Proceedings of 7th Transport Research Arena TRA 2018, April 16-19, 2018, Vienna, Austria

Application of the magnetic leakage field method to investigate wire strands

Michael Schreiner, Frank Lehmann

MPA University of Stuttgart, Pfaffenwaldrinf 32, 70569 Stuttgart, Germany

Abstract

The magnetic leakage measurement method is useful for the nondestructive investigation of the integrity of tendons used in prestressed concrete components [1, 2]. It is based on the fact that ruptures or sudden changes in the cross sections of prestressing steel can be detected by characteristic magnetic anomalies. Due to the fact that all ferromagnetic elements of the reinforcement cause magnetic signals, these anomalies have to be obtained by using a magnetization scheme adapted to the given geometrical conditions and according signal analysis. The measuring of the remanence magnetic leakage field, in combination with numerical methods, leads to the satisfactory suppression of unwanted signals from the mild reinforcement. Ruptures of prestressing steel of pretensioned concrete members can be reliably detected with good repeatability. In case of tensioning steel arranged as bundle, the detection limit becomes severely limited because the adjacent intact steels cause a considerable attenuation of the signal of a rupture.

This paper shows different applications of the magnetic field leakage method for the investigation of wire strands.

Keywords: Prestressed steel, non-destructive testing, bridge inspection, magnetic leakage field method, reinforcement evaluation

1. Method

To conduct the magnetic measurements, a probe (Fig 1, top) containing the magnetization device (an electrically controlled yoke magnet) and the magnetic field sensors is moved along the prestressed tendons. Local disturbances of the magnetization of a longitudinally arranged steel cause typical magnetic leakage signals (Fig 1, bottom) due to ruptures or reduction of the cross-section. The shape and amplitude of these rupture signals depends on the length of the yoke magnet, the strength of the applied exciting field, the cross-section of the steel and the distance to the tendon and the mild reinforcement.

