Experimental measurement of the diameter and cover depth of steel reinforcement using an electromagnetic concrete cover meter

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Abstract. In spite of the fact that concrete cover meters are some of the most commonly used non-destructive means of measuring reinforcement diameter, position, and cover, there are barely any specific measurement results available in published literature. This paper focuses on the use of a Profometer PM-630 concrete cover meter for in-situ measurements of such things as the cover depth of stirrups in the column of a high-rise building or determining the diameter of main reinforcement in hollow-core ceiling slabs.

1. Introduction

Unless reinforcement is completely exposed, it is difficult to assess its quality and type in an existing concrete structure. Where no technical documentation is available and destructive tests cannot be performed, non-destructive tests assume a prominent role in building diagnostics [1]. One of the most widespread non-destructive methods for locating steel reinforcement is the use of electromagnetic cover meters (rebar locators). However, literary sources provide almost no results or examples of measurement. The main reason for this may be the rather primitive imaging capability of existing cover meters. Therefore, measurement outcomes have thus far been presented mainly as photographs or lines drawn directly onto the surface of the structure being tested, or into a technical drawing of the building.

Progress in reinforcement visualization was made by the introduction of the Ferroscan by Hilti, which enabled the area scanning of reinforcement [2]. The Profometer PM-630 (or PM-650) from the company Proceq expanded the possibilities of the method’s application including visual outputs of the measurement. It also greatly improved the accuracy of estimating the reinforcement diameter because it allows for correction in the distance of adjacent rebars, thus increasing the quality of the measurement outputs [3]. In the case of this instrument, the quality and accuracy of results is proportional to the qualification and experience of the operator. The history and development of these instruments is described e.g. in [1]. Besides electromagnetic cover meters, other non-destructive instruments that can locate the reinforcement in concrete is e.g. the PS 1000 radar manufactured by Hilti, which is described in more detail in [4,5]. In an ideal case, both instruments would be used at the same time (e.g. there was an experiment performed using a GPR-EMI prototype dual sensor [6]) and their results compared, as discussed in [7].
The examples discussed in this paper document innovation in the applicability of electromagnetic cover meters. The paper is focused on practical examples of using a Profometer PM-630 cover meter for determining the cover depth and diameter of steel reinforcement.

2. Method description and examples of measurement

Cover meters use the principle of eddy currents that occur in conductors placed in an electromagnetic field. Originally, the method exploited the magnetic properties of the material being detected. The Profometer PM-630 operates on the pulse induction principle, as described in [3]. The probe houses coils without a magnetic core, which means it is unaffected by magnetic fields in the surrounding area. Advanced signal processing allows locating a rebar as well as measuring of cover and rebar diameter.

Some of the strong points of the instrument include immediate visual output, high accuracy, the option to make corrections for the distance of adjacent reinforcement, and the considerable speed of measurement. Measurements can suffer e.g. by mis-detecting rebars that are too close, whether next to or behind one another. Another limiting factor can be the instrument’s range (in normal probes about 60 – 100 mm, in depth probes approximately 150 mm to 220 mm). The measurements can also be impaired by strong electromagnetic fields near the structure being tested [8].

Prior to the actual measurement it is important to become well acquainted with the instrument and follow the manufacturer’s instructions. It is recommended to test the instrument’s sensitivity on a model element with a known position of reinforcement, especially if the rebars are close to each other. Where the concrete is not familiar to the user, it is also necessary to ascertain whether there is any magnetic aggregate present, as it could sway the results [9]. The principle and procedure of correct measurement are described by the manufacturer in [3]. This paper presents practical examples of using a Profometer PM-630. Specifically, it describes measurements of the coverage of stirrups in the column of a high-rise building in Bratislava and measurements of hollow-core ceiling slabs of a high-rise building in Brno.

2.1. Determining cover depth

The building in Bratislava was being surveyed for structural stability, which involved measuring the cover depth of stirrups in an 800 × 500 mm column. Figure 1 shows the column and the line scans of all of its four sides performed from the floor upwards.

