EFFECT OF SURFACE ROUGHNESS ON NON-DESTRUCTIVE TESTS FOR SCREENING OF LOW-STRENGTH CONCRETE

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Abstract

The existence of very low-strength concrete (LSC) has been found in buildings from the recent surveys in Bangladesh. Catastrophic building collapse due to substandard concrete is not an unknown phenomenon in the country and the risk of future earthquakes cannot be neglected because the country lies in a seismically active region. To prevent future loss of lives it is essential to identify the vulnerable buildings due to the presence of LSC. However, a detailed investigation of a large number of buildings is unrealistic and a rapid method is necessary to screen out the very LSC structures first so that these buildings can be demolished for safety. For this purpose, non-destructive tests (NDTs) combining rebound hammer (RH) type L and scratching test (ST) devices are focused due to their quickness, ease, and efficiency. Calibration curves are developed by performing laboratory tests and field surveys in Japan and Bangladesh. The surface of the concrete in existing buildings during field surveys in Bangladesh was found rough. The existing structural members have an outer plaster mortar layer which is peeled off before testing. Aggregates can be seen on the exposed rough surface of the concrete after such treatment. Non-destructive tests used in this research are surface hardness methods and affected by roughness, obstructing the examiner from acquiring accurate results. In this study, we examined the effect of surface roughness for non-destructive test devices, rebound hammer type L and scratching test devices using rectangular prism-shaped specimens in the laboratory. Three types of surfaces with varying degrees of roughness as low, medium and high, were made on each specimen. The roughness of the surfaces is quantified using a 3D scanner. It was observed that the surface roughness has a significant effect on high strength concrete rather than LSC. A lower rebound quotient Q and a higher groove width (GW) from the scratching test are obtained due to rough surface.

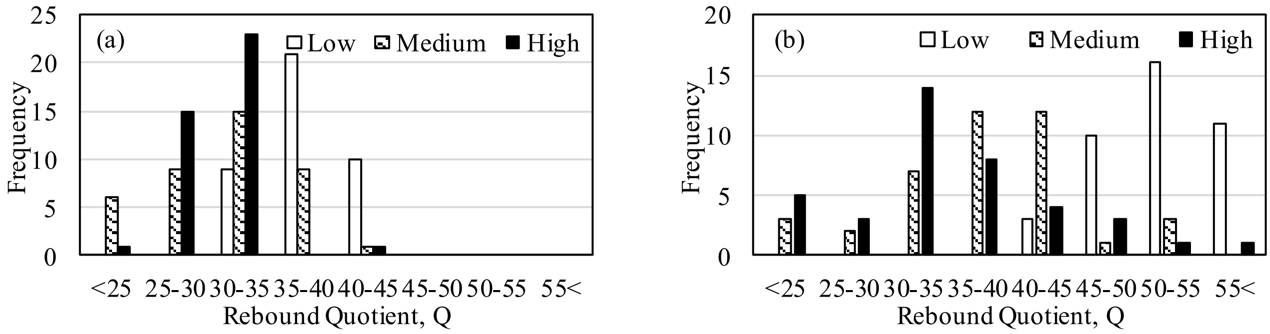


Fig 1. Variation of effect of surface roughness on different compressive strength levels of concrete. (a) Concrete compressive strength 19.1 MPa; (b) Concrete compressive strength 57.2 MPa.

Keywords: low-strength concrete; rebound hammer type L; scratching test device; surface roughness; 3D scanner.

1. Introduction

Bangladesh, a developing country in Southeast Asia has been affected by five earthquakes of large magnitude greater than 7.0 (Richter) within the last 150 years. Historical evidence shows significant damages occurred in the capital city, Dhaka, during the 1897 Great Indian Earthquake (Magnitude 8.7) and 1885 Bengal Earthquake (Magnitude 7.0) [1]. Currently, small to moderate earthquakes are regularly occurring due to tectonic deformation along the plate boundaries of the Indian plate and Eurasian plate [2]. Major human tragedy and economic disaster are associated with structural failure of many buildings due to earthquakes.