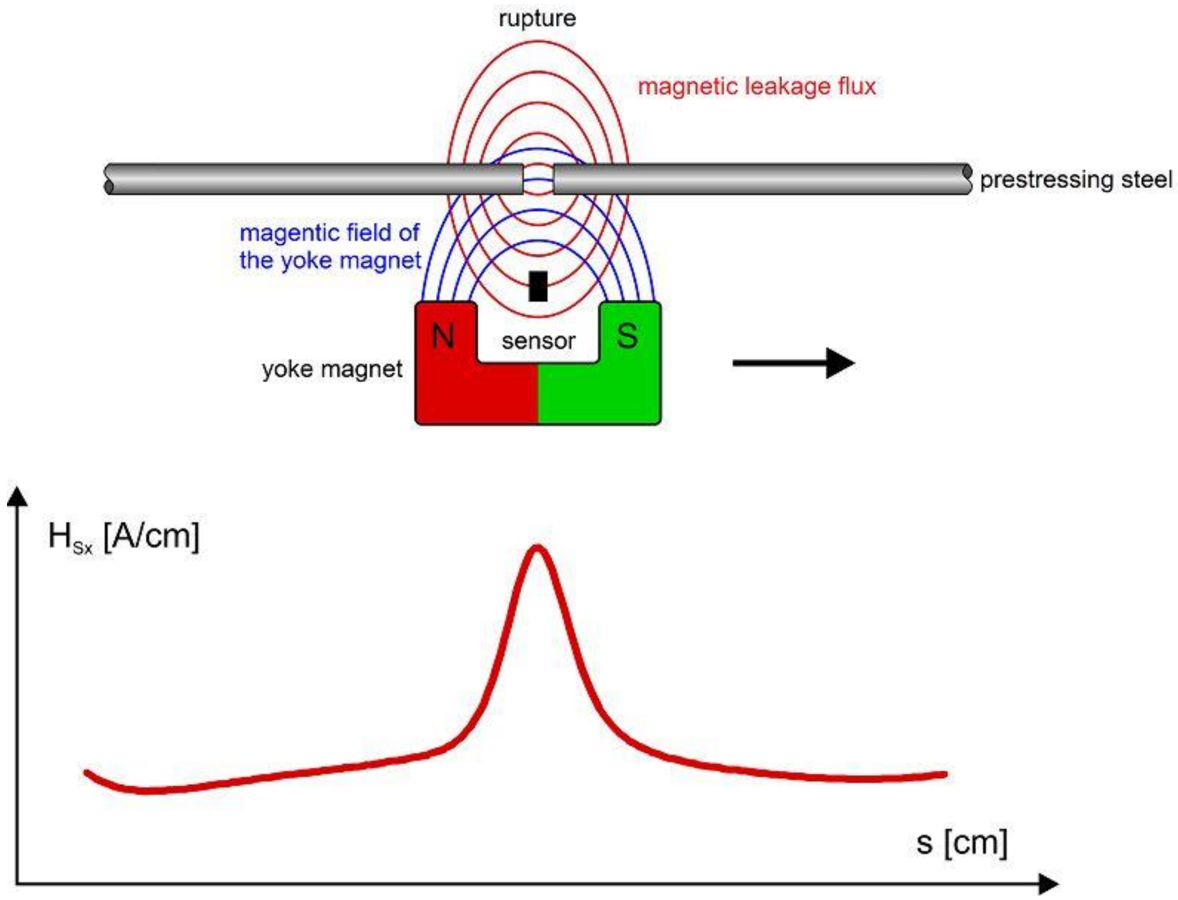

Fig. 1: Scheme of a magnetic field from the rupture of a prestressing steel

Magnetic flux leakage measurements can be performed during magnetization (active field measurement) or as a residual field measurement after a defined sequence of magnetizations (remanence field measurement).

The magnetic signals are affected not only by ruptures of the tendons but also by the mild steel reinforcement bars (stirrups), which are located at a shorter distance to the probe than the tendons. Figure 2b shows the typical signals of stirrups. To suppress these unwanted signals, several techniques for measurement and analysis have been developed. After a suitable sequence of magnetizations, the relationship between signals caused by cracks in tendons and the signals caused by ducts and rebars (stirrups) can be improved [1].

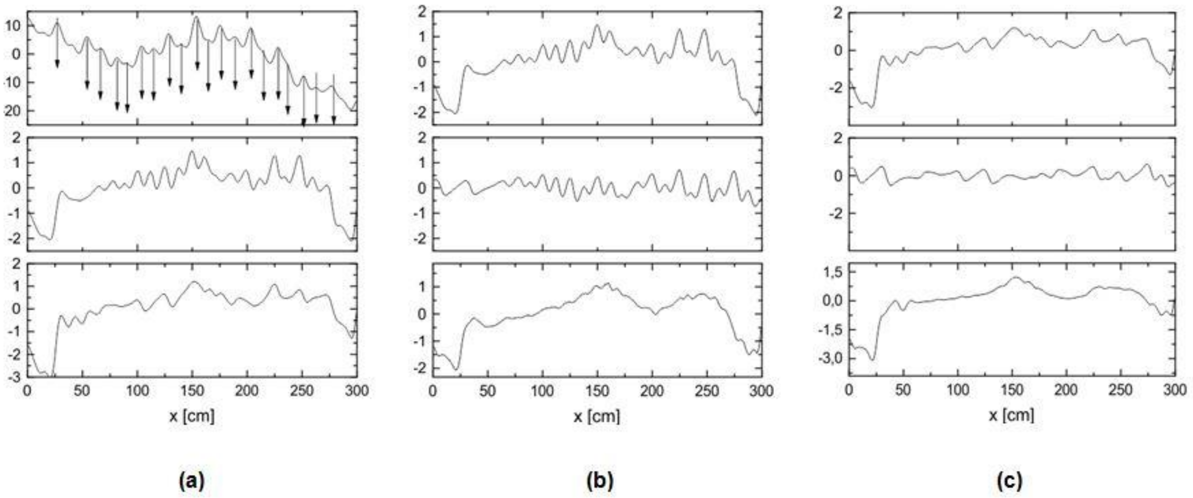

Fig 2: Evaluation of a magnetic stray field measurement at the example of a damaged tendon at 150 cm. (a) Scan 1, 6 und 7 according to table 1. (b) Scan 6, part of the signal of the crossbar, differential signal. (c) Scan 7, part of the signal of the crossbar, differential signal

