Int'l Journal of Advances in Agricultural & Environmental Engg. (IJAAEE) Vol. 1, Issue 2 (2014) ISSN 2349-1523 EISSN 2349-1531

Reliability of Rebound Hammer Test in Concrete Compressive Strength Estimation

Kristine Sanchez, and Nathaniel Tarranza

***Abstract*—**The reliability of the non-destructive Schmidt Hammer Test as a means of estimating the compressive strength of concrete is investigated by testing three groups of concrete cube specimens. The first group was exposed to cycles of alternate drying and wetting in brackish water; the second group, to continuous immersion in brackish water; and the third (control) group, to normal room condition. Results show that the average Schmidt Hammer Rebound Number (RN) for samples in the first and second group is significantly less than that of the third group. These indicate the reliability of the Schmidt Hammer Test in predicting the reducing effect of exposure to brackish water on the compressive strength of concrete. Moreover, results show that in each of the three groups, the average estimated compressive strength of concrete based on Schmidt Hammer Test (using the rebound curve provided by the manufacturer of the device) underestimates the average actual compressive strengths based on direct compression test. Thus, in a quick strength and safety assessment of existing concrete structures, the Schmidt Hammer Test is fairly reliable in determining whether the further use of the structure would still be safe, but may not be so in concluding whether the use is no longer safe. In the latter case, the Schmidt Hammer Test should be supplemented by core sampling and testing.

***Keywords*—** Compressive strength, Concrete, Rebound hammer, Reliability.

I. INTRODUCTION

TO determine the strength of concrete in existing structures, cylinder specimens are usually taken from the structures and brought to laboratories where they are loaded to failure to obtain actual compressive strength. This procedure is the most accurate way but it requires considerable time and expenses. In order to assess in-situ concrete strength in a faster manner, non-destructive testing (NDT) techniques have been developed and adopted. These techniques estimate the strength of existing structures by measuring some concrete properties other than its strength, and then relate these properties to strength or other mechanical properties of concrete [1].

Among the many available NDT techniques, the most widely employed is the one using a device called the rebound hammer, also known as the Schmidt Hammer, due to the advantage that the device is portable, less expensive and easy to use. It was developed in 1948 by Swiss engineer Ernst Schmidt. The device uses a spring and measures the hardness of concrete surface using the rebound principle [2]. The aim of rebound hammer tests of concrete is usually to find a relationship between surface hardness and compressive strength within an acceptable error [3].

However, studies have shown that rebound readings are sensitive to near-surface properties, thereby casting doubts on the accuracy of the test in estimating compressive strength. Factors that were found to influence the surface hardness include surface smoothness, age of concrete, moisture content, carbonation, presence of aggregates, presence of air voids and steel reinforcement, temperature, and calibration of the rebound hammer [2]. Because of these factors, it has been proven that the rebound hammer measurements are not unique and test result is dependent upon the characteristics of the concrete tested, which in turn varies with the different parameters of construction.

A great number of research works have been conducted in order to verify whether or not the hammer test is a reliable tool for estimating concrete compressive strength. Some of the recent scientific works reveal that the hammer test can actually provide useful information about the quality of concrete, for as long as that the device has been calibrated for the type of concrete being tested. According to the American Concrete Institute (ACI), the use of non-destructive tests in the field should be preceded by the development of rebound correlation curves (Schmidt curves) from laboratory tests done on standard concrete specimens made with the same materials used in the concrete structure that is under evaluation. These findings, however, are still not being generally considered in estimating strength using rebound hammer test [4]. In the Philippines, for instance, most local construction companies do not develop their own rebound correlation curves, and tests carried out in construction sites rely primarily on the rebound curve provided by the manufacturer of the device, either in assessing whether the concrete mix is of good quality or an existing structure is still in good condition.

