An optimal method of determining the position of bends on shear reinforcement as part of the diagnosis of reinforced concrete beam structures

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Abstract. The current period in the development of building industry can be characterized as a period of rapid development in this field, not only in the area of new constructions, but also in the area of a new uses of old constructions which find a new use after restoration, and as regards traffic facilities, especially bridge structures, in the area of verification of the existing functional characteristics and prediction of the lifetime of structures. This puts a strain on the field of diagnosis of structures, the development of which can be observed in the last 10 years in the form of a new wave of innovations of the existing NDT (non-destructive testing) methods as well as of the development of completely new devices and technologies. In spite of these facts, it can be said that in a number of cases, the diagnosis of structures is performed in traditional ways without using modern techniques and technologies. The aim of this paper is to present an optimal way of using NDT methods in the diagnosis of reinforced concrete beam structures, specifically in the determination of the position of shear bends on the main load-bearing reinforcement. The paper deals with the current state of the issue and illustrates, on a number of examples from practice, the applicability of individual methods as well as their limitations given by their physical principles and technological solutions.

1. Introduction to the issue

Today, there is a large number of reinforced concrete structures in the Czech Republic originating from various periods of the more than hundred-year-old tradition of manufacturing reinforced concrete. It is characteristic especially of the old structures that no project and construction documentation has been preserved. The reason of this can be found in the dramatic changes of political regimes in the past, in times of crisis such as World War Two, etc. These historic moments were often the cause of destruction or loss of the above-mentioned documents. A similar phenomenon is encountered, paradoxically, in the case of structures from the recent past, where the cause can be seen in the reluctance of the construction companies to provide construction documentation.

It is therefore a frequent task for the field of diagnosis of structural elements to determine characteristic properties of concrete in the selected elements of a reinforced concrete structure, and to detect the reinforcement of typical elements so that it is possible to perform a reanalysis of the actual load capacity of the structure, either to verify its functional characteristics or as a basis for restoration.

The present paper is focused on the specific field of diagnosis. Very frequent elements of monolithic reinforced concrete structures are reinforced concrete beams of various cross-sections and lengths. As regards the reinforcement survey aimed at static recalculation, the standard requirement is
to detect the main load-bearing reinforcement in the middle of the element span near the bottom face and to detect the reinforcement near the upper face above the support. Apart from that, spacings of stirrups are detected. In those cases where reinforcement above the support is inaccessible for various reasons, it is possible to determine the number of reinforcing bars near the bottom face of the support, and to estimate the number of shear bends on the main reinforcement from the difference between the bars in comparison to the centre of the span. What is somewhat neglected is the possibility of determining the position and number of shear bends directly in the measurement on the side faces of the girder. And it is precisely this specific part of diagnosis that is the focus of this paper.

2. Selection of applicable diagnostic methods for determining the position of reinforcement

The field of diagnosis of building structures can utilize in fact four methods of localizing steel reinforcement in the reinforced concrete structure.

- **Chopped probes** – a method based on a mechanical removal of the covering layer of concrete using a hammer drill. It is a method widely used in the civil engineering surveys of aged structures, with a limited potential, involving the risk of frequent impossibility to detect all the reinforcement, local limitation of the method and the necessity of a destructive intervention. For a specific case of determining the position of shear bends of the main reinforcement, it is a completely unsuitable method [1, 2].

- **Electromagnetic indicators of reinforcement** – devices based on the principle of electromagnetic field, formation of eddy currents, and the magnetic properties of steel reinforcement. The major disadvantage of this method is a limitation given by the principle of the method, by the depth of the reinforcement under the structure surface, by the distance between individual bars and by the complexity of reinforcement in general. The applicability of this method is problematic in terms of detecting the position of the shear bends of main reinforcement, due to the fact that the detection depth of the probes is very limited, and it is also probable that there might be some stirrups or horizontal reinforcement between the concrete surface and shear reinforcement, which will not allow for localizing the reinforcement behind them [1, 2].

- **Georadar** – a method based on the principle of transmitting radio-frequency electromagnetic pulses into the material and the detection of their reflection from the inhomogeneities in the environment. With the appearance of the Hilti PS-1000 radar, this method started to be highly applicable also for the above-mentioned problem. Its advantages include the detection depth (Hilti PS1000 up to 400 mm, GPR Proceq up to 700 mm), immediate visualization of the result, and independence of other reinforcement closer to the surface. For the purposes of determining the position of bends on the main load-bearing reinforcement it is possible to use both areal scans and line scans, as is demonstrated in detail in the following chapter. Today, only two georadars are available on the market, designed primarily for the diagnosis of reinforced concrete structures. Hilti PS1000 X-Scan and Proceq GPR Live. Hilti PS1000 is equipped with three aerials in one probe with a frequency of 1.5 GHz and a detection depth of 300 mm, Proceq is equipped with one aerial of 0.9 – 3.5 GHz with a depth of up to 700 mm. Both devices allow for performing areal and line scans from the concrete surface, in both cases areal scans can be transformed into 3D pictures of the detected reinforcement [1, 2].

