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# Detection of reinforcement in the non-traditional building structures - historical statues

**O Anton, L Vitek, V Hermankova, T Komarkova and P Cikrle**

Department of Building Testing, Faculty of Civil Engineering, BUT in Brno, Veveri 95, Brno, Czech Republic

**Abstract.** During restoration and maintenance of historical buildings, statues and sculptures are often neglected elements in the pre-construction condition surveys, especially in case they are not part of the supporting structure but only an ornamental and aesthetic complement of the architectural whole. The condition of a number of such artworks requires restoration or static assessment from the viewpoint of safety and durability. In the case of statues made of stone, artificial stone or concrete, an inseparable part of the pre-construction condition survey is determining the method of their reinforcement with steel elements, which is, considering the often complex spatial aspects of their surface, relatively complicated. The paper offers some possibilities of its solution on three examples. The diagnostic methods were proposed based on the authors' workplace's long-term experience with the diagnostics of reinforced concrete structures. During the past 10 years, about 1,000 such diagnostics have been performed. These experiences were subsequently experimentally applied to several historical sculptures with great success.

## 1. Introduction

During restoration and maintenance of especially historical buildings, we relatively often face a situation where the structure includes statues or sculptures whose function is mostly not structural, but only aesthetic and architecturally decorative. The condition of a number of such artworks requires restoration or static assessment from the viewpoint of safety and durability. In the case of statues made of stone, artificial stone or concrete, an inseparable part of the pre-construction condition survey is determining the method of their reinforcement with steel elements, which is, considering the often complex spatial aspects of their surface, relatively complicated [1,2].

If we use an analogy from the pre-construction condition surveys of reinforced concrete structures, it is possible to use four different methods [1,2]:

- chopped probes,
- electromagnetic indicators,
- georadar,
- radiography.

In the case of artworks, the chopped probes method is unacceptable in most cases. The use of georadar or electromagnetic indicators is possible but only in the most elementary simple cases where the reinforcement is simple and the structure surface consists of large areas curved as little as possible (the probes of the radar and electromagnetic indicators are designed for use on flat surfaces of reinforced concrete structures). As regards electromagnetic indicators, critical moments of their use are their limited maximum depth and other aspects given by the principle of the method. An effective use of the electromagnetic indicator technology can be illustrated on an example of the reinforcement detection in the sculptures of the sculptural group called "Health" on the building of Zahradníkova 2-8 / Nerudova

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11 in Brno. It is the building of a former Regional Sickness Fund from 1925, and the author of the sculptures was Myslbek's pupil, academic sculptor Václav Hynek Mach. In the sculptures made from artificial stone, we detected only sporadic reinforcement with several smooth reinforcing bars with a circular cross-section of 20 mm, which are insufficient in terms of statics, as is apparent in figure 1.

If the reinforcement of sculptures was more complicated, the method used would probably have failed to yield relevant results.

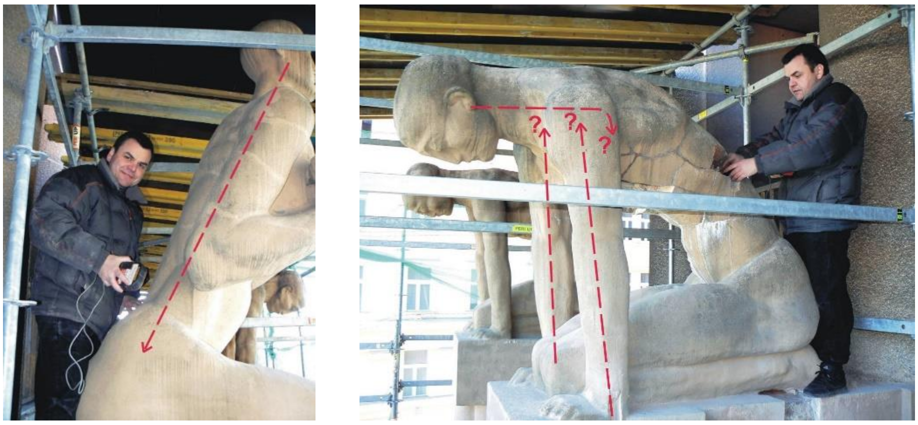

**Figure 1.** Measurement of the position of reinforcement in individual sculptures from artificial stone in the sculptural group called Health. The detection of reinforcement was relatively precise, considering the low number of reinforcing bars. Nevertheless, it was not possible to precisely determine the location and method of anchoring of individual reinforcing bars [3].