Thus, this study aimed to further evaluate the reliability of the hammer test by determining how the rebound hammer test estimates actual concrete compressive strength, and how the rebound reading varies when concrete is exposed to different environmental conditions. The investigation was conducted on 150-mm concrete cubes which were cured for 28 days before the exposures. Determination of the estimated strength was performed using Schmidt hammer test and the rebound curve provided by the manufacturer of the device, while the actual compressive strength was obtained by direct loading of

Kristine Sanchez is with the Civil Engineering Department of Mindanao State University-Iligan Institute of Technology, Iligan City 9200 Philippines. (+639487744107; e-mail: kristinesanchez22@yahoo.com).

Nathaniel Tarranza is with the Civil Engineering Department of Mindanao State University-Iligan Institute of Technology, Iligan City 9200 Philippines. (e-mail: nathanieltarranza@yahoo.com).

This research was sponsored by the Department of Science and Technology-Engineering Research and Development for Technology (ERDT-DOST), Philippines.

http://dx.doi.org/10.15242/IJAAEE.C1114040

the specimens to failure.

II. EXPERIMENTAL PROGRAM

A. Materials and Mix Proportions

A total of 108 samples of 150-mm concrete cubes were made. Ordinary Portland Cement Type I was used, along with ¾-inch crushed coarse aggregates and washed fine aggregates that were sourced locally. A ¾-inch thick ordinary plywood was utilized for formworks, with Formica tiles glued on the inner sides of the formworks to ensure a smooth concrete finish. This was done to minimize roughness of the concrete surface which could be a major factor affecting rebound reading. Since the designed sample variations require some of the concrete cubes to be exposed to brackish water, low permeability is necessary and, hence, the concrete mix used was 0.45 water-cement ratio [5] by weight for all concrete cubes. A 28-day curing period in standard conditions was observed for all samples.

B. Exposure of Test Specimens to Sample Variations

After 28 days of curing, the concrete cubes were grouped into three, and each group is exposed to a different environment, as follows:

1. Samples subjected to cycles of alternate drying and wetting in brackish water

One third of the concrete cubes were placed in a covered concrete tank that was alternately filled and emptied with brackish water. One cycle of alternate drying and wetting consists of leaving the samples to dry for six hours when the tank is empty after draining the water, and fully immersing the samples for another six hours when the tank is filled with water. Brackish water was replaced weekly. The cycles of alternate drying and wetting were maintained until the samples were taken out to undergo the rebound hammer and direct compression tests.

2. Samples continuously immersed in brackish water

Another third of the concrete cubes were fully immersed in brackish water in another covered concrete tank. Cube specimens in this group remained undisturbed during their immersion until they were tested for rebound reading and direct compression. Brackish water was also replaced weekly.

3. Samples stored in and exposed to normal room conditions

The last third of the samples were exposed to normal room condition and served as the control group of the study. They were stored, adequately covered with canvass and left undisturbed in a storage area under normal room temperature. The storage area was relatively dry at 75% relative humidity.

C. Conducting Schmidt Hammer Test and Direct Compression Test

From each group of concrete samples, 12 cubes were tested for strength after the 28-day curing period; 12 cubes, after 80 days (108-day old) of exposure to a specific environment; and 12 cubes, after 114 days (142-day old) of exposure to the same environment. The concrete cube specimens were selected at random from the same group and tested for rebound reading and direct compression. A laboratory-calibration procedure outlined by Kishore, K. [6] served as guide for the research work. Rebound hammer testing followed the requirements set forth by ASTM C 805-02 [7] and ACI 228-03 [8]. The rebound hammer used is digital, relatively new, and had not been extensively used prior to the research work.

Before being tested for rebound reading, the concrete specimens exposed to cycles of alternate drying and wetting in brackish water and to continuous immersion in brackish water were removed from their specific exposure and left to air-dry for 24 hours. In order to simulate pre-loading of concrete in existing structures, an initial load of approximately 15% of the estimated ultimate load was applied to the specimens before they were tested. To ensure uniformity, the following procedures were consistently observed for the rebound hammer test:

a) the hammer was positioned at 90 degrees downward, with a level ground surface supporting the specimen;
b) a total of 16 rebound readings were obtained from each specimen tested;
c) hitting a portion of the concrete surface with voids and cracks was avoided; and
d) spacing between points hit by the hammer was at least 25 mm.