![Figure 1. Both georadars available have a similar size of the probe.](image-url)
Figure 2. Both georadars for determining the position of reinforcement can produce line scans with online display of the results or a recording, on the left, Hilti PS1000 X-Scan, on the right, Proceq GPR Live [6].

Figure 3. Areal scans, on the left, Hilti PS1000 X-Scan, on the right, Proceq GPR Live [6].

Figure 4. Both Hilti PS1000 X-Scan and Proceq GPR Live make it possible to display the detected reinforcement in a fully-fledged 3D projection [6].

- **Radiography** – a well-known traditional method utilizing the irradiation of the structure with γ-rays from the Co60 source, and subsequently the attenuation of the radiation when passing through the structure depending on the volume mass. Considering the fundamental difference between the volume
mass of concrete and the density of steel, it is possible to represent the entire reinforcement on the output medium (radiographic film, electronic imaging media, etc.), and in the case of irradiation from several points of view, to determine precisely both the position of reinforcement, and its diameters. [1, 2].

3. Examples of practical application

3.1. Radiography
It is obvious from the above descriptions of the individual methods that the methods applicable for the solution of the given problem are radiography and georadar.

In the past, these tasks were performed by means of radiography but at the cost of accepting the expensiveness and time-consumingness of this method. Considering the necessary considerable irradiated width of the material given by the width of the reinforced concrete beam, we used, almost exclusively, Co60 radiography where the source of radiation was placed near one side face of the element examined, while the recording medium was situated near the opposite side face of the beam. With the appropriately set parameters of irradiation, the result was a radiogram with the reinforcement displayed in the irradiated place. The basic advantage was the 100% results in the determination of the reinforcement position while maintaining the principle of non-destructivity of this method. Its disadvantage was a long exposure time (given by the activity of the emitter and by the irradiated width of the concrete - in massive elements, tens of minutes to hours) and simultaneously a relatively small area of the element examined (given by the dimensions of the recording medium, usually 400 x 300 mm). Another limitation of this method is the fact that the method uses a high-activity gamma-ray source, which brings about a number of limitations resulting from the necessity to define and secure a temporary controlled area with all the requisites required by the regulations concerning health protection against ionising radiation. In practice it means that in order to apply radiography on the structure, it is necessary to prohibit completely the stay and movement of persons in the vicinity of the structure for the period of irradiation. Nevertheless, the method has been used successfully many times. Unfortunately, this method was abandoned in the Czech Republic at present due to its financial cost and the tightening safety regulations.

Figure 5. The left picture shows a diagram of the irradiation geometry of the reinforced concrete beam, where 1 – source of Co60 radiation, 2 – radiographic film, 3 – lead marks for precise identification of the position of the image. The picture on the right shows a radiogram of the beam with a well apparent main load-bearing reinforcement in one layer, the last shear bend before the support, and one bar of the main reinforcement which bends simultaneously with the face of the beam haunch before the support [3].

3.2. Georadar - Example 1
Typical structures, in which the number and position of bends on the main reinforcement are important for the reanalysis of the structure, are reinforced concrete girder bridges. The first example of an
appropriate use of the radar is the reinforced concrete girder bridge on the 1st class road near Holasovice. The bridge had already been diagnosed in 1990 and 2000 as part of its prepared restoration, and it was concluded that in the bridge girders, there are always 15 main reinforcements ROXOR R45 in three layers of 5, and it was supposed that part of them are shear bent in several places. Due to the budget constraints of the survey, the number and position of bends were not radiographically determined. In the subsequent survey in 2014, a series of successive areal scans were performed using the PS1000 radar, always on both side faces of the girders (considering the girder width of 600 mm and the radar's detection depth of 300 mm, the whole inner area was covered), which unequivocally detected the position of bends on the main load-bearing reinforcement, as is apparent from the pictures below.

