Determining reinforcement coverage using an electromagnetic rebar detector

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Abstract. Correct reinforcement is an essential part of constructing reinforced concrete structures. Errors in positioning, diameter, or coverage may result in defects, which is why it is necessary to make sure the reinforcement is implemented well. Even though electromagnetic detection is the most common non-destructive method for locating reinforcement in reinforced concrete, science literary sources hardly discuss it. The main reason is a lack of graphic test results – thus far the most common research outcomes have been photographs of lines drawn on the concrete surface or additions to technical drawings of the reinforcement. Only modern detectors expanded the possibilities of the method’s application including graphic measurement records and a more accurate estimation of reinforcement diameter including corrections for adjacent reinforcement spacing. The paper focuses on the principle of measurement and practical examples of determining the position and coverage of reinforcement in reinforced-concrete structures using a state-of-the-art electromagnetic rebar detector – a Profometer PM-630. Aside from data recording and statistical evaluation during coverage measurement, modern instruments also allow the data to be exported and visualised.

1. Introduction

Originally, the method exploited the magnetic properties of the material being detected. Older instruments responded to changes in the magnetic resistance in a magnetic circuit [1,2]. The stability of measurement was affected by the dependence of the magnetic properties of the detection coil’s core on temperature, as well as interference of other magnetic fields including Earth’s magnetic field. The contemporary method operates on the principle of pulse induction [3].

Only very sensitive instruments can be used for this kind of measurement. Here, the most important fact is whether a reinforcement bar is solitary, or if there are any other rebars in its vicinity (whether parallel or perpendicular). Measurements made on a solitary rebar return straightforward results. Based on a change in the indicator (needle motion, numerical value) coverage is determined by means of a fitted curve. Newer instruments allow the user to enter the rebar diameter and directly obtain the coverage value.

A rebar is considered solitary if the indicator response is not affected by adjacent reinforcement (whether parallel or perpendicular) by more than 5 %. The minimum distance of adjacent reinforcement is determined by measurements using a model concrete member [4]. If this distance is not kept, the instrument returns a value of coverage which is smaller than the actual one (several rebars deep inside the member behave like a single rebar closer to the surface). During the determination of reinforcement coverage in a member with dense reinforcement and known distribution it is possible to set correction for coverage using a calibration measurement performed on a model member with reinforcement which is identical to that of the member being measured.
However, the diameter of reinforcement is not always known, in spite of the fact that it is an important parameter. For instance, if coverage is evaluated using a curve for reinforcement of Ø 16 mm in diameter, but the real diameter is Ø 20 mm, the resulting coverage would be lower than the actual value. However, as long as the diameter can be at least approximately estimated or non-destructively measured, the distortion of concrete cover measurement is relatively low.

2. Determining the position of reinforcement bends in a bridge cross beam in Ostrava
To give an example of accurate determination of reinforcement cover, we can describe the diagnostics of an end cross beam of a bridge in Ostrava - Mariánské Hory (see figure 1). The impulse for the diagnostics was given by the city planner. The end beam suffered some transverse cracking and thus required remedial measures to seal the cracks and prevent their further propagation. To stabilise the cross beam structurally, it was post-tensioned in the longitudinal direction. However, this required core drilling at a diameter of 57 mm in order to allow the installation of post-tensioning cables and thus introducing additional reinforcement to the structure. The drilling posed a risk of damage to the cross beam’s main reinforcement (of 32 mm in diameter), which was a serious problem. The goal of the diagnostics was to ascertain whether the position of the rebars and especially the bends corresponds accurately to the project documentation. Only after the positions of the bends were identified, the post-tensioning ducts could be drilled.

Figure 1. A view of the bridge in Ostrava - Mariánské Hory; the deck is terminated by a massive cross beam.

The proposal intended to perform core drills through the beam in places where it lacks three rebars (numbers 4, 6, 8) out of a total of eleven main reinforcement bars with a diameter of Ø 32 mm (see figure 2). This is because the rebars identified as 4, 6, and 8 bend at a distance of approx. 1.9 m from the end of the beam. The position of the bends in main reinforcement as well as the ducts for post-tensioning cables can be seen in figure 3.

The inclined drills were to be performed downward from the end faces of the cross beam and exit through its bottom at an approximate distance of 1.85 m from either end, i.e. in close proximity to the bends in the main reinforcement. This reinforcement was not to be been damaged by the drilling; according to the construction design, the drills would miss the reinforcement by a mere 50 mm.
Figure 2. Three rebars (4, 6, 8) bent an incline, remaining 8 bent by 90° straight upwards from the bottom.

Figure 3. Positioning of main reinforcement and the proposed post-tensioning cables for the structural stabilization of the bridge.