Immediately after the rebound hammer test was conducted, the concrete specimens were loaded to failure using the direct compression machine to determine their actual compressive strength.

All the samples were also tested for surface carbonation using the phenolphthalein test. This was done to verify both the existence and extent of carbonation – a factor that can greatly influence rebound reading by as much as 50% higher than the reading on non-carbonated surfaces [3]. The test was performed such that immediately after breaking the samples, liquid drops of phenolphthalein were applied. Within less than two minutes of application, the tested portion of the samples, both inside the cracked portion and on the surface, turned pink, indicating no occurrence of carbonation. This was observed even for concrete samples exposed to brackish water.

III. RESULTS AND OBSERVATIONS

A. Comparing Rebound Number between Two Sample Variations

It is noted that after some samples were exposed to brackish water for 80 to 114 days, three observations were significant:

a) the concrete surface became slightly rough such that the smooth finish resulting from the use of Formica board was significantly diminished;
b) the change in surface smoothness was due to the presence of salts and silt-like particles in the brackish water; and
c) although the surface was air-dried for 24 hours prior to the rebound hammer test, the samples were still partially saturated with brackish water in its interior.

These observations are important since surface smoothness and moisture content of the samples are factors that has been proven to affect surface hardness and, hence, the rebound number generated by the rebound hammer.

Table 1 shows the comparison of average rebound numbers (RN) between every pair of sample variation. To carry out the comparison, statistical t-test for two independent observations was employed. The purpose of the comparison was to determine whether the rebound reading was affected by the type of environment the samples were exposed to. The null hypothesis is that there is no significant difference between the average RN of samples between two groups, and the alternative hypothesis is otherwise. In selecting which hypothesis was appropriate based from the data, p-value was compared with the level of significance of 0.05. The null hypothesis is accepted if the p-value is greater than 0.05, while the alternative hypothesis is accepted if the p-value is lesser than 0.05. Data consisted of samples at ages 108 and 142 days.

TABLE I
T-TEST RESULTS FOR COMPARISON OF AVERAGE REBOUND NUMBER BETWEEN TWO SAMPLE VARIATIONS

Sample Variation	P-value vs. Level of Significance, α	Conclusion
Exposed to cycles of alternate drying and wetting in brackish water vs. Stored in normal room condition	P-value = 0.0195 α = 0.05 P-value < α; Reject the null hypothesis in favor of the alternative hypothesis	The average Rebound Number (RN) of concrete exposed to cycles of alternate drying and wetting in brackish water is significantly 1.0 unit less than the average RN of concrete in normal room condition.
Immersed in brackish water vs. Stored in normal room condition	P-value = 0.0011 α = 0.05 P-value < α; Reject the null hypothesis in favor of the alternative hypothesis	The average RN of concrete immersed in brackish water is significantly 1.5 units less than the average RN of concrete in normal room condition.
Exposed to cycles of alternate drying and wetting in brackish water vs. Immersed in brackish water	P-value = 0.8399 α = 0.05 P-value > α; Fail to reject the null hypothesis in favor of the alternative hypothesis	There is no significant difference between the average RN of concrete exposed to cycles of alternate drying and wetting in brackish water and the average RN of samples immersed in brackish water

Table 1 shows that concrete cubes exposed to brackish water have significantly lower rebound readings compared to samples in normal room condition with a relative humidity of 75%. However, when comparing the samples exposed to cycles of alternate drying and wetting in brackish water and samples immersed in brackish water, the difference in their average rebound readings is not significant. One can infer that the period of exposure to brackish water and the experimental set-up was not sufficient to cause a significant change in the rebound reading. Actual marine conditions such as the presence of waves and extreme changes in temperature for concrete in the tidal zone were not considered in the study.

B. Plotting Actual Compressive Strength versus Rebound Number

Fig. 1 shows the rebound curves generated for the concrete cubes exposed to three sample variations: (a) for samples stored in normal room conditions, with 75% relative humidity; (b) for samples immersed in brackish water, and (c) for samples exposed to cycles of alternate drying and wetting in brackish water. Linear regression model was employed, plotting rebound number versus concrete compressive strength. The choice of the regression model is dictated by the established linear relationship between force and deformation of a spring, as buttressed by the linearity of rebound curve provided by the manufacturer of the device.

