NDT.net - The e-Journal of Nondestructive Testing (December 2008)
For more papers of this publication click: www.ndt.net/search/docs.php3?MainSource=25

Research on Factors Affecting Concrete Cover Measurement

Reuben BARNES [1], Tony ZHENG [2]
[1] Papworths Construction Testing Equipment Pty Ltd (PCTE), Brookvale, NSW, Australia
[2] Building & Construction, Research and Consultancy (BCRC), Nowergup, WA, Australia
Paper contact: Tony ZHENG, Email: t.zheng@bcrc.com.au

Abstract
Concrete cover is the distance from the surface of the concrete to the surface of the reinforcing bars embedded in the concrete. Ensuring sufficient concrete cover is critical for the durability of some concrete structures subject to poor environment during their service life. Concrete cover can be measured using covermeters. In this paper, some factors affecting cover measurement were briefly introduced. An in-house study carried out by BCRC was introduced. This study was to understand the extent of some factors affecting cover measurement, such as bar diameter setting, scan location relative to secondary bar, covermeter probe selection (shallow or deep probes) or covermeter probe detectable range setting (low or high ranges). Conclusions were made based on the results in this study.

Keyword: concrete cover, cover measurement, covermeter

1. Introduction

Concrete cover is the distance from the surface of the concrete to the surface of the reinforcing bars embedded in the concrete. Ensuring sufficient concrete cover is critical for the durability of some concrete structures subject to poor environment during their service life, such as seawater desalination plants, jetties, bridges and reservoirs etc. Concrete cover can be measured using commercially available covermeters, such as Proceq Profometer 5+, Elcometer 331 (formally Protovale CoverMaster), Micro Covermeter etc. However, many factors can affect the accuracy of cover measurement. The assessment of concrete cover for such important concrete structures should be only based on accurate measurement results by professionals. In order to understand some common factors affecting cover measurement, BCRC carried out an in-house study in 2008.

2. Cover Meter Accuracy and Factors Affecting Cover Measurement

Each measurement comes with certain variation and every measuring equipment has own accuracy. Covermeter is one of such measuring equipments. British Standard 1881 Part 204 "Recommendations on the use of electromagnetic covermeters" [1] states that the indicated cover to steel reinforcement by a calibrated covemeter should be accurate to with +/- 5% or +/-2mm, whichever is the greater, over the working range given by the manufacture. It also states that under the most favourable site conditions, indicated cover can be measured to an accuracy approaching that obtainable in the laboratory when the bar size is known. The accuracy of measurement likely to be obtained on the average site is within +/-15% or +/-5mm, whichever is the greater, for reinforcement at covers of less than 100mm.

Many factors can affect cover measurement. These include neighbouring bars parallel to the bar being measured, setting of bar diameter during cover measurement, scan location relative to secondary bars under the bar being measured, different measurement probes (deep or shallow) or different probe settings (low or high range for covermeters using universal probe) etc. These factors will be discussed in this paper. Other factors such as magnetic effects from the aggregate or matrix of the concrete, variations in the properties of the steel, cross-sectional shape of bars and rib height, roughness of the surface can also influence cover measurement. However, these factors are insignificant compared to former factors and are not discussed here. Only limited research on cover meter accuracy is available [2].

3. Calibration Block Design and Cover Measurement

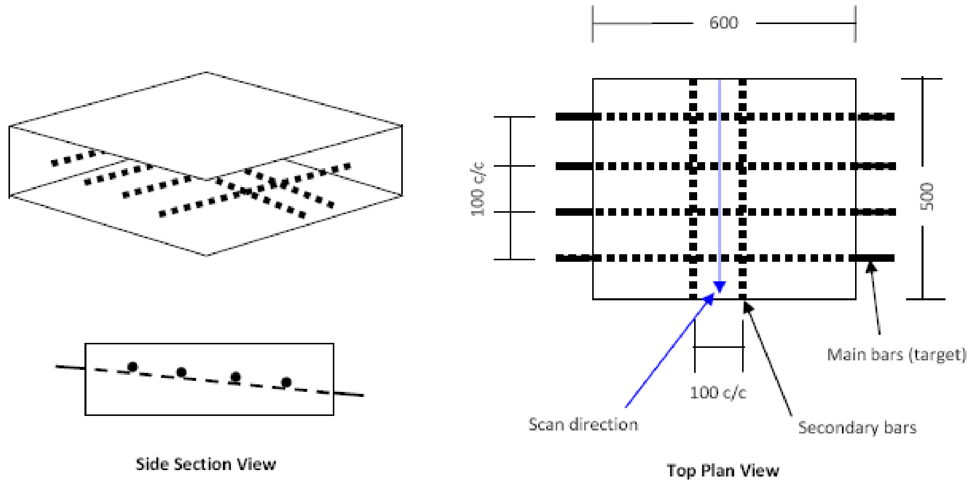

Figure 1 Calibration block design

Figure 2 a) Calibration blocks with N24 & N28 bars, b) Scanning of bars using Profometer 5 Scanlog