During the forward scans no. 1, 4 and 5, active stray field measurements are performed. The measurements at the forward scans no. 2, 3, 6 and 7 are residual field measurements. The magnetization at the backward scans no. 2 and 6 causes an inversion of the magnetic signals of the transversely arranged stirrups. Therefore the signal portion of the stirrups can be suppressed by adding the measurements 2 + 3 and 6 + 7. Further the signal portion caused by the stirrups can be removed from the measured signal by filtering. The remaining signal is evaluated by means of local correlation inside the interval $x_0 - l \leqslant x < x_0 + l$ with a typical signal $H_r(x)$ caused by a rupture at the position x_0 [1].

$$H_r(x) = P(x_0) \cdot \frac{1}{((x-x_0)^2+z^2)^{\frac{3}{2}}} \qquad (1)$$

For this the rupture amplitude $P(x_0)$ and the correlation coefficient $r(x_0)$, which de-scribes the similarity of the filtered signal to the rupture signal H_r, is calculated. At positions with sufficiently large values of both the rupture amplitude and its signal correlation with the benchmark, ruptures are very likely.

2. Situation

The magnetic method gives satisfying results in case of single rod tendons. The situation becomes more complicated in case of a bundle shaped tendons or where prestressed steels are closely spaced. In this case, a strongly magnetic interaction exists between the intact and broken steels. To clarify this effect, tests on several arrangements of prestressing steels in order to simulate bundle shaped tendons were performed [3].

3. Measurements

For the experiments, the number of intact and broken steel was varied (Fig 3). Additional reinforcements, like iron and stirrups were not used and so only idealized bundles were considered. All arrangements were detected by using a very detailed procedure for magnetizing, which ensures optimal magnetization of the steel. In summary, the specimens were subjected to a sequence of 23 scans. The exiting current of the electrical yoke magnet was changed for every scan in the following manner:

Table 1: Extended measurement scheme for magnetization.

Scan	Current I [A]	
	Forward	backward
1	0	0
2	2	0
3	0	0
4	4	0
5	0	0
6	6	0
7	0	0
8	8	0
9	0	0
10	10	0
11	0	10
12	0	0
13	8	0
14	0	0
15	6	0
16	0	0
17	4	0
18	0	0
19	2	0
20	0	0
21	1	0
22	0	1
23	0	0

The magnetic measurement was only preformed during the forward scan. The measurements of the scans 2, 4, 6, 8, 10, 13, 15, 17, 19, 21 occur in the active field, all the rest in the residual field. In order to obtain defined magnetic stats at the beginning of a sequence, all used steels were demagnetized. After finishing the sequence, the intact steels were removed and the residual fields of the broken steels were measured.

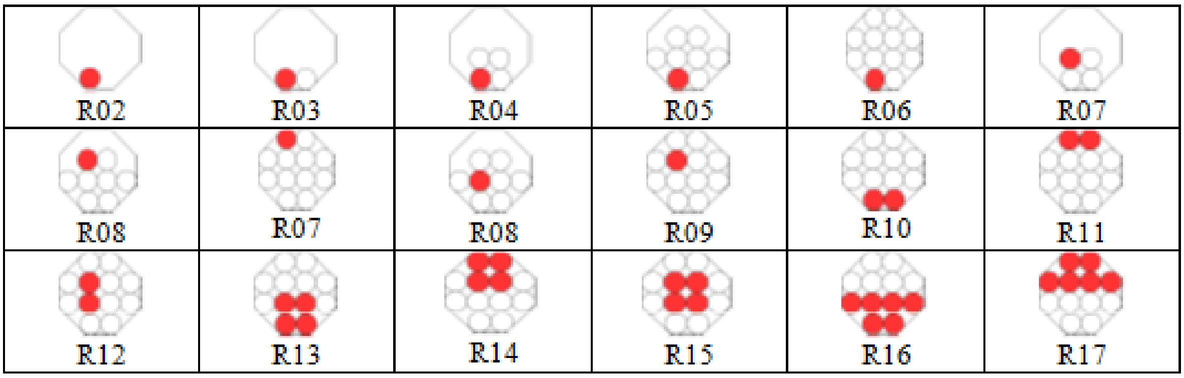

Fig 3: Arrangement of the bundles: broken steel (red), intact steels (white)

The ruptures were simulated by cutting of the steel and subsequent locking of a crack width at about 3 mm. The distance between the probe and the steel was exactly 110 mm. For the evaluation of the fracture results, in particular the measurement results of the residual fields (scan 22 and 23) are important. The signal analysis was performed according to equation (1).

Some measured signals from the arrangement R04 are shown in Figure 4 as an example.