Recently, several incidents of reinforced concrete building's collapse with no seismic event owing to the existence of substandard concrete material in buildings has been observed [3]. Construction of reinforced concrete buildings with substandard concrete can be attributed to the unavailability of building design and construction regulation after the country's independence in 1971 until the publication of Bangladesh National Building Code (BNBC) 1993 [4]. However, Strict adherence to construction regulations is not followed by workers due to lack of engineering knowledge. Moreover, brick aggregate is abundantly used instead of stone aggregate for producing concrete which is a softer material with greater porosity than stone [5]. The nearest sources of rocks suitable for concreting are in India and the use of crushed bricks by burning clay deposits became a popular practice in the construction industry of Bangladesh. All these reasons have act as a catalyst of sudden structural failures in the recent past. A previous study by Nakajima et al. (2016) also indicates the presence of concrete compressive strength lower than 10 MPa in 43% of the of the collected core samples from 194 buildings of Dhaka city [6]. Present condition of concrete materials in buildings demand a detailed seismic investigation to prevent the future loss of lives.

As a first step, an easy method is necessary to identify the very low-strength concrete (LSC) buildings because of numerous buildings and inconvenience of detailed seismic investigation. Concrete compressive strength ≤ 9 MPa is defined as very low strength concrete according to the existing guidelines in Bangladesh [4]. Non-destructive test (NDT) methods are an extremely effective means to get quicker results about the compressive strength of concrete in existing structures. Rebound hammer (RH), penetration resistance, pullout, break-off, ultrasonic pulse velocity tests etc. are some popular non-destructive or semi destructive tests already in practice [7]. Much research has been devoted to the development of NDTs combining two methods [8]. In this study, rebound hammer type-L with mushroom head and scratch testing (ST) device developed by the Japan Society for Finishing's Technology are focused for their easiness. The rebound quotient collected by hitting the concrete surface with a rebound hammer and the groove widths created by the scratch testing device can be related to the compressive strength of the tested concrete. Roughness of the concrete surface to be tested is a matter of concern as surface hardness test methods are easily affected by the near surface properties of concrete [7]. The structural members in Bangladesh have an outer mortar plaster layer which needs to be peeled before performing the NDTs. Such treatment reveals a rough concrete surface with exposed aggregates difficult for grinding to prepare a smooth surface for tests. Therefore, it is necessary to address the effect of surface roughness on the non-destructive test results.

In this study, the effect of surface roughness on the NDT methods of rebound hammer and scratching test is investigated by performing tests on three types of surfaces of different roughness on laboratory specimens where the roughness is quantified with a 3D scanner. The results obtained from surfaces of different roughness is compared with calibration curves of laboratory experiments and field survey in Bangladesh.

2. Overview of Non-destructive Tests (NDTs)

2.1 Rebound hammer

Figure 1(a) shows a common NDT device, known commercially as the Silver Schmidt hammer. Basically, it is a rebound hammer type L, manufactured by Proceq Co. Ltd. This hammer consists of a spring-loaded piston which is released when the plunger is pressed against a surface. The impact of the piston onto the plunger transfers the energy to the target material. Part of the piston's impact energy is consumed by absorption and is transformed into heat and sound. The remaining energy represents the impact penetration resistance (i.e. the hardness) of the surface. This is shown as the rebound quotient, Q, on the digital screen accompanied in the instrument. Q is obtained by measuring the velocity of impact and rebound immediately before and after the impact [9].

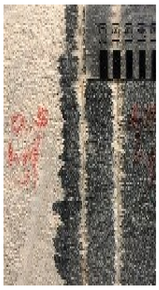
$$Q = \left({v_r^2}/{v_0^2} \right) \times 100 \tag{1}$$

Here, v_o indicates the velocity reached by hammer mass before impact and v_r indicates the velocity reached by hammer mass after impact, respectively.