However, it is noted that the correlation coefficients of the curves for all types of sample variation are very low due to the high dispersion of data. The correlation coefficient R^2 of the curve developed for samples exposed to cycles of alternate drying and wetting in brackish water is the lowest among the sample variations. This observation could be attributed to the fact that unlike the samples exposed to cycles of alternate drying and wetting, the samples immersed in brackish water and those under normal room conditions were kept in a relatively constant state and lesser disturbance.

The high dispersion of data also showed how the rebound reading is easily affected by factors that influence surface hardness, particularly by the presence of moisture, age of concrete, surface smoothness and the type of environment to which the concrete samples were exposed.

C. Comparing Average Actual Compressive Strength versus Average Estimated Strength from Rebound Hammer

Table II shows the comparison between the average actual concrete compressive strength versus average estimated strength derived from the rebound hammer test. Statistical T-test was employed to show the comparison. The null hypothesis is that there is no significant difference between the average estimated strength and the average actual compressive strength. The alternative hypothesis, on the other hand, is that the average estimated strength is less than the average actual compressive strength. The hypotheses were stated in this manner because based from the results it was generally observed that the average estimated strength derived from the rebound hammer test was lower than the average actual compressive strength. The null hypothesis is accepted if the p-value is greater than the level of significance set at 0.05, while the alternative hypothesis is accepted if the p-value is lesser than 0.05. Data also consisted of samples at ages 108 and 142 days. T-test revealed that the average estimated strength was significantly less than the average actual compressive strength for all groups of sample variation. Hence, for all the three different environmental exposure of the samples, the average estimated compressive strength consistently underestimated the average actual compressive strength. The samples which were kept under room condition have the highest estimated and actual compressive strengths, as compared to those which were exposed to brackish water. It is very probable that the exposure to brackish water caused the concrete surface to be "softer" and resulted to lower rebound reading.

TABLE II
T-TEST RESULTS FOR COMPARISON OF ACTUAL COMPRESSIVE STRENGTH VERSUS ESTIMATED REBOUND STRENGTH

Sample Variation	P-value vs. Level of Significance, α	Conclusion
Samples exposed to Alternate drying and wetting cycle of brackish water	P-value = 0.0382 α = 0.05 P-value < α; Reject the null hypothesis in favor of the alternative hypothesis	The average estimated strength generated from the rebound hammer underestimates by 9% the average actual concrete compressive strength.
Samples immersed in brackish water	P-value = 0.0006 α = 0.05 P-value < α; Reject the null hypothesis in favor of the alternative hypothesis	The average estimated strength generated from the rebound hammer underestimates by 13% the average actual concrete compressive strength.
Samples exposed to normal room conditions	P-value = 0.0000 α = 0.05 P-value > α; Fail to reject the null hypothesis in favor of the alternative hypothesis	The average estimated strength generated from the rebound hammer underestimates by 17% the average actual concrete compressive strength.

In addition, as the age of concrete increased from 28 days, 108 days and 142 days, the following observations were noted:

a) Both the actual concrete compressive strength and estimated strength from rebound hammer significantly increased for samples in normal room condition. Although the hammer was not accurate in predicting the actual strength, the observation still shows the reliability of the hammer in predicting an increase in strength as time varies.

b) The actual concrete compressive strength decreased with time for samples exposed to cycles in alternate drying and wetting of brackish water, and for samples immersed in brackish water. Also, the estimated strength from rebound hammer for samples in the two aforementioned exposure groups did not show a significant increase in strength as time progressed. In this case, although the hammer was not accurate in predicting the actual strength, the observation still shows the reliability of the hammer in determining the reducing effect of exposure of brackish water on compressive strength.

IV. CONCLUSION AND RECOMMENDATION

The high dispersion of data for rebound number plotted against actual concrete compressive strength invariably reinforced the prior findings that the Schmidt Hammer Test is influenced by a number of factors that affect surface hardness, e.g. moisture content, age, surface smoothness, carbonation, and temperature of concrete. Hence, the Schmidt Hammer Test is not a substitute for obtaining the actual compressive strength of concrete.