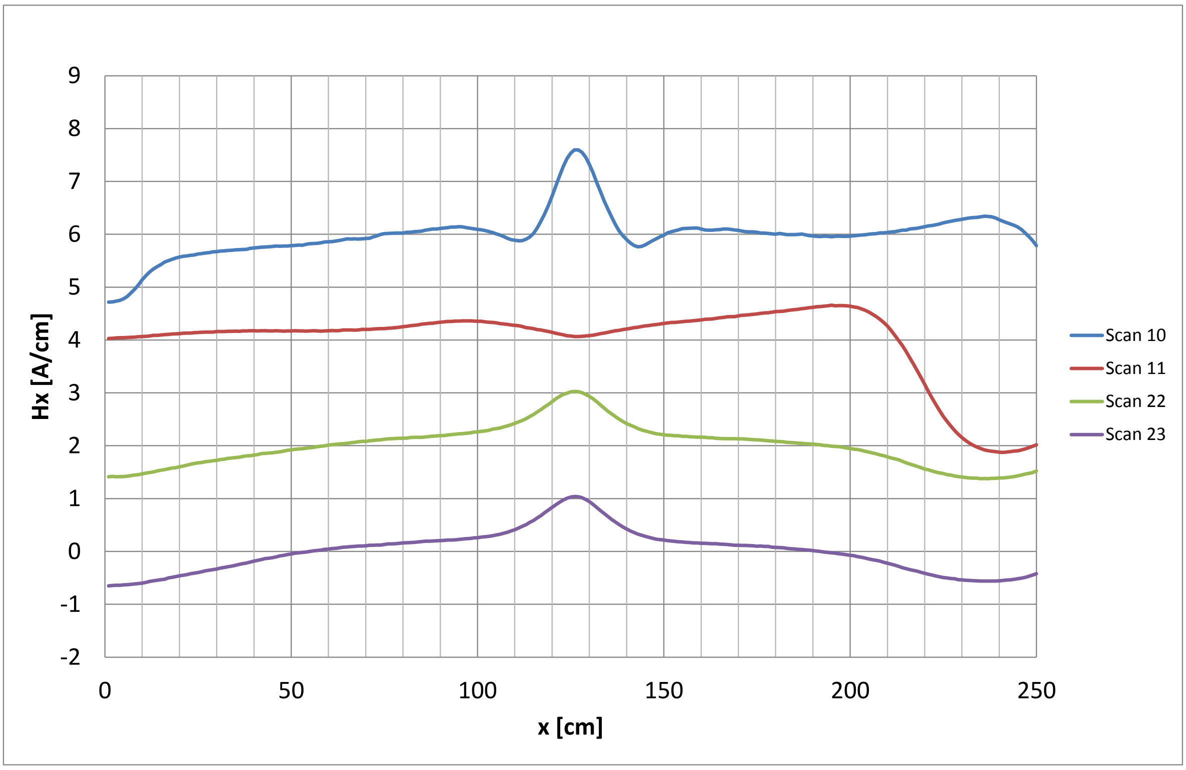

Fig 4: Measured signals from the arrangement R04 for different scans [3]

The rupture amplitudes for all arrangements were taken from the sum of the scans 22 and 23 according to equation (1). The parameter z was choosen as 11 cm.

4. Some examples

The magnetic leakage measurement method is useful for the non-destructive investigation of the integrity of tendons used in prestressed concrete components. The three examples (Fig 5) given in the following show some tasks and recently applied measurement methods to verify the results of the experiments. Figure 5 bottom left shows the special application to measure the undermost strands in the bottom plate and the curved strands in the webs of a hollow-girder bridge with an underbridge inspection unit. This application is unique and offers the possibility to measure nearly every position of a bridge from below if normal access is impossible. Figure 5 top left shows the measurement application on constructions, in this case again a bridge, with a scissor lift. It also allows measuring the underneath and side strands and is one of the regular accessibilities. Figure 5 right shows the application to measure constructions from above with a measurement system designed and constructed at the MPA Stuttgart. It is flexible and can be adjusted for nearly every geometry.