RH type L has a prime advantage of lower impact energy over other RHs, thus has more applicability for LSC. In addition, a mushroom-shaped head can be attached with the device capable of covering a larger area of concrete while testing. It is thus considered suitable for testing thin sections of concrete. The impact energy is 0.735 Nm with a measuring range of 5-100 MPa [10]. Other types of hammers with greater impact energy are not suitable for LSC. For example, RH type N has an impact energy of 2.207 Nm, which would leave an indentation mark on the concrete surface, in case of LSC. Moreover, in conventional rebound hammers, the obtained rebound value R is the mechanical travel of the mallet on rebound which is affected by its friction on the guide rod and gravity. On the other hand, high quality construction of type L hammer provides results not affected by the impact angle or internal friction. Moreover, it is 600 g in weight which is very light and easy to carry.

(a) Rebound hammer

(b) Scratching test device



(c) Measurement of groove width

Fig. 1 - Non-destructive test devices

2.2 Scratching test

The scratching test (ST) device shown in Figure 1(b) is developed by Japan Society for Finishing's Technology, by using test device certified by Japan Floor Coating Industry The ST includes a small portable device with an easier working principle that only requires scratching on the concrete surface and measuring the groove width (GW) made with the two pins inserted in the plastic material body [11]. It is a simple tester that can scratch the concrete surface at a constant angle with loads of 1kg and 0.5 kg. The two pins inside the device when pressed against the surface apply constant stresses of 9.8 N and 4.9 N. The pins are made of carbide tungsten alloy which has high hardness and wear resistant. The pins are inserted in a rectangular prism made of plastic material at the center with 90^{o} angle. Load adjustment is performed by spring coils inside the device installed along the body of pins. Approximately 10 cm long grooves are made on the concrete surface by scratching at a speed of 2 cm/sec and groove width (GW) is measured by the various scales available with the device for measuring the surface hardness as shown in Figure 1(c). The GW measured for 9.8 N is considered for calibration curves in this study.

3. Experimental Program

3.1 Concrete Mixtures

This investigation was done in two stages. In the first stage, laboratory tests were performed on prism specimens made of brick and stone aggregate concrete in Japan and field survey was performed on existing buildings in Bangladesh of both types of aggregates. As shown in the upper part of Table 1, high water cement ratio, 0.6 to 2.0, was used to make the laboratory specimens and limestone powder (density 2.71 g/cm^3) was used as a filler powder to prevent segregation. In the second stage, to observe the variation of surface roughness, prism shaped laboratory specimens were prepared with stone aggregate concrete in Japan, as shown in the lower part of Table 1. Three different types of surfaces were made on each specimen. The roughest surface is made by chipping the surface with an air compressor chipper. The medium rough surface is selected as the open surface of the specimen when inside the mold and had a trowel finish. The smooth surface is the side of specimen attached to the mold while casting. The three surfaces are indicated in the following sections as the legends; Low (smooth surface, low degree of roughness), Medium (moderate roughness) and High (rough surface, high degree of roughness), shown in Fig 2 (c-e). The brick and stone aggregates used for making laboratory specimens listed in Table 1 are of Japan origin.

Table 1 - Mix proportion of concrete specimens

Aggregate Type	W/C ratio	Water (kg/m^3)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Limestone powder (g/cm^3)
Brick, stone, recycled stone (first stage)	0.6 ~ 2.0	200 ~354	100 ~350	481 ~ 880	98~995	0 ~ 218
Stone (Second stage)	1.0	188.5	188.5	700	1292.4	
	0.67	209	310.6	797.7	931	
	0.56	178	318	842	947	
	0.55	180	328	808	978	
	0.54	175	324	832	971	
	0.30	170	577	726	882	

3.2 Field survey

For developing a calibration curve for LSC, three existing reinforced concrete buildings were surveyed as follows:

- Housing and Building Research Institute, brick aggregate reinforced concrete building.
- Bangladesh Meteorological Building, stone aggregate reinforced concrete building
- Yamagata Dhaka Hospital, stone aggregate concrete building.

One laboratory column specimen made with brick aggregate concrete at the Bangladesh University of Engineering and Technology in Dhaka was also tested. While performing the non-destructive tests on the existing buildings it was necessary to peel off the 10-20mm thickness of the plaster mortar layer. After peeling off the plaster mortar layer, a rough surface with exposed aggregates could be seen. A stone grinder was used to make the surface as smooth as possible before performing the NDTs. On the other hand, the laboratory column specimen had a very smooth surface.