Detecting the reinforcement by means of the radiographic method offers substantially greater possibilities. This progressive method (described inter alia in ČSN 73 1376) is based on the utilization of the passage of X-rays, or gamma rays, through the material, where the radiation is attenuated according to the material's thickness and density. The passed-through radiation then hits the radiographic film (or one of the digital recording media), which, after development, shows blackening corresponding to the dose of radiation to which individual parts of the film were exposed. Any inhomogeneities in the irradiated area (metal reinforcement) are clearly displayed in the film by different blackening. The advantage of radiography is its visualization of the internal structure of the object and a possibility to identify even complicated types of reinforcement or holes, etc. [3,4,7].

As a radiation source, it is possible to use a radioactive emitter (Co60) for massive structures, or a technical X-ray for more subtle elements. As regards the Co60 emitter, it field use, especially in urban areas, is complicated, if not impossible, in the context of current safety regulations, and is therefore limited to closed irradiation facilities. As regards the X-ray, there is no problem to perform radiography in the field under certain conditions. The effective use of radiography with an X-ray is described in the following examples.

## 2. Survey of a part of the statue of Archangel Michael in Malešovice

The aim of the survey was to establish the existence or shape of reinforcement in the supplied fragment of the Baroque sandstone statue of Archangel Michael from Malešovice. It was the right hand of the statue broken under the shoulder. There were three other fractures on the fragment, in the elbow, in the middle of the forearm and in the wrist. In the past, these fractures had been repaired in an unknown manner, and at some places cement was added. The tests performed were to verify whether the statue fragment is reinforced at all, both at the fracture points, and outside them.

As a radiation source, we used a macrostructural Andrex CP 490 X-ray – 160 kV. The assessment was performed in the irradiation room of the Radiation Defectoscopy Centre at the Department of Building Testing of the Brno University of Technology. During irradiation, we used exposure parameters which guaranteed an ideal imaging of the potential metal parts in the statue fragment, and chose a higher focal distance (1,250 mm). Radiograms were exposed do Agfa Testix C7 films + Pb in darkroom packaging with the dimensions of 0.3 x 0.4 m placed in cassettes. The exposed films were developed in the laboratory using a standard procedure.

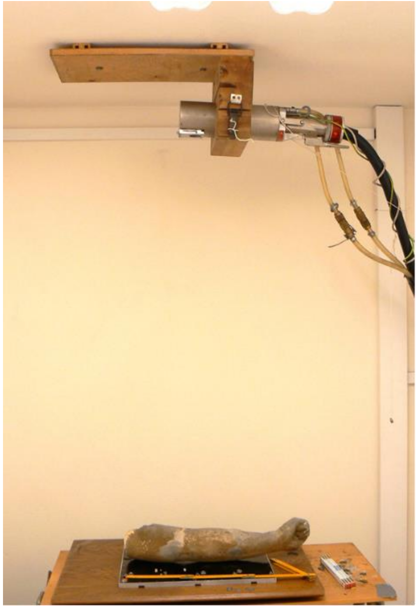

**Figure 2**. Radiography of the arm from the statue of Archangel Michael from Malešovice, above: x-ray tube of the Andrex CP 490 – 160 kV device, at the very bottom: cassette with an Agfa Testix C7 film.

The radiology revealed that the original reinforcement consists of one, probably forged, rod-like element with a diameter of approximately 13 mm. This element originally linked the arm with the corpus of the statue and ended at the elbow level, in the plane of the first repaired fracture. The image of this reinforcing element is well apparent in figure 3 and also in figure 5. The reinforcement is located in the cavity with a diameter of approximately 20 mm which is sealed with sulphur. An additional reinforcement was detected at the point of the repaired fracture in the elbow. The reinforcement consists of two steel reinforcing bars with a diameter of approximately 6 mm and a length of approx. 53 and 55 mm. According to the surface finish of the reinforcement apparent on the radiogram, it is probably a cut piece of the Kari net for concrete.