Design concept of the calibration blocks was from the calibration method C in clause 6.4 in British Standard BS1881 Part 204 [1]. Figure 1 shows the design details of the calibration blocks and Figure 2 shows photographs of the calibration blocks. Two calibration blocks were made using plywood with N24 and N28 bars respectively (which were particularly needed for calibration in a recent BCRC project). Four bars (either N24 or N28 for each block) with 100mm spacing were used as the main bars for each block. These four bars were in different depth (i.e. approximately 20mm, 30mm, 40mm and 50mm). Actual bar depths were measured from the bar both ends using a digital calliper and average values were used as the actual cover depth. Two secondary bars with the same diameter and 100mm spacing were also installed under the main bars perpendicular to the first layer.

The “concrete cover” for each bar was the distance between the surface of the calibration block and the top surface of the measuring bars which consists of plywood and air gap. Since covermeter operation is based on measuring electromagnetic field, it can be reasonably accepted as recommended in British Standard BS1881 Part 204.

A Profometer 5 of Scanlog model from Proceq was used in this research since the Proceq products have the good reputation for its reliability and accuracy in concrete Non-Destructive Testing. The measure with scanning mode was used to measure concrete cover and also monitor the effect of neighbouring bars. Five scans were carried out and five readings were taken for each bar sample. Scanned data were downloaded to a laptop and concrete covers were analysed and recorded. Figure 3 shows an example of the scanned data. After each scan, additional plywood was added on top of the calibration block and the cover measurements were repeated. So, available cover measurement samples in this study were from minimum of 20mm to the maximum of covermeter detectable range (i.e. out of the ability of covermeter for measuring covers with 100mm bar spacing).

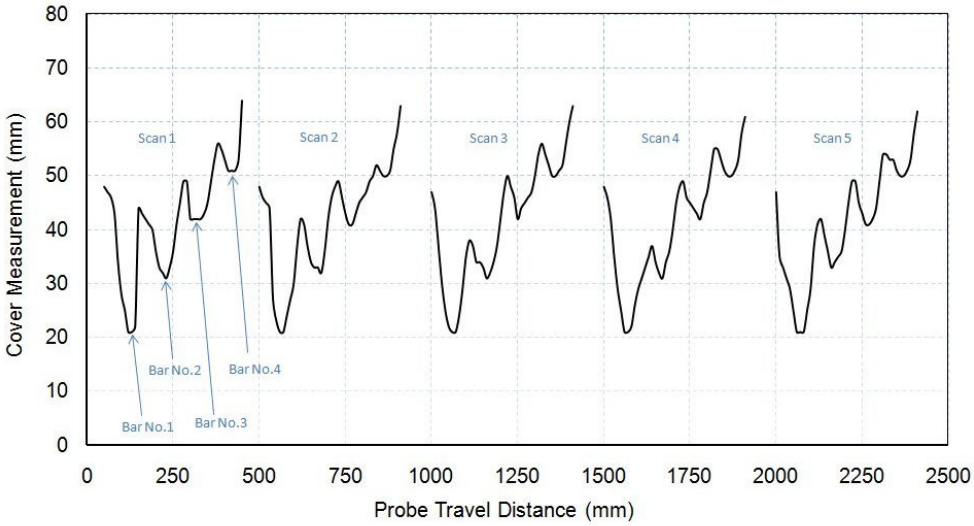

Figure 3 Cover measurement data from scanning

4. Cover Measurement With and Without Calibration, Correlation Graphs

Cover measurements were taken on both the N24 and N28 calibration blocks. Bar diameters were set to the known diameter (24mm or 28mm) in covermeter during the cover measurements. The correlation graphs from the two different diameter blocks were quite similar. Figure 4 show the results for N24 block and N28 block. The slopes of the equations (trend lines) were 0.9228 and 0.9795. The constants for both equations (trend lines) were also less than 2mm. These indicate that measured covers were reasonably accurate even without calibration. In fact, all the measured covers (without calibration) were well within [the greater of] ±5% or ±2mm as specified in BS standard.