3.3 Compressive strength and non-destructive tests

Compressive strength test was performed on cylindrical specimens of 100 mm diameter and 200 mm height according to ASTM C42 / C42M. Rebound hammer test and scratching test were performed on prism shaped specimens of 150 × 150 × 600 mm. Type L hammer with a mushroom head and scratch tests were conducted on the same day of the compressive strength measurement. Rebound hammer test was performed in accordance with JIS A 1155 (based on ISO 1920-7). Nine or more points were measured that were 50 mm or more away from the edge of the specimen and by 30 mm or more away from each other. Scratching test was carried on the painted surface to make scratch grooves clear. The pins of the device were pushed on the surface and moved at a constant speed of 2 cm per second to make grooves. The maximum value of the groove width made with 9.8 N was taken as the representative value. During field surveys, core samples were collected from the same locations where non-destructive tests were performed. Cores were tested to obtain the compressive strength.

3.4 Measurement of surface roughness

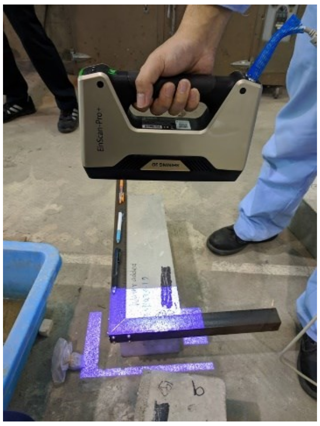
Surface roughness is generally measured following JIS B 0671-1 and ISO-13565-1 which are based on analysis using a stylus method. Whereas, ISO 25178 surface texture is a collection of international standards relating to the analysis of surface roughness that supports two evaluation methods; contact type (stylus method) and non-contact type (optical probe). In this study, the roughness of the concrete surfaces was measured quantitatively with a 3D scanner as shown in Fig. 2(a) without contact of the concrete surface. With this method, it was possible to obtain a full 3D sample of the concrete surface instead of only 2D profiles. A mean surface is considered on the height screen for the measurement area specified. While calculating the deviation of height distribution the height of the reference surface is considered 0. The arithmetic mean height S_a is calculated as follows.

$$S_a = \frac{1}{A} \iint |z(x,y)|\, dxdy \tag{2}$$

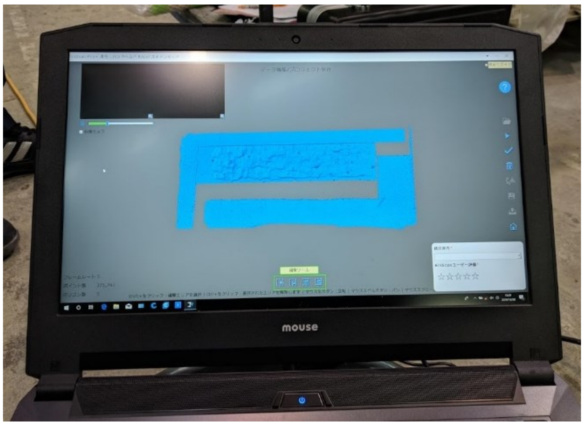
Where, A is the number of measurement points along area A, $z\ (x,\ y)$ is height at position (x,y). The higher the value of S_a the higher the roughness.

4. Results

In Fig. 3 the results of rebound quotient Q according to varying surface roughness are shown. For a lower degree of roughness, the rebound quotient Q is higher compared to high or medium degree of roughness. For specimens of high strength of concrete of 59.4 MPa, 57.2 MPa, 48.9 MPa and 47.3 MPa, the Q values are distributed through a wider range for high and medium degrees of roughness. For medium strength of concrete, 19.1 MPa and 16.3 MPa the distribution of rebound quotient decreases for all the three types of surfaces. As the compressive strength decreases the distribution of Q decreases evidently. For 3.31 MPa specimen the variation of rebound value according to surface roughness decreases significantly, proving that surface roughness has less effect when the concrete is of lower strength.