Fig 5: Top left: Bridge near Würzburg, measuring the underneath and side strands with a scissor lift. Bottom left: Bridge in northern Bavaria, measuring the underneath and side strands with an underbridge inspection unit. Right: Bridge near Karlsruhe, measuring the topmost strands with a measurement system designed and constructed at the MPA Stuttgart

4.1 Bridge near Würzburg, measuring the underneath and side strands with a scissor lift

In 2008, corroded and cracked tensioning steels were found in the area of damaged drainage grommets during reconstruction measures at a bridge near Würzburg. The MPA Stuttgart was commissioned with the non-destructive detection of wire strand ruptures by using the magnetic leakage measurement method. Figure 6 shows the prevailing geometry. Due to this geometry, the measurements of the underneath and side strands could only be carried out by means of a scissor lift (Fig 5 top left).

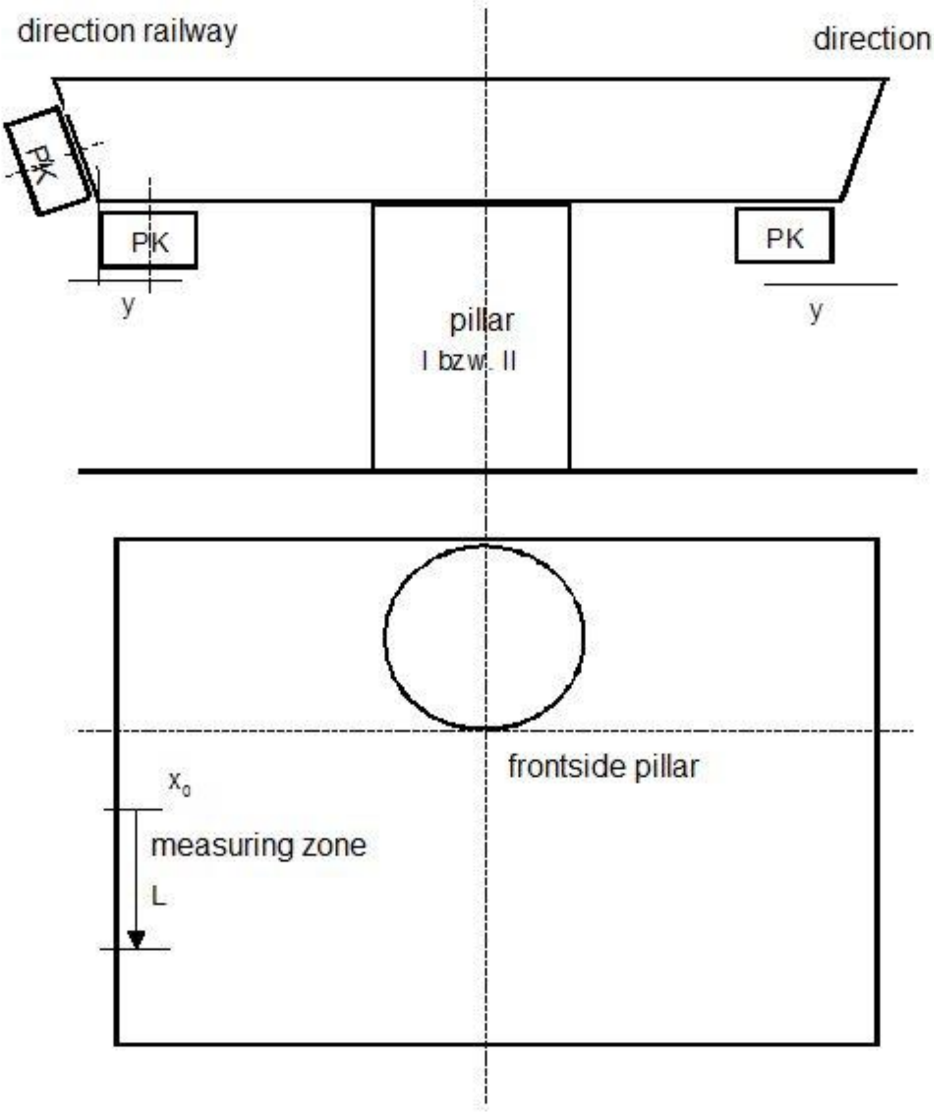

Fig 6: Overview of the measurement area, pillar I and the abutment. Top: Front view. Bottom: Top down view

4.2 Bridge in northern Bavaria, measuring the underneath and side strands with an underbridge inspection unit

The bridge was built in 1961 as a three-section T-beam with a total length of 122 m. Renovation plans required the inspection of the underneath and side strands. Therefore, the MPA Stuttgart was commissioned with the non-destructive detection of wire strand ruptures by using the magnetic leakage measurement method. Figure 7 shows the measurement area of each bridge section and Figure 8 shows the profile of the bridge bars. Due to the fact, that the measurements take place in more than 5 m high over the ground, the measurements of the underneath and side strands could only be carried out by using an underbridge inspection unit (Fig 5 bottom left).