![Reinforced concrete girder bridge](image1)

**Figure 6.** Reinforced concrete girder bridge on the 1st class road near Holasovice [4].

![Grid and radarogram](image2)

**Figure 7.** A grid for performing areal scans of 600 x 600 mm with the PS1000 probe, and on the right, a radarogram with the well apparent reinforcement – the main load-bearing reinforcement, its bends, stirrups and horizontal structural bars [4].
By combining areal scans (radarograms) it is possible to get an overview of the overall reinforcement of the element [4].

Diagram of the positions of bends on the main load-bearing reinforcement and a cross-section of the girder with the assignment of bend positions to individual bars; it is apparent that 10 of a total of 15 bars are bent in 5 positions [4].

Radarograms of reinforcement in comparison with the original project documentation, which was found, paradoxically, in the possession of a private person only after performing the survey [4].

3.3. Georadar - Example 2
The second example is the determination of the position of bends on the main load-bearing reinforcement in the elements of the ceiling structure of the Pavilion Z at the Brno Exhibition Centre. On the subtle joists of 150 – 250 mm, it was possible to detect the bends by measurement from one side face of the joist only. Figure 11 documents the traditional way of determining the position of bends on the main reinforcement using the areal radar scan.
Figure 11. On the left, the monolithic ceiling structure of the gallery in the Pavilion Z at the Brno Exhibition Centre, the picture shows the already installed grid for areal measurement with the PS 1000 probe. The right picture shows a flat scan of 600 x 600 mm with a clearly visible bend of the main reinforcement [5].

On site it was also possible to test an alternative method based on the fact that the PS 1000 probe is equipped with three aerials, therefore, even when doing a line scan, we in fact get a picture made of three line sections of the measured environment. On the line scan (composed of two parts, a view of the measured line and a section), the “view” part clearly shows the position of bends, especially when we set the device to display in the “view” part only the reinforcement from the inner area of the joist and not the stirrups situated near the surface (see Figure 12). It is apparent from the measurement results that it is possible to make the measurement of the position of bends in the main load-bearing reinforcement even simpler by means of the basic line scans, although the areal scans have a higher information and documentation value.

Figure 12. A line scan on the side face of the rib, in the picture above, only stirrups near the surface are displayed in the visible part, in the picture below, bends of the main load-bearing reinforcement bars are unequivocally identified in the visible part [5].
4. Conclusion

On the basis of three decades of the institution's experience with the use of radiography and several years of testing of georadar sets in the checks of the position of reinforcement in several hundreds of structures, it is undoubtedly possible to say that in most cases, the georadar method will be ideal for determining the position of bends in the main load-bearing reinforcement in the girders of reinforced concrete structures. It is currently the only NDT method with fully-fledged results in the desired extent. The only limitation could be the width of the element examined, if it exceeds double the detection depth of the radar set. This is, however, not very likely with the appearance of Proceq GPR Live (detection depth 700 mm, i.e. the limit width of the beam 1400 mm).

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References

[1] Anton O, Komárková T, Heřmánková V 2018 Conclusive Determination of Compliance with the Prescribed Reinforcement Elements of Concrete Structures - The Appropriate Methods and their Capabilities. Key Engineering Materials 776:76-80. [accessed 2019Apr.10]. https://www.scientific.net/KEM.776.76

[2] Anton O, Komárková T, Hefmánková V 2018 Methods Appropriate for Determination of the Prescribed Reinforcement of the Elements of Reinforced Concrete Structures - Nowadays Used Methods. Key Engineering Materials 776:41-45. [accessed 2019Apr.10]. https://www.scientific.net/KEM.776.41

[3] Hobst L 2007 Important Role of Radiography for determination of Conditions in Reinforced Concrete Structures. Engenharia Estudo e Pesquisa 9:7.

[4] Anton O 2014 REPORT: Diagnostic Survey of Shear Reinforcement (Bends) of Beams of Bridge Structure on Road I / 57 in Holasovice, id. 57-016. ZPRÁVA: O diagnostickém průzkumu smykové výztuže (ohybů) trámů nosné konstrukce mostu na silnici I/57 v Holasovicích, ev.č. 57-016 (in Czech). Brno.

[5] Anton O 2014 REPORT: Determination of Reinforcement of Selected Elements of Reinforced Concrete Structure of Hall Z in the Area of BVV, Brno, ZPRÁVA: O stanovení vyztužení vybraných prvků železobetonové konstrukce pavilonu Z, v areálu BVV, Brno (in Czech). Brno.

[6] Products: Portable Ground Penetrating Radar - Proceq GPR Live. 2018. Proceq. [accessed 2019Feb.10]. https://www.proceq.com