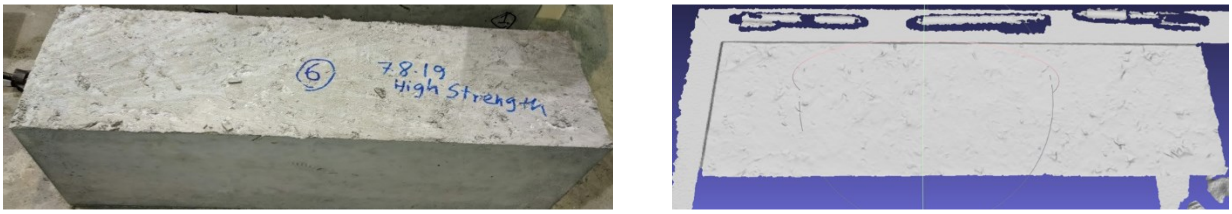


(a) 3D scanning device

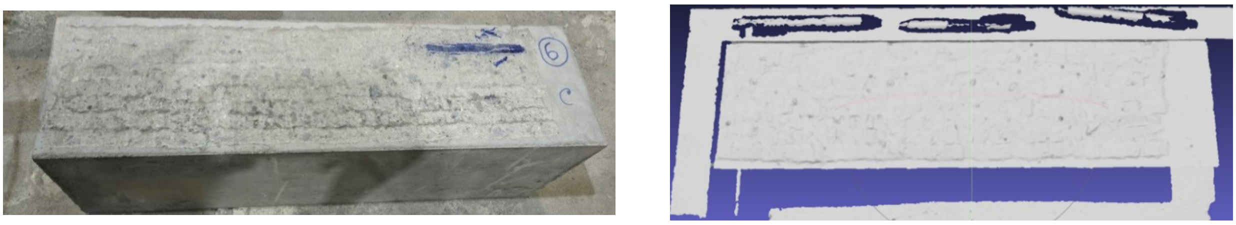


(b) Recorded image in PC

(c) Actual surface and recorded image with 3D scanning device for low degree of roughness



(d) Actual surface and recorded image with 3D scanning device for medium degree of roughness



(e) Actual surface and recorded image with 3D scanning device for high degree of roughness