The study also shows that the type of environment to which concrete is exposed is a factor that affects concrete compressive strength. Although a Schmidt Hammer Test which employs the rebound curve provided by the manufacturer of the device cannot be expected to give an accurate measure of concrete compressive strength, it can be relied upon to establish a finding of reduction or increase in the strength brought about by sample variations.

The study further shows that the manufacturer's rebound curve generally underestimates the actual compressive strength of concrete. Thus, conclusions as to the good condition and safe continued use of in-situ concrete based on the manufacturer's rebound curve are conservative and can be fairly reliable.

Nevertheless, the rebound hammer can be a reliable device for assessing the general condition of a structure and the homogeneity of concrete, provided that it is calibrated and a rebound correlation curve is developed and used for the specific type of concrete to be tested. The accuracy of the correlation curve is increased by testing a large number of concrete specimens.

ACKNOWLEDGMENT

K. Sanchez thanks the Quality Control Division of the Office of the City Engineer, Iligan City, Lanao del Norte, Philippines for the support given to the research work. Thanks and gratitude are also due the Department of Science and Technology-Engineering Research and Development for Technology (DOST-ERDT) for the scholarship granted to the researcher during the conduct of the work.

REFERENCES

[1] H. S. Shang, S. Yi, and L. S. Yang, "Experimental study on the compressive strength of big mobility concrete with nondestructive testing method," *Advances in Materials Science and Engineering*, vol. 2012, pp. 1-6, Oct. 2012. http://dx.doi.org/10.1155/2012/345214

[2] Cemex USA Technical Bulletin 2.0, "Proper use of the rebound hammer," 2008.

[3] K. Szilàgyi, A. Borosnyói, and I. Zsigovicset, "Rebound surface hardness of concrete: Introduction of an empirical constitutive model," *Construction and Building Materials*, vol. 25, pp. 2480-2487, Nov. 2010.

[4] A. Brencich, G. Cassini, D. Pera, and G. Riotto, "Calibration and reliability of the Rebound (Schmidt) Hammer Test," *Civil Engineering and Architecture*, vol. 3, pp. 66-78, 2013.

[5] ACI 350-01, "Code Requirements for Environmental Engineering Concrete Structures," USA: ACI, 2001.

[6] K. Kishore. "Non-destructive testing of concrete by rebound hammer," Civil Engineering Portal, Retrieved September 1, 2014 from http://www.engineeringcivil.com/non-destructive-testing-of-concrete-by-rebound-hammer.html.

[7] ASTM C 805-02, "Standard test method for rebound number of hardened concrete," USA: ASTM, 2002.

[8] ACI 228-03, "In-place methods to estimate concrete strength," ," USA: ACI, 2003.

Kristine D. Sanchez is currently teaching at the Department of Civil Engineering of Mindanao State University-Iligan Institute of Technology (MSU-IIT), Iligan City, Lanao del Norte, Philippines. She obtained her degree of M.S. Civil Engineering (2014) and B.S. Civil Engineering (2010) at MSU-IIT. Her research interests include alternative construction techniques and Water Resources Engineering.

Nathaniel C. Tarranza was born in Cebu City, Philippines, on November 22, 1958. He obtained his degree of Bachelor of Science in Civil Engineering from the Mindanao State University, Marawi City, Philippines, in 1980. He also had a law degree from the same university in 2005. In 1985, he finished his degree of Master of Engineering from the Asian Institute of Technology in

Bangkok, Thailand. His major fields of study are structural engineering, construction management, and law.

He is presently a professor in civil engineering at the Department of Civil Engineering, Mindanao State University- Iligan Institute of Technology, Iligan City, Philippines. He acted as the adviser of Ms. Kristine Sanchez in conducting this research work.

Professor Tarranza is a practicing civil engineer and lawyer in his home country. He is an active member of the Philippine Institute of Civil Engineers and the Integrated Bar of the Philippines.