It is well apparent on the radiograms that reinforcements were inserted into the holes pre-drilled in both fragments, and the holes exceed the inserted reinforcement by approx. 11 - 17 mm. From the image of the pre-drilled holes it is possible to assume that they are either not filled at all, or that they are filled with a material with a substantially lower density than the volume mass of the arm's sandstone. The image of these reinforcing elements is well apparent in figure 3 and 4.

Another additional reinforcement was detected at the point of the repaired fracture in the middle of the forearm. The reinforcement consists of one steel reinforcing bar with a diameter of 6 mm and a length of 70 mm. According to the surface finish of the reinforcement apparent on the radiogram, it is probably a cut piece of the Kari net for concrete.

It is well apparent on the radiograms that reinforcement was inserted into the hole pre-drilled in both fragments, similarly to the additional reinforcement 1. The image of this reinforcing element is well apparent in figure 3 and 4.

**Figure 3**. Radiography of the sandstone arm from shoulder to wrist in geometry 1, view from the x-ray tube (from the focus of irradiation), right picture: the resulting radiogram, well apparent metal connecting elements in both parts of the fracture (in the elbow and in the middle of the forearm) as well as the reinforcement ending in the elbow. The picture clearly shows also the pre-drilled holes for inserting the connecting elements in the fracture points. Also apparent is the hole in which the original reinforcement is placed, filled with sulphur.

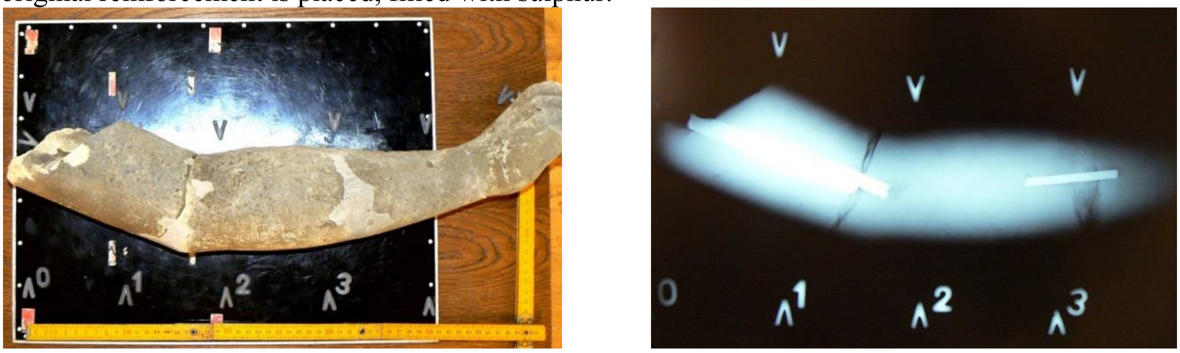

**Figure 4.** Radiography of the sandstone arm from shoulder to wrist in the control geometry 2, view from x-ray tube (from the focus of irradiation).

In the last fracture in the wrist of the arm, there is no reinforcement. Apparently, the joint is connected only by bonding.

As can be seen, radiography allowed for obtaining quite relevant data for an assessment of the damage to the statue and preparation of its restoration.

## 3. Survey of Pieta sculpture

The object of the survey was the sculpture of a musician from the scattering meadow of the cemetery in Přerov. As assumed, the sculpture was made of artificial stone or concrete composite, the aggregate used was not known. The sculpture was apparently reinforced with steel rods with square and circular cross-sections, which was obvious in parts that were damaged by exposure of the sculpture to weather. In these places, there were cracks or parts of the composite had fallen off, and the reinforcement was exposed. Surprisingly, even in these places, no serious corrosion of steel reinforcement was apparent.
The aim of the research was to detect reinforcement in the sculpture (position and shape of reinforcing bars) and simultaneously to localize potential internal cavities in the object.

The sculpture was made from reinforced cement composite. The composite used was apparently a mixture of a cement binder and fine aggregate with an estimated fraction of 0 – 4 mm. The aggregate used was single-sized with a very high volume mass and high content of magnetic particles (a permanent magnet attached to the surface of the composite displayed high attraction).