Fig. 2 - 3D scanning for surface roughness measurement

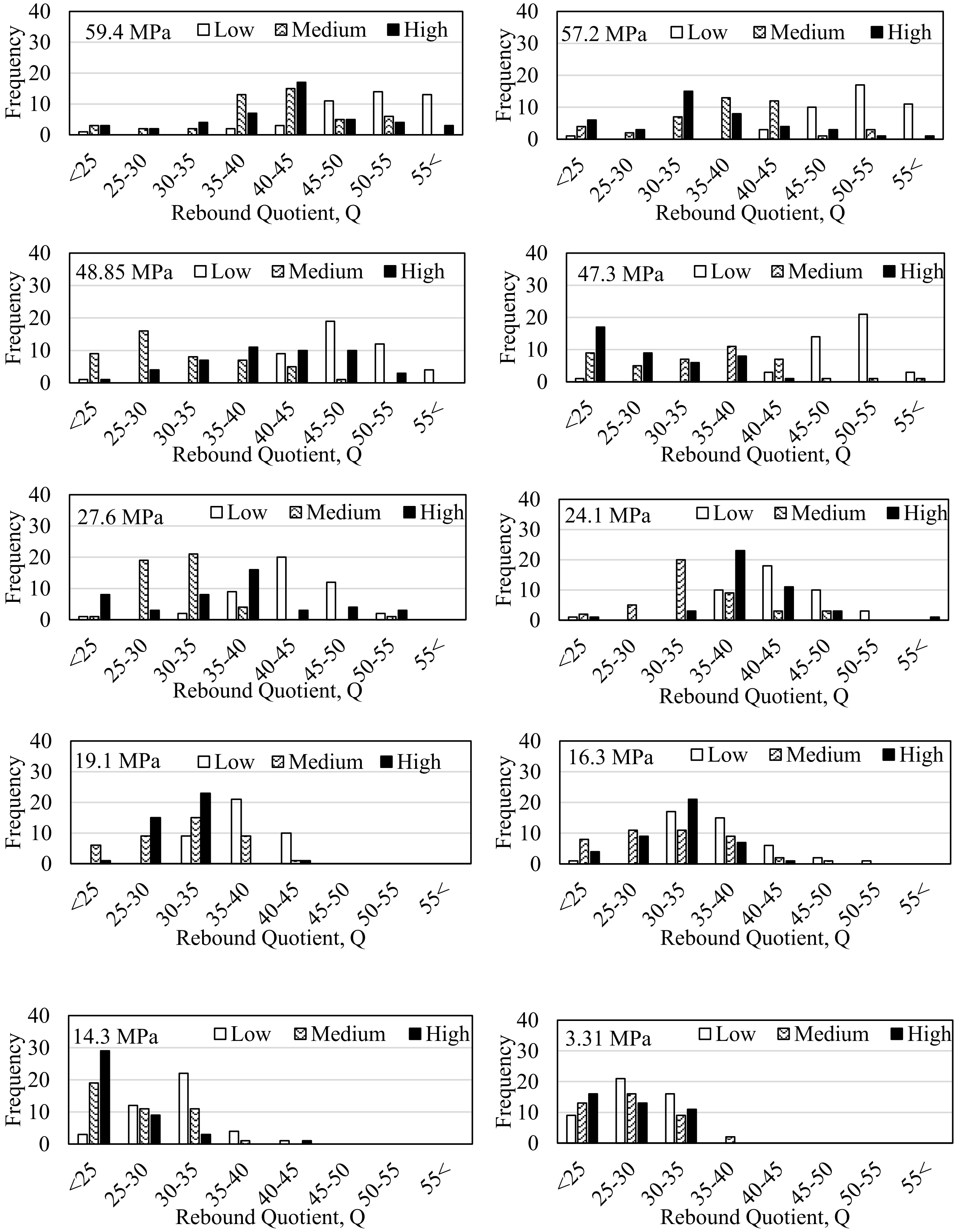


Fig . 3 – Results of rebound quotient Q depending on various degree of roughness

Figure 4 shows the mean rebound quotient Q corresponding to different surface for 4 specimens from lower to higher compressive strengths. The mean rebound quotient values are determined considering ±20% of the first calculated mean Q. The X-axis shows increasing compressive strength, primary Y-axis shows the rebound quotients and secondary Y-axis shows values of surface roughness measured by S_a. Definite S_a values as the boundary of low, medium or high roughness is not selected for all the specimens, however, for one specimen the surface having the highest S_a value is the high roughness surface. The medium rough surface in the low-strength concrete specimen 3.31 shows a S_a of 0.88mm which is quite higher than the high roughness surface for specimens 19.1 MPa (S_a = 0.33 mm), 47.3 MPa (S_a = 0.29 mm) and 57.2 MPa (S_a = 0.35 mm). Although the minimum and maximum Q values for all data are distributed over a wider range of primary Y axis, the mean value of 3.31 MPa on three types of surfaces are almost the same in spite of the higher S_a values. The 19.1 MPa specimen also shows closer mean values with very little difference on three types of surfaces. On the other hand, the mean values of higher strength of concrete, 47.3MPa and 57.2MPa show greater variation depending on the roughness. Therefore, the roughness of the surface is negligible if the compressive strength is ≤ 9 MPa.