Thanks to sufficient distance between the bridge’s bearing bed and the cross beam, i.e. 0.48 m, it was fairly simple to perform measurements on the bottom face of the beam using a new-generation rebar detector Profometer PM-630. The measurement took the form of several linear scans across the cross beam at a varying distance.
Even though the concrete cover was 50 mm, it was possible to locate each bar on the bottom of the beam as they were spaced at a great enough distance of 100 mm to 150 mm.

The Profometer PM-630 retains data from each linear scan in its memory, allowing access to it after the measurement. A total of 7 linear scans were performed at a distance of 1.71 m, 1.77 m, 1.83 m, 1.89 m, 1.95 m, and 2.01 m from the end so as to capture the area from the left as well as from the right from where the bends were expected to be located. Figure 4 shows one of the linear scans performed in the transverse direction at a distance of 1.89 from the end of the beam. In this place the 3 “red” bars are covered by up to 15 to 20 mm more concrete than the other 8 bars.

![Figure 4](image_url)

**Figure 4.** Visualisation of the line scan performed by the Profometer PM-630 in the transverse direction and distance of 1.89 from the end of the beam. The red rebars bend and are covered by up to 15 to 20 mm more concrete.

The results of coverage measurements from all 7 scans were later compiled into a table and plotted in a graph. Table 1 shows the values of concrete coverage in mm for each of the 11 main reinforcement bars. Figure 5 shows an accurate plot of reinforcement coverage in place where the bars bend as well as the location of the drill.

**Table 1.** Cover depth of all 11 reinforcement bars measured along 7 lines using the electromagnetic rebar detector Profometer PM-630.

| Reinforcement No. / Position | Coverage [mm] along lines from the end of the beam |
|-----------------------------|--------------------------------------------------|
|                             | 1.71 m  | 1.77 m  | 1.83 m  | 1.89 m  | 1.95 m  | 2.01 m  | 2.07 m  |
| 1                           | 52.6    | 52.5    | 52.6    | 52.8    | 53.2    | 53.6    | 55.3    |
| 2                           | 49.7    | 49.6    | 49.4    | 49.8    | 50.0    | 49.8    | 49.7    |
| 3                           | 48.9    | 48.7    | 48.8    | 49.1    | 49.1    | 49.4    | 49.3    |
| 4                           | 108.0   | 92.0    | 76.7    | 63.1    | 56.3    | 52.3    | 52.3    |
| 5                           | 49.7    | 49.4    | 49.5    | 49.7    | 49.6    | 49.9    | 49.8    |
| 6                           | 116.0   | 99.0    | 84.0    | 69.5    | 60.7    | 52.7    | 52.6    |
| 7                           | 47.4    | 47.2    | 47.4    | 47.6    | 47.6    | 47.8    | 47.8    |
| 8                           | 109.5   | 95.0    | 78.0    | 64.0    | 56.6    | 50.8    | 50.7    |
| 9                           | 49.2    | 48.9    | 49.1    | 49.3    | 49.5    | 48.9    | 49.0    |
| 10                          | 50.0    | 49.4    | 49.5    | 49.4    | 49.1    | 49.5    | 49.3    |
| 11                          | 48.5    | 48.2    | 48.0    | 48.4    | 48.4    | 48.3    | 48.1    |
Figure 5. A plot showing the thickness of concrete cover for each of the reinforcement bars; the post-tensioning duct is shown in red.

The diagram in figure 5 shows that the edge of the drill is in fact 35 mm from the surface of the reinforcement, which ensures sufficient cover. Given the axial spacing of 100 - 150 mm there was a chance that adjacent reinforcement might affect the accuracy of measurement. This is why a laboratory measurement was performed with a model incorporating three Ø 32 mm bars, two of which were straight and the third, middle one, was bent. The model measurement showed that the adjacent reinforcement has the greater an effect on measurement, the deeper the bend is. As long as the cover of all the bars was 50 mm, the measurement was very accurate with a deviation of only ± 1 mm. Measurements in place where the bend was 75 mm deep showed a deviation of -3 mm (adjacent reinforcement reduces the depth of cover), and at a depth of 100 mm, the deviation was -10 mm. This means that the reinforcement is actually located a little deeper than the instrument shows. However, the location of the beginning of the bend has been located very accurately [5].

3. Conclusion
Methods for locating reinforcement have recently seen substantial progress. This also applies to the Profometer PM-630, which is the first instrument currently available on the market to allow visualising a cross-section through a steel-reinforced element, indicating the number of bars, coverage, spacing, and diameter of reinforcement. The paper presents a specific example of a fairly sophisticated determination of the precise location of bends in main reinforcement, which allowed effective post-tensioning of the damaged cross beam of the road bridge.

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