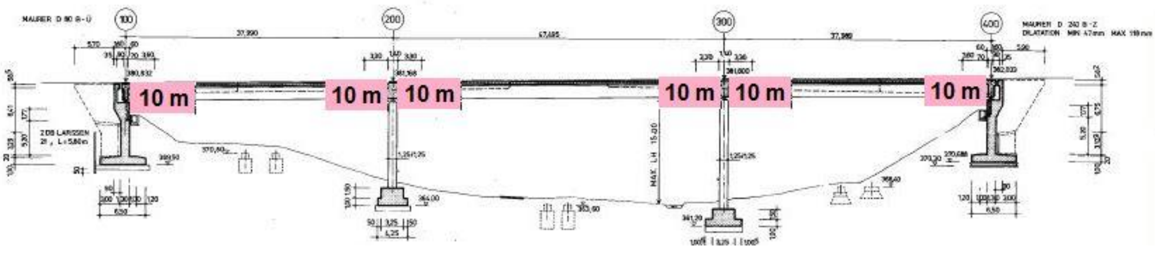

Fig 7: Top view of the measurement area of each bridge section

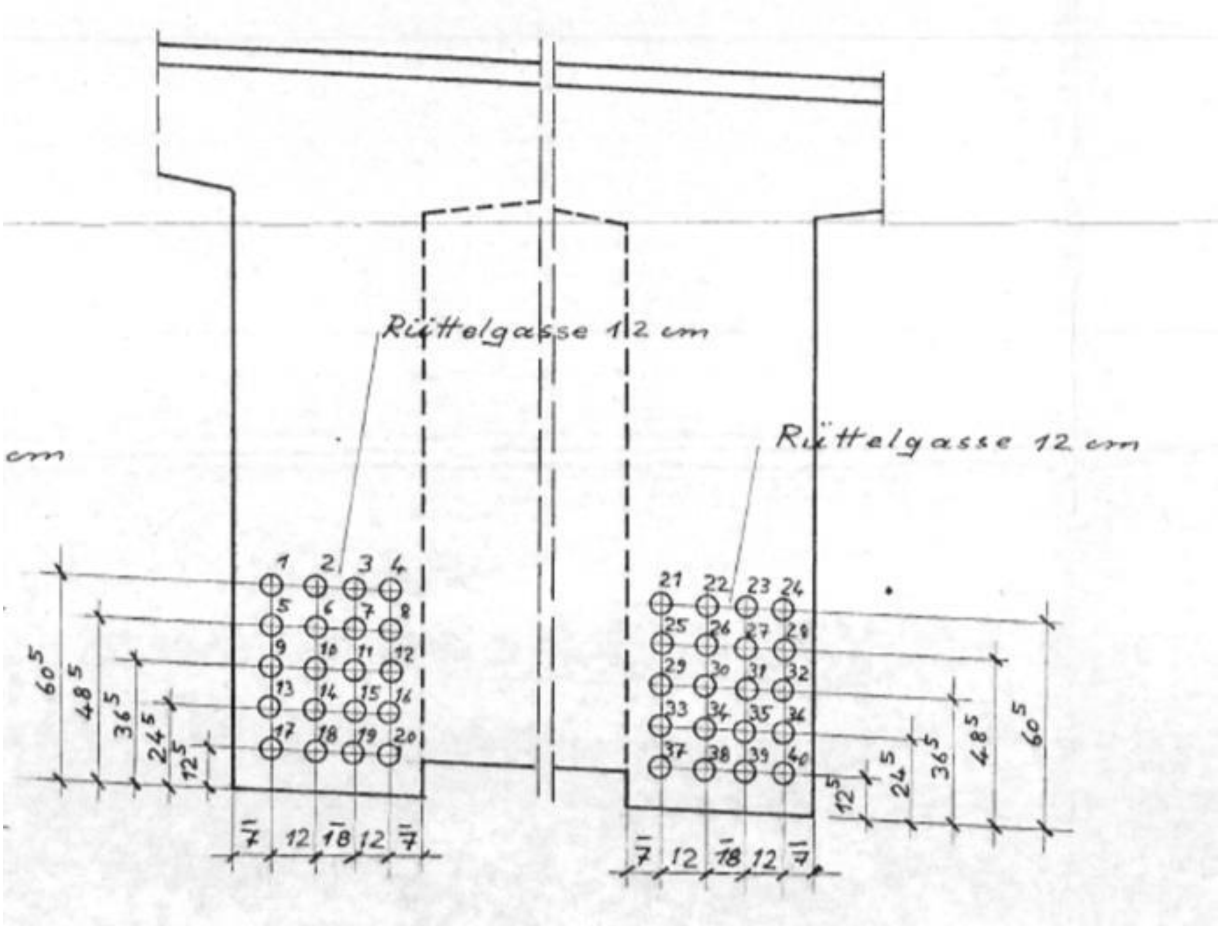

Fig 8: Profile of the bridge bars

4.3 Bridge near Karlsruhe, measuring the above strands with a measurement system designed and constructed at the MPA Stuttgart

In 2015, corroded and cracked tensioning steels were found during reconstruction measures at a bridge near Karlsruhe. The MPA Stuttgart was commissioned with the non-destructive detection of the topmost strands by using the magnetic leakage measurement method. Figure 9 shows the profile of the measurement areas over the maximum points of the strands. The measurements had to be executed from the top of the bridge and that is why we used a measurement system designed and constructed at the MPA Stuttgart (Fig 5 right).

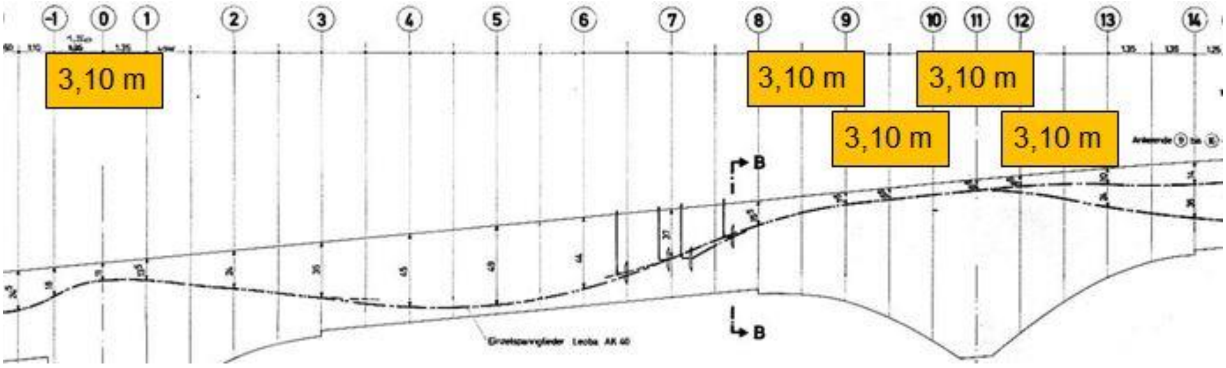

Fig 9: Profile of the measurement areas over the maximum points of the strands

5. Conclusions

These three different applications (Fig 5) of the magnetic leakage measurement method are useful to measure wire strands used in prestressed concrete components, especially of a bridge. The MPA Stuttgart is the only institute in Europe who has this complete range of equipment to guarantee the accessibility to nearly every component.

The sub-section headings (2nd order-head) should be arranged by numbers and sub-numbers, using Times New Roman 10pt and, italic, with 12pt spacing before the heading and 6pt spacing after. Manuscript files must be submitted as Portable Document Format (PDF). Figures and tables should be embedded in the document and not supplied separately.

6. References

[1] Sawade, G.; Krause, H.-J., Inspection of prestressed concrete members using the magnetic leakage flux measurement method - Estimation of detection limit, Springer-Verlag, Berlin, 2007.
[2] Hillemeier, B., Zustandsanalyse von Spanngliedern in Spannbetonbauwerken, Vortrag 6, DGZfP-Fachtagung Bauwerksdiagnose, 2012
[3] Steinfeld, B., Untersuchung zur Bestimmung der Nachweisgrenzen der Detektion von Spannstahlbrüchen in Spannbündeln mit der Methode der magnetischen Streufeld-messung, Diplomarbeit MPA Universität Stuttgart, 2014.