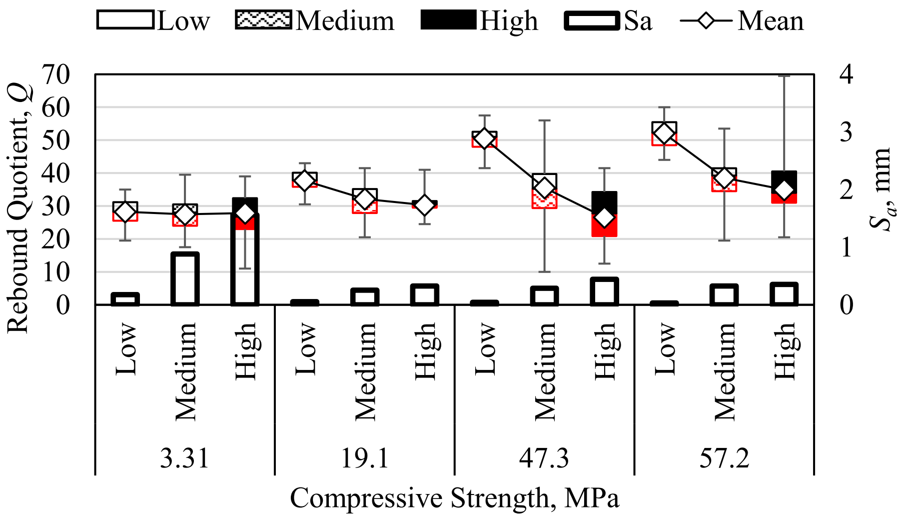


Fig.4 – Comparison of mean rebound quotient according to lower to higher compressive strength of concrete

In Fig. 5 and Fig. 6 the blank, hatched and filled square legends represent result from low, medium and high degrees of roughness surface of laboratory specimens in Japan. Square legends in a single line represent Q values for the same compressive strength. The filled round legends represent field survey results from Bangladesh which are of rough surface. The round blank legends represent laboratory test results on smooth surface specimens in Japan. JP-B and JP-S show brick and stone specimens in Japan. BD-B and BD-S show the stone and brick aggregate results from field survey in Bangladesh. These four data produces a calibration curve shown as the black solid line. In case of higher strength of concrete, the mean rebound quotient Q values on three types of surfaces show that Q values will be lower if the surface is rough as shown in Fig. 5. Greater errors in the test results as the filled legends, representing high roughness, appear further away from the calibration curve. On the other hand, the lower strength concrete does not have any significant effect because of the three surfaces shown for the 3.31 MPa specimen for rebound hammer.

On the contrary, a smooth surface is required for the scratching test as it was difficult to make grooves and read groove widths on the surface which has high roughness. For example, the surfaces with a higher S_a in 3.31 MPa specimen, it was not possible to make and record a groove width on the surfaces with medium and high roughness. Therefore, the square legends in Fig. 6 only contain 9 results of the scratching test for varying degrees of roughness. The groove widths for surfaces with low roughness show narrower groove widths than on high roughness on the same specimen. Groove widths from a high degree of roughness shows wider readings and greater deviation from the calibration curve. Therefore, a surface with higher roughness may introduce errors on the groove width results which emphasize that a smooth surface is necessary for the scratching test.

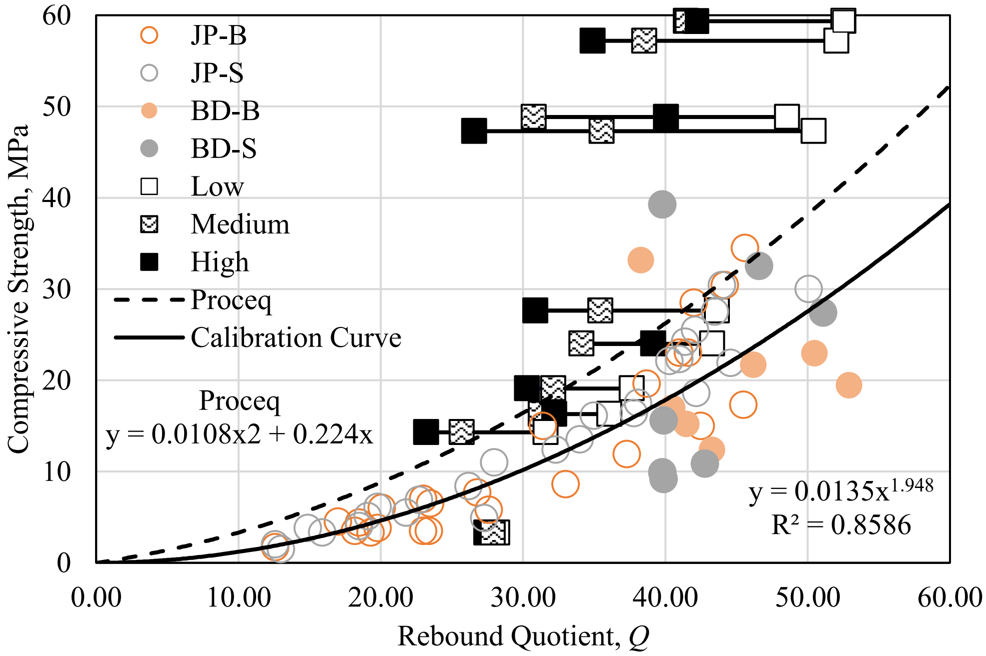


Fig. 5 – Comparison of mean rebound quotient Q on three types of surfaces of different roughness with developed calibration equation