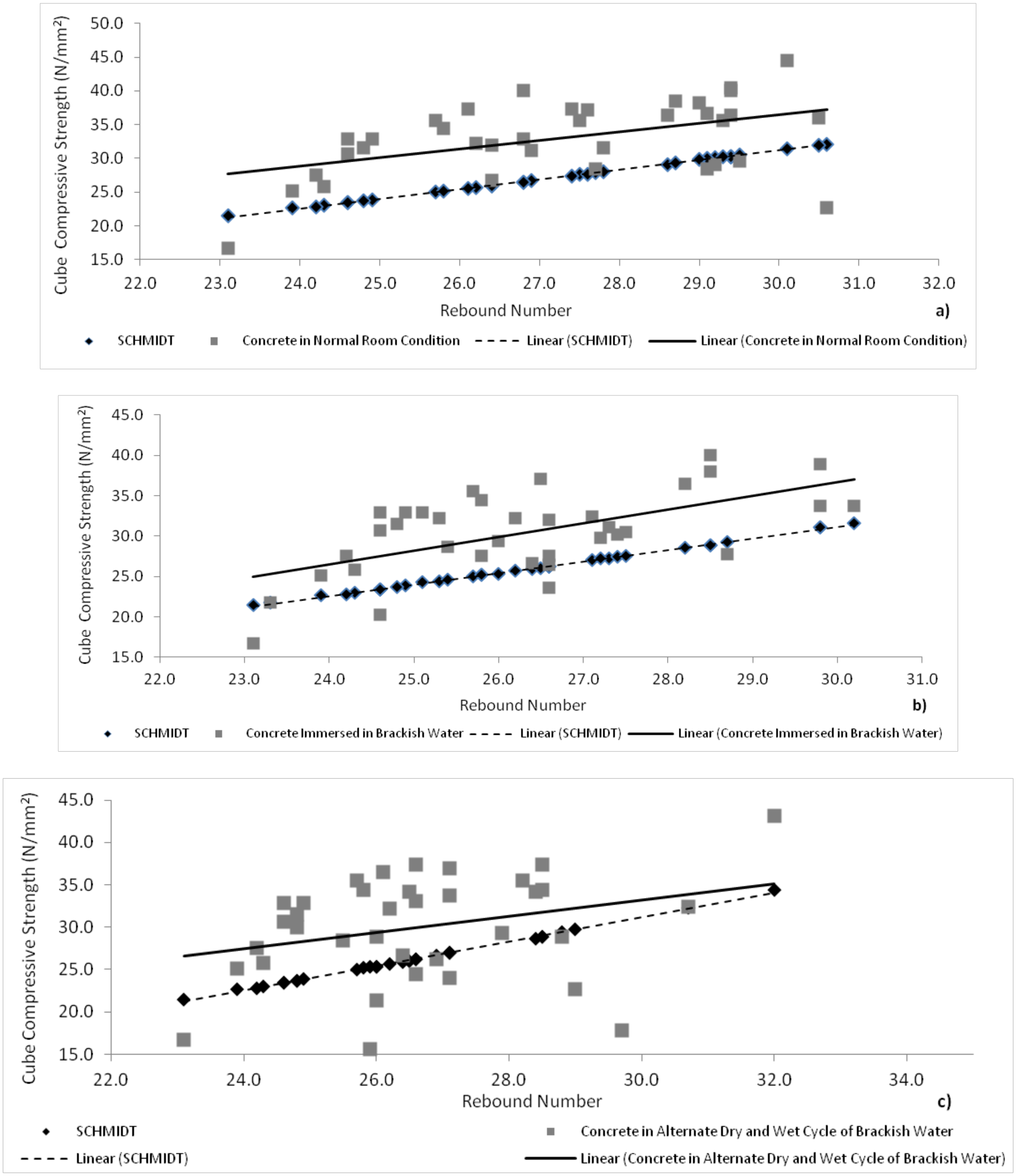

Fig. 1 Rebound Curves for concrete cubes in different sample variations: (a) stored in normal room conditions; (b) immersed in brackish water, and (c) exposed to cycles of alternate drying and wetting in brackish water