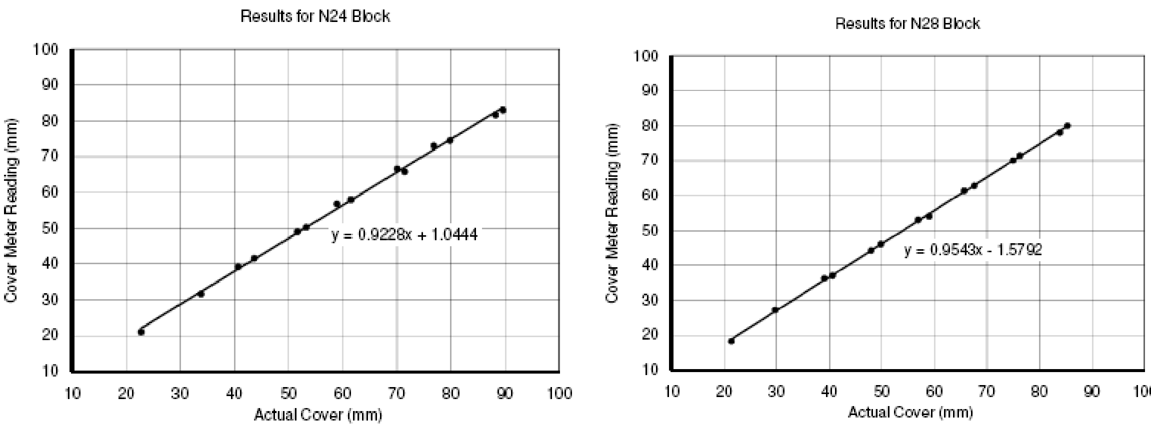

Figure 4 Results for N24 block (left) and N28 block (right)

Correlation graphs for N24 block and N28 block are slightly different. This shows that correlation is necessary to improve cover measurement accuracy and correlation should be carried out for rebars with different sizes.

Cover measurement is often influenced by neighbouring bars (i.e. parallel bars that are close to the one being measured). In this study, the bar spacing was 100mm. Since cover measurement accuracy will increase if bar spacing increases, this study does not include other bigger bar spacing (i.e. 150mm or 200mm).

Bar spacing also affects the maximum measurable cover depth. The maximum measurable cover depth decreases when the bar spacing decreases. In this study, the bar spacing was 100mm with bar diameters of either 24mm or 28mm, the maximum measurable cover depth was about 85 ~ 90mm which is deeper than the data provided by the manufacturer in the owner's manual [3].

Bar spacing and bar diameter could affect the correlation graphs. Covermeters from different manufactures could also cause certain variation. Correlation for particular project (particular bar spacing and bar diameters) and the covermeter to be used can greatly improve cover measurement accuracy. Correlation is recommended if greater cover measurement accuracy is required, i.e. a structure subject to aggressive environment and concrete durability is the major concern.

5. Effect of Bar Diameter Setting

To carry out a covermeter survey, NDT personnel often have to input the bar diameter on their covermeters on site without knowing the actual diameter of the reinforcing bar in the concrete. This is especially the case when surveying older structures. Using a default setting for the bar diameter such as 12mm or 16mm will not produce concrete cover readings as accurately as indicated in the previous section. In order to measure concrete cover in the most accurate manner, the bar diameter needs to be known and set accordingly in the covermeter. However it is interesting to consider how large an affect an educated "guestimate" would have on the accuracy of cover measurements.

In this study, covers for N24 bars were measured with the setting for the bar diameter to 16mm, 20mm and 24mm respectively. Figure 5a shows the comparison. Covers for N28 bars were also measured by setting bar diameter to 24mm and 28mm respectively. Figure 5b shows the comparison.

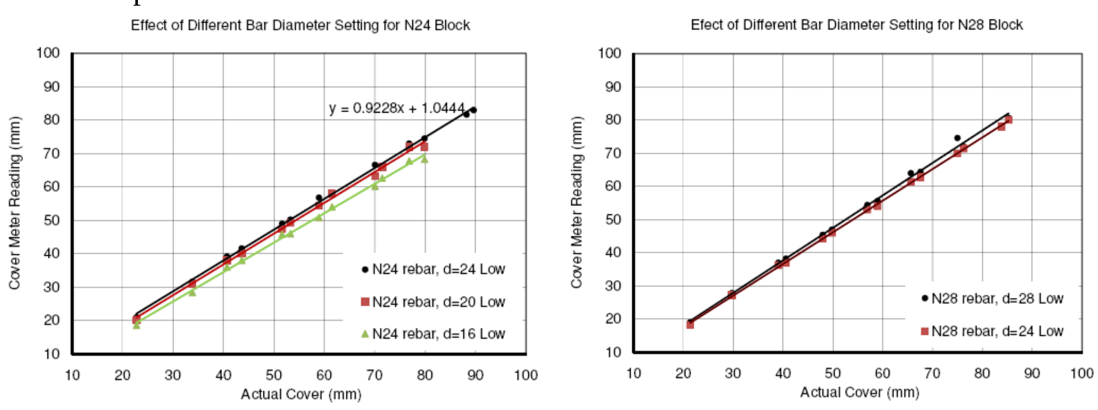

Figure 5 Comparison of different bar diameter settings on measured cover to the same bars a) N24 bar block, b) N28 bar block