After consulting a geologist, doc. RNDr. Pavel Pospíšil, Ph.D. from the Department of Geotechnics and Underground Engineering at VŠB TU – Ostrava, we identified the aggregate used, with high probability, as basalt originating from Bílčice area (active quarry). This is also supported by the high volume mass of the cement composite which, in spite of the porosity of the binder, has a wet volume mass of approx. 2700 kg/m$^3$.

The position of reinforcements was determined by rentgenography (radiography with X-ray as the source of radiation). As the source of x-ray radiation, we used a 300 kV technical X-ray called YXLON, the passed through and attenuated radiation was captured with memory films and the Dürr scanning system.

The assessed object was irradiated in various directions across it key parts. During the irradiation it became apparent that considering the extreme type of aggregate used with a high shielding capability, the widths of certain parts of the sculpture (back, pedestal) were on the very edge of, or behind, the possibilities of the X-ray (high width and simultaneously small differences in the surface mass at points with and without the reinforcement). That is why it was possible to irradiate, step by step, only small sections of the sculpture, always with a markedly different exposure parameters suitable for the imaging of reinforcement in the given section. At the same time it is necessary to say that the sculpture's shape was so complicated that the irradiation of certain parts was not possible – it was not possible to determine the axis Radiation source – Object – Memory film without interfering with another part of the object. Examples of irradiation configurations, examples of radiograms and the anticipated position of reinforcement are shown in the following figures.

**Figure 5.** Radiography of an object with such a complicated shape whose individual parts have various widths, requires a number of exposures with different exposure parameters and irradiation angles.

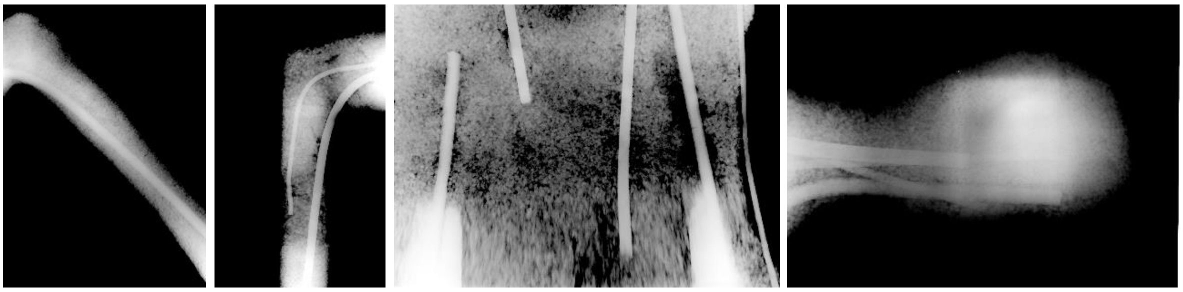

**Figure 6.** Examples of individual radiograms capturing reinforcement of individual sections of the sculpture.

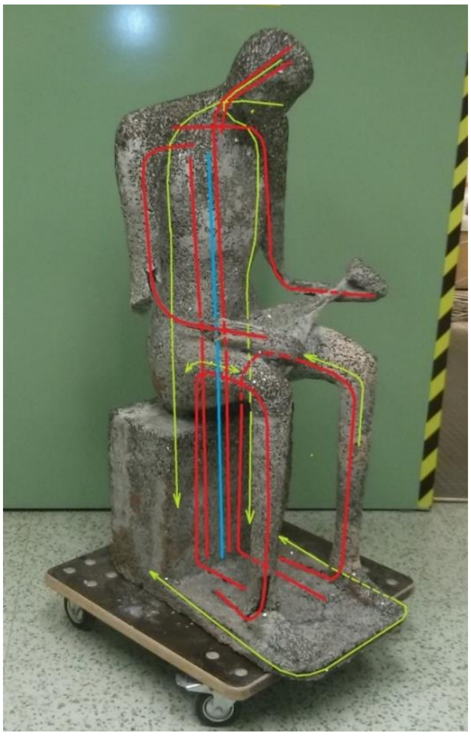

**Figure 7.** The anticipated pathways of the detected reinforcement in the sculpture. Red – rectangular cross-section of 10 x 10 mm, green – circular cross-section of Ø 6 mm, blue – reinforcement