![Figure 1](image)

Figure 1. Measurement of the cover depth of stirrups in a monolithic column with the minimum cover depth set at \( cp = 25 \) mm – stirrups which are nearer to the surface are in red.
Another example discussed herein is the measurement of the main reinforcement in a column with a 500 × 800 mm cross-section, which is basically identical with that shown in figure 1. This measurement was made about 1.50 m above the floor. When measuring cover depth it is important to remember whether only one rebar is being measured or whether there are others nearby. If there is only one rebar, the results are clear. The operator only needs to enter the diameter and the instrument shows the cover depth. If there is interference from adjacent reinforcement (i.e. if the minimum distance between the main reinforcement bars is not kept), the instrument returns a depth value which is smaller than the real one. This is because more rebars at a greater depth behave the same as one rebar at a shallower depth. Therefore, when measuring a densely reinforced element, it is important to make calibration measurements on a model (followed by a correlation), which has the same reinforcement the building being diagnosed. However, the diameter is not always known and the building plans are not always available. If the diameter is incorrectly estimated, the cover value will be incorrect [9].

2.2. Determining reinforcement diameter

The determination of reinforcement diameter is affected by multiple parameters, some of which are more easily foreseeable (e.g. longitudinal or transverse rebar spacing), some less so (e.g. the effect of welded meshes, overlapping reinforcement, etc.). The diameter value may also appear higher due to the action of electromagnetic fields (crane rails, interconnected reinforcement in multi-storey buildings). This is why it is better to combine the method with other techniques, e.g. a destructive probe.

Modern instruments have rebar diameter probes, which make it easy to determine the diameter of the reinforcement, however, it is necessary for the individual bars to be far enough apart [9]. An example of determining reinforcement diameter is a measurement made on hollow-core ceiling slabs in a high-rise building at Šumavská street in Brno. According to available information, these were precast elements with 6 hollows, made in 1975, spanning 6.0 m in length and with a width of 1.2 m (see figure 2).

![Figure 2. View of the bottom surface of a 1.20 m wide ceiling slab showing the position of the main reinforcement (1, 2, 3, 4) as well as distribution reinforcement (r1, r2) – the red arrows show the joint between the slabs, the unmarked reinforcement belongs to the adjacent slabs.](image)

3. Results and discussion

3.1. Determining cover depth

Every line scan of the column made from the floor upwards (see section 2.1) shows 16 stirrups with an average spacing of 150 mm. The dotted lines show cover depth according to the building design...
documentation; \( cp = 25 \text{ mm} \). All stirrups which are closer than 25 mm from the surface are in red, stirrups located deeper are in blue (figure 1). The measurements show that while the cover depth of side A is clearly smaller than prescribed, the situation is reversed on the opposite side C. Values of deviation from the prescribed cover depth are plotted in Figure 3. It shows that the column’s rebar cage was off-centre and closer to the side A.

![Figure 3](image-url)  
**Figure 3.** Plot of deviations from the prescribed stirrup cover of \( cp = 25 \text{ mm} \) – the cover depth was not kept on side A (stirrups in the bottom part of the column were closest to the surface), the cover depth on the opposite side C was highest.

Figure 5 shows the results of main reinforcement measurements performed on all four sides of the column at a height of 1.5 m above the floor. An advantage of the Profometer PM-630 is its ability to record an uninterrupted linear scan of up to 15 m. Figure 4 therefore shows a continuous scan of the column’s entire circumference. The scan shows that the main rebars nearer to the left edge of every face always had deeper cover as opposed to those on the right. The measured values were then used to create a cross-section through the column, see Figure 5. It clearly show how the rebar cage is rotated out of alignment with the column’s intended outline.

![Figure 4](image-url)  
**Figure 4.** Continuous line scan of the main reinforcement around all four sides of the column – the cage’s deformation is regularly repeated and ranges between 10 mm and 60 mm.
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Figure 5. A series of line scans to determine the position of main reinforcement in the column of 500 × 800 mm performed in sequence on sides A, B, C, and D.

This example is only one of many measurements made on dozens of the columns in the building in Bratislava. It was intentionally picked to demonstrate the use of the Profometer PM-630 for measuring reinforcement cover depth. It is clear that this cover meter is very fast and accurate in determining whether the prescribed cover depth has been kept and allows for immediate visualisation and logging of the results.