The above comparisons suggest that setting the bar size to different diameters can affect measured concrete cover. Setting to actual bar diameter will give more accurate results than setting to assumed bar diameter. Reducing the bar diameter in covermeter settings will reduce the measured covers, and vice versa. It will be desirable to obtain the information on bar diameter in the concrete before cover measurement in order to achieve more accurate results.

It is also observed in Figure 5a, once the bar diameter and bar spacing are fixed, setting to bigger bar diameter could increase the maximum cover measurable depth. This phenomenon was also observed in several projects by the authors where the concrete covers were thick and the objectives were purely to locate reinforcing bars.

6. Effect of Scan Location Relative to Secondary Bar

Generally, it is recommended that secondary (perpendicular) bars be located before cover measurements on the target reinforcing bar are carried out. Once the secondary bars are located, the probe can be place in between two secondary bars and be moved traverse across to the target main bars (refer to Figure 6). Scan location relative to the secondary bars under the main bars can affect cover measurement accuracy. However, extent of this effect has not been fully studied.

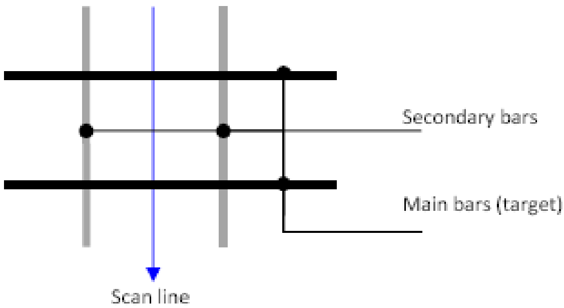

Figure 6 Main bar (target), secondary bar and proposed scan location

Certain covermeter uses universal probe and the probe is designed to function in relation to the direction. This means it reacts most sensitively to the bars to its longitudinal axis, and least sensitively to the ones at right angles to its longitudinal axis. For this reason the probe should be positioned parallel to the bars to be tested and moved across them when scanning [3]. With this improved design, the effect of the scan location relative to secondary bars is likely reduced.

In this study, covers were measured on N24 bar block in three different ways: Scan1 – between two secondary bars, Scan2 – exactly on top of a secondary bar, Scan3 – away from the secondary bars. Figure 7 shows the scan locations relative to the secondary bars.