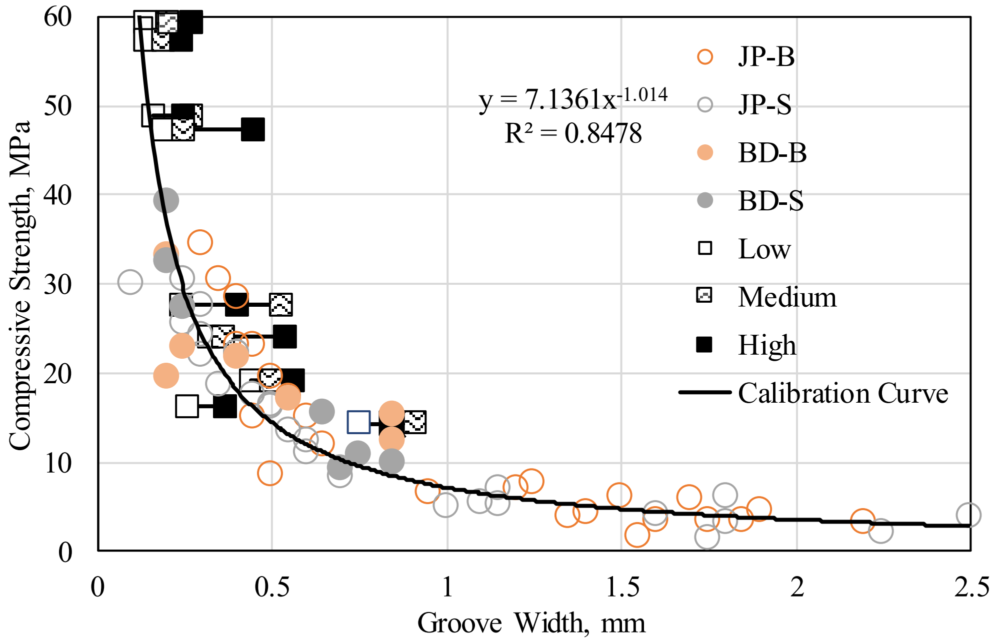


Fig. 6 – Comparison mean groove width (GW) on three types of surfaces of different roughness with developed calibration equation

5. Conclusions

This study investigates the effect of surface roughness for non-destructive test methods, rebound hammer and scratching test, by performing laboratory tests on three types of surfaces of prism-shaped specimens. The compressive strength of the specimens ranges from 3.31 MPa to 59.4 MPa. One of the key finding of the study is, surface roughness does not affect the rebound quotient Q for low-strength concrete when the mean Q is calculated considering ±20% of the first calculated mean Q value. Therefore, for applying the rebound hammer for screening the low-strength concrete (≤9 MPa) buildings, the effect of surface roughness is negligible. However, with increasing compressive strength the difference of mean rebound quotient Q corresponding to different roughness surfaces becomes greater. High roughness gives a lower Q value and low roughness gives a higher Q value. Because of limited data available to the authors at present, it was impossible to judge whether various aggregates (brick or stone from Bangladesh or Japan origin) used in this investigation have any diverse effect on the rebound quotient. Another key finding is, for scratching test device smooth surface is necessary, because surface with higher S_a provided greater groove widths and surfaces with lower S_a provided narrower groove widths. Therefore, rough surface induces errors for scratching test and it is difficult to make grooves and measure the groove widths when the surface is excessively rough with exposed aggregates. It is imperative to grind the surface as much as possible to get accurate results with the two non-destructive test methods in this study.

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7. Copyrights

8. References

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