3.2. Determining reinforcement diameter

Measurements of the hollow-core slab (see section 2.2) showed that there is only a minimum of distribution reinforcement – only two stirrups in the middle for the entire span, see figure 6, and then several stirrups near the ends where the slab is seated against the girder. Because the stirrups are far enough apart (approx. 200 mm), as are the bars of the main reinforcement (approx. 380 mm), the stirrup measurement could be done without correction for the proximity of adjacent reinforcement. The result is the diameter of 7 mm (see figure 6). The true diameter may vary only to a small degree; between 6 and 8 mm. Next, the profiles of the main reinforcement were measured, however, only on
two of the inner rebars, because the rebars near the edge were too close to those in adjacent slabs. The diameter of the inner rebars was measured at 18 to 19 mm; see figure 7.

Once the diameter is measured with a Profometer PM-630, it is then verified by a destructive probe where a small portion of the cover is chiselled away to reveal the actual reinforcement. In this case, however, the documentation contained all the necessary information – it was a ribbed reinforcement of the type 10425 (V), 4 × Ø 18 mm. The destructive probe was therefore not necessary, as there was no doubt as to the veracity of the measured data, not even in the case of stirrups. It should be noted, however, that in older buildings some of the planned reinforcement may not have been available in sufficient amounts and could have been replaced by other, whether in in terms of the number of rebars, or their type and diameter.

**Figure 6.** Measurements of the position, cover depth, and diameter of stirrups in the ceiling slab – diameter was determined at 7 mm, cover depth at 9 mm to 13 mm.

**Figure 7.** Measurements of the position, cover depth, and diameter of main reinforcement in the ceiling slab – the red interrupted line shows the edges, the diameter was measured at 18 mm and 19 mm.

4. Conclusion
The determination of the reinforcement diameter and depth is objectively a rather complicated task. However, nowadays there are highly sophisticated electromagnetic cover meters available, which can determine the diameter and cover depth of reinforcement non-destructively and with good accuracy. Still, it should be noted that the more advanced the instrument, the more qualified the operator, who therefore needs to have the appropriate training and experience.

Based on the experiments described here, it can be concluded that electromagnetic cover meters are well suited for determining the reinforcement diameter in hollow-core ceiling slabs. This is because such slabs meet basically all the requirements for making the measurements correctly; most notably
because they possess the sufficient spacing in the main and distribution reinforcement. Because the building’s project documentation was available and was therefore able to provide enough information about the reinforcement being measured, it was not necessary to verify the diameter destructively. The example of measuring reinforcement in concrete columns showed that the instrument is fast and accurate in revealing errors in the positioning of reinforcement cages inside formwork.

If one were to choose the most important task for the cover meter, it would likely be measuring cover depth. This is because of its accuracy, because most professional instruments can (as long as the conditions for accurate measurement are kept) determine cover depth of up to 50 mm with a ± 1 mm accuracy. The Profometer PM-630 is thus an ideal instrument for monitoring cover depth, but also for verifying reinforcement diameter providing all rebars can be satisfactorily identified, making it far better than any of the older types of cover meters.

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References
[1] Cikrle P and Anton O 2015 Development of nondestructive methods for testing of concrete since 1990 Beton TKS 3(2018) pp 3-7 (in Czech)
[2] HILTI PS 200: PS 200 Ferroscan TechRentals, www.hilti.cz/c/CLS_MEA_TOOL_INSERT_7127/CLS_CONCRETE_SCANNERS_7127/r 6436646
[3] Proceq: Profometer PM-600/PM-630 Operating instructions, https://www.proceq.com/compare/rebar-detection-and-cover-measurement
[4] Balayssac J and Garnier V 2018 Non-destructive testing and evaluation of civil engineering structures (Kidlington, Oxford, UK: Elsevier)
[5] Gaydecki P, Silva I, Fernandes B and Yu Z 2000 A portable inductive scanning system for imaging steel-reinforcing bars embedded within concrete Sensors and Actuators A: Physical 84 pp 25-32
[6] Zhou F, Chen Z, Liu H, Cui J, Spencer B and Fang G 2018 Simultaneous Estimation of Rebar Diameter and Cover Thickness by a GPR-EMI Dual Sensor Sensors 18(9): 2969
[7] Gregory J and Riley P 2003 Rebar locators Structure magazine 2003 pp 28-30
[8] Cikrle P 2017 Importance of non-destructive diagnostic methods for surveying steel-reinforced concrete structures – habilitation thesis (Brno: BUT) (in Czech)
[9] ČSN 73 2011:2012 Non-destructive testing of concrete structures (Prague: UNMZ) (in Czech)