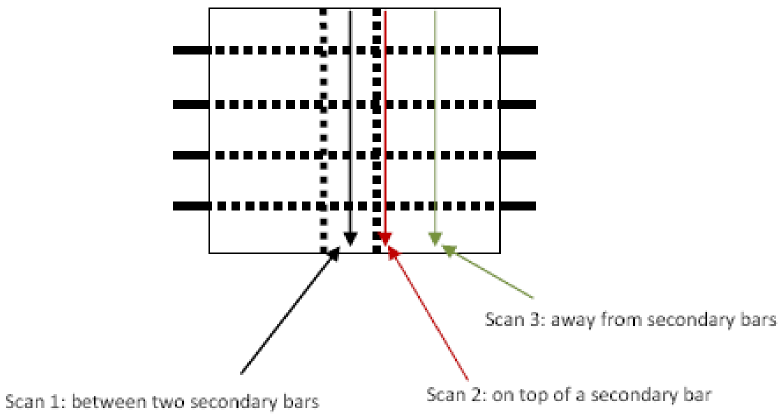

Figure 7 Three Different Scans Relative to Secondary Bars

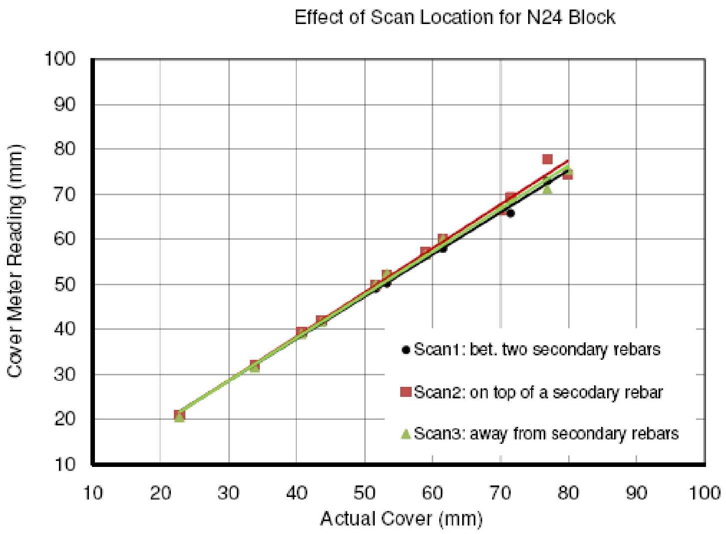

Figure 8 Comparison of Results from Different Scan locations

The above comparison shows that scan location relative to secondary bars could affect measured covers, but it seems insignificant, especially in lower cover range. For example, the maximum difference for 40mm cover is 1.1%, for 60mm cover is 2.7%, for 80mm cover is 3.5%. This suggests scan location relative to secondary bar is less sensitive than other factors for a well designed covermeter.

7. Effect of Cover Meter Probe Setting (Low or High)

All covermeters have different measurement probes to measure the full range of concrete covers, either by using a universal probe with different probe settings (low or high range) or by using two different probes (deep or shallow). In the over lapping range where both probe settings could measure concrete covers, the measured covers by different probe settings do not match. Manufactures recommend that high range setting should only be used if the concrete cover could not be detected when the probe is set to low range.

In this study, relatively deep bars had their covers measured with the cover meter setting on both “low” and “high” ranges for comparison. Figure 9a shows the comparison for N24 block and Figure 9b shows the comparison for N28 bar block.

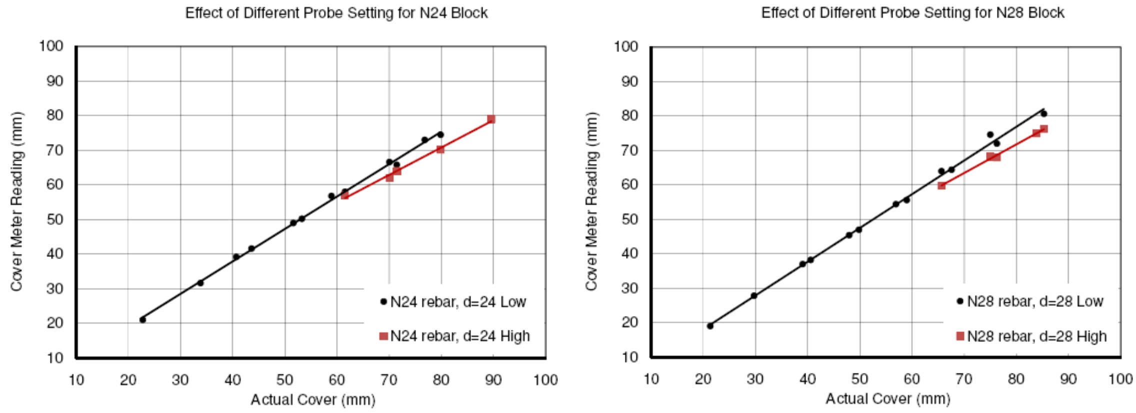

Figure 9 Comparison of probe setting, a) N24 block, b) N28 block

The above comparison shows that “high” range probe setting gives lower values than “low” range probe setting. This could explain why manufacturers suggest “high” range probe setting only be used when “low” range probe setting could not measure concrete covers. In addition, the measured covers have significant errors, giving much lower readings than actual covers. Although by setting cover meter to “high” range can increase the maximum cover measurable depth, it is likely to introduce more errors at the same time. Proper correlation should be established prior to actual cover measurement if “high” range probe setting will be used.

8. Conclusions

Many factors could affect cover measurement. Among them, bar diameter setting and range setting (low or high) in the covermeter have a greater affect than the other factors explored in this study.

Setting to actual bar diameter will give more accurate results than setting to assumed bar diameter. It is desirable to obtain the information on bar diameter in the concrete before cover measurement in order to achieve more accurate results.

“High” range settings should only be used when “low” range probe is not capable of detecting the reinforcing bars. If cover measurement is required for thick concrete cover structural elements, a proper calibration should be carried out prior to actual cover measurement.

References

1. British Standard BS1881 Part 204 "Recommendations on the use of electromagnetic covermeters".
2. John C Alldred, “Quantifying the losses in concrete cover-meter accuracy due to congestion of reinforcement”, Structural Faults & Repair, London, July 1995.
3. Operating instructions for Proceq Profometer 5 Model Scanlog.