Non-destructive diagnostics of steel-reinforced concrete structures: detecting and locating reinforcement

P Cikrle¹, S Hüblová¹, D Kocáb¹ and O Karel¹

¹ Brno University of Technology, Faculty of Civil Engineering, Veveří 331/95, Brno, Czech Republic

E-mail: petr.cikrle@vutbr.cz

Abstract. The paper describes the possibilities of non-destructive determination of the location and depth of reinforcement in concrete structures using electromagnetic cover meters. It is currently one of the most popular methods for determining the location, cover depth and diameter of reinforcement. However, there are not many sources that would give a detailed description of specific measurement results. This paper describes the use of the Profometer PM-630 cover meter for in-situ measurement of a steel-reinforced-concrete road bridge deck. The paper details the results of measurements of cover depth, bends in reinforcement, and discusses the strong and weak points of the method.

1. Introduction

Determining the precise location, cover depth, and diameter of concrete reinforcement in existing structures can be rather difficult. Especially in densely reinforced elements, where there are several layers of reinforcement, clear results may not be achieved even by a destructive technique. Still, non-destructive methods assume a strong position in building diagnostics. Certain limitations notwithstanding, non-destructive techniques can determine (or, in some cases, approximate) the cover depth and diameter of reinforcement bars as well as their type and quality [1,2].

One of the most common non-destructive methods for locating reinforcement is the use of electromagnetic cover meters. It has been used for many decades; however, until recently, the imaging capability of available instruments had been rather limited. This is why most measurement outputs consisted of photographs of the tested surface with lines drawn to indicate the rebar locations. This may be the reason for the near absence of any detailed measurement results, including a thorough discussion of the method’s strong points and shortcomings, or suggestions as to the suitability of its use across various cases. A significant advance in the instruments was made in the form of the Ferroscan cover meter introduced by the company Hilti, which was capable of performing area scans [3]. More progress was made by Proceq, who have marketed the Profometer PM-630 (or Profometer PM-650). A more detailed description of the development and history of measuring instruments is presented [4].

Nowadays, when radiography is only rarely used to inspect and locate reinforcement, it also possible to use e.g. the Radar PS 1000 produced by Hilti. Its use is described in [5,6]. It is a good choice to use the instruments in combination, as described in [7], or comparing their results [8].
2. Using a cover meter to locate reinforcement

2.1. Method and instrument

The measurement examples described here testify to how widespread the use of cover meters is and what innovations have taken place in recent years. The paper describes a practical example of the use of the Profometer PM-630 – specifically detecting and locating reinforcement in a steel-reinforced-concrete bridge deck.

Detecting concrete reinforcement by a cover meter works on the principle of registering eddy currents that occur in conductors placed in an electromagnetic field. It used to be common that instruments exploited the magnetic properties of the reinforcement. The Profometer PM-630, which was used for measurement in this paper, however, uses pulse-induction technology – it is described e.g. in the manual to the instrument [9]. The probe of the Profometer PM-630 holds two coils without a magnetic core, which is beneficial, as it is not susceptible to interference from other magnetic fields.

Modern magnetic cover meters have their strong and weak points. Advantages certainly include the measurement accuracy and speed, immediate visual output, and the option to correct for the proximity of adjacent reinforcement when measuring the cover depth of individual rebars (applies to the Profometer PM-630). A drawback is the inability to detect rebars if they are too close (regardless of whether they are behind or next to each other), shorter range compared to e.g. radiography (most probes cannot scan deeper than 100 mm, deep probes reach a maximum of 200 mm), or the near impossibility of measurement in the vicinity of other electromagnetic fields [10].

Prior to the actual measurement, it is recommended to test the instrument’s sensitivity on a model element, especially in cases where the rebars are close. It is also good to make sure there is no magnetic aggregate present, as it could significantly distort the results; see [11]. The correct use of the Profometer PM-630, including the principle of operation and the method, are described in the user manual [9]. It should be noted that in order for this result to deliver accurate results, the operator has to be trained and experienced in its use. Even though the Profometer PM-630 can locate concrete reinforcement very accurately, a novice user may still arrive at very wrong results.

2.2. Detecting and locating reinforcement

This paper discusses detecting and locating reinforcement bars using the example of finding the beginning of bends in straight rebars in a reinforced-concrete slab near the abutment. Tests were performed on a load-bearing steel-reinforced concrete bridge spanning a stream near the town of Nosislav near Brno. It consists of a slab with the thickness of 280 mm resting on bitumen sheets on solid abutments. The inner distance between the abutments is 3.0 m and the bridge is 8.0 m wide. The deck consists of two 4.0 m slabs separated by an expansion joint.

The reinforcement was measured using a Profometer PM-630. Besides locating bends, the goal was to ascertain the number of profiles, their spacing and cover depth. Learning the reinforcement type and diameter was easy, as a part of the deck near the ledge was missing a piece of cover, revealing several reinforcement bars made of type 10216 (E) smooth circular reinforcement with the diameter of 16 mm.

The methodology of locating the bends was first tested in a laboratory. When reinforcement is being located, the instrument is pushed along the surface of the slab waiting for the signal to peak. This occurs when the instrument, moving in a perpendicular direction to the reinforcement, is at the shortest distance from a bar. The position of the reinforcement is always drawn onto the concrete surface, having been determined using several line scans.

During cover depth measurement it is possible to locate inward-bending bars with an accuracy of ±10 mm, as their cover depth is increasing. A 1.2 m long line scan was performed in the middle of the bridge. It identified 12 profiles with the spacing of 80 - 90 mm. The average cover depth was only approx. 12 mm. The next step involved making several line scans at a distance of 0.12 m, 0.22 m, 0.26 m, 0.29 m, 0.32 m and 0.40 m from the abutment. Figure 1 shows where on the slab the line scans
were performed. In addition, one of the bends was examined (specifically bar no. 8 – this is an internal designation of the rebars starting from the ledge inward) by chiselling its cover away; see figure 2.

![Figure 1](image1.png)

**Figure 1.** A view of the deck with line scans shown in blue.

![Figure 2](image2.png)

**Figure 2.** Bend in rebar no. 8 – it begins precisely in the position of the black marker line at a distance of 0.32 m from the abutment.

3. **Results and discussion**

Figure 3 shows the key line scans (made at a distance of 0.12 m, 0.22 m, 0.29 m and 0.32 m from the abutment) exported from the cover meter. The vertical axis is the cover depth and the horizontal axis is the length of the scan. It is clear that bent bars are not recorded on the top scan (closest to the abutment) while on the bottom scan they are already at the level of the other bars. Figure 4 shows the results of cover depth measurement for rebars no. 1 through 12, out of which rebars no. 2, 8 and 11 bend at a distance of 0.32 from the abutment and rebar no. 5 at 0.29 from the abutment.

It is, of course, possible to measure bent reinforcement only up to a certain depth, as stated above. By default, if reinforcement is being located by the electromagnetic method, rebars placed deeper inside the concrete will appear overshadowed by parallel rebars nearer to the surface. During the destructive measurement of the bend in rebar no. 8, the beginning of the bend was measured with an accuracy of ± 10 mm at a distance of 0.32 m from the abutment. The electromagnetic cover meter appeared to be very accurate in identifying bends in reinforcement in the present case, and can be used in all cases where the individual rebars are easily distinguishable.
Figure 3. A series of line scans (top to bottom) at a distance of 0.12, 0.22, 0.29 and 0.32 m from the abutment – the bent shear reinforcement (red) is slowly rising to the surface to the same level as continuous reinforcement.

Figure 4. A plot of the cover depth for rebars no. 1 through 12 – rebars no. 2, 8 and 11 bend at a distance of 0.32 m, rebar no. 5 at 0.29 m from the abutment.
4. Conclusion
In conclusion, this particular example of detecting bends in the reinforcement of a bridge deck showed that the method and instrument are an ideal non-destructive choice. The distance of the bend from the abutment was measured with an accuracy of ± 10 mm, and was confirmed by a destructive probe. The method is very accurate for this purpose and can be effectively used in all cases where it is possible to clearly discern between the individual rebars in the slab. The Profometer PM-630 thus appears ideal not only for locating reinforcement, but also for ascertaining the location of bends. In terms of quality, it performs far better than previous models of cover meters.

Acknowledgement
This paper has been worked out under the specific research project No. FAST-S-19-6002 at Brno University of Technology.

References
[1] Malhotra V and Carino N 2004 Handbook on nondestructive testing of concrete (Boca Raton, Fla.: CRC Press)
[2] Bungey J, Millard S and Grantham M 2006 Testing of concrete in structures (New York: CRC Press)
[3] HILTI PS 200: PS 200 Ferroscan TechRentals, www.hilti.cz/c/CLS_MEA_TOOL_INSERT_7127/CLS_CONCRETE_SCANNERS_7127/r 6436646
[4] Cikrle P and Anton O 2015 Development of nondestructive methods for testing of concrete since 1990 (original: Vývoj nedestruktivních metod pro zkoušení betonu od roku 1990) Beton TKS 3(2015) pp 3-7 (in Czech)
[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] Balayssac J and Garnier V 2018 Non-destructive testing and evaluation of civil engineering structures (Kidlington, Oxford, UK: Elsevier)
[7] 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
[8] Gregory J and Riley P 2003 Rebar locators Structure magazine 2003 pp 28-30
[9] Proceq: Profometer PM-600/PM-630 Operating instructions, https://www.proceq.com/compare/rebar-detection-and-cover-measurement
[10] Cikrle P 2017 Importance of non-destructive diagnostic methods for surveying steel-reinforced concrete structures – habilitation thesis (Brno: BUT) (in Czech)
[11] ČSN 73 2011:2012 Non-destructive testing of concrete structures (Prague: UNMZ) (in Czech)