to data but the polynomial 2nd degree curves which was obtained by the intended software has the best result.

Figure 3: Correlation: Rebound Number-Q vs. Compressive Strength

Figure 3 was demonstrates Rebound-Q versus Compressive strength. In order to lack of information in standard for Rebound-Q hammer and due to higher values reached from this hammer which is not allowed in standard equation limits, there are no EN 13790 and its shifted curves in this figure for intended hammer. Thus, Polynomial 2nd degree and Polynomial 3rd degree was selected to show the correlation for this data.

Figure 4: Correlation: Rebound Number-R vs. Compressive Strength

Ultrasonic Pulse Velocity (UPV) versus Compressive strength correlation observed in Fig. 4. The EN 13791 line was derived using standard suggested equation (2) for Ultrasonic Pulse Velocity and EN 13791 (shifted) line was drawn by shifting the EN 13791 line by delta value ($\Delta = 9.1409$). Polynomial 2nd degree correlation curves was demonstrated in Fig. 5 also for obtaining the differences between standard suggestion curve and the one that derived using Matlab software considering that standard suggestion as observed in Equation (2) is reliable for values between 4 and 4.8; however, the Polynomial 2nd degree correlation was derived using entire data.

$$F_V = 62.5 \times V^2 - 497.5 \times V + 990 \quad 4 \leq V \leq 4.8 \quad (2)$$

Figure 5: Correlation: Combined SonReb Method with Rebound Number-R

Combined SonReb method including Rebound Number-R, UPV, and Compressive strength was demonstrated in Fig. 5. The intended correlation plate is a 2nd degree plate both for Rebound Number-R and UPV (as R, and V). This method could significantly improve the R-

square value to 0.5956 from 0.3973 which is Linear correlation R-square value of UPV (see Table 1).

Figure 6: Correlation: Combined SonReb Method with Rebound Number-Q

There is lack of information both for Rebound Number-Q and combined method using Rebound Number-Q. Figure 6 shows the combined SonReb method using Rebound Number-Q which is demonstrates decrease in R-square values both for 1st and 2nd degree plates compared with combined SonReb correlation using Rebound Number-R; This decrease could effected due to external parameters such as operators performance and it does not proof that using this hammer which is more accurate is not regional.

Figure 7: Equation based R-square values comparison

The various R-Square values for all different test method including SonReb methods considering all various equation which is demonstrated in Table 1 was shown in Fig. 7. There is a peak value in all test methods which is Polynomial 3rd degree; however, in Rebound-Q test method Poly. 2nd degree and Power correlation are close which it means using Poly. 2nd degree is more logical due to simplicity. In UPV method due to special dispersion of data which is more close to Poly. 2nd the results of Poly.3rd and Poly. 2nd are so close and using Poly. 2nd

degree correlations seems more logical again due to simplicity. In addition, increasing the degree of variables in SonReb method could directly improve the R-square value due to covering more surface by the 2nd degree plate for instance. SonReb-Q due to higher SD and previously mentioned reasons has lower value compared SonReb-R; however, this difference could be negligible considering 1st degree variables only.

Figure 8: Standard deviation for each method

Standard Deviation is a factor that could significantly influence the reliability of test and correlation results which is shown in Fig.9. In addition, the lower value of R-Square for SonReb-Q compared SonReb-R could be affected from the high standard deviation value for this test method as observed in Fig. 9. In order to small values for UPV test measurements SD value for this test method is too small compared others.

4. Conclusion

Condition assessment of existing RC building is an important issue that could have a great effect on costs and time of evaluation.

Rebound-R, Rebound-Q, and UPV method was used to evaluate the condition of an existing half-finished RC building. Combined SonReb method was used in this paper to improve the R-square values due to weak UPV correlation R-square values.

It has been observed that by increasing the degree of equation its reliability increase; however, in some cases such as UPV correlations this way is not effected in order to dispersion of data.

It has been proved that by increasing the degree of variables in SonReb method the R-square value improve for this method.

In addition, there is a difference between SonReb-R and SonReb-Q with is significantly influenced by standard deviation value and the operators performance due to the parameters which were evaluated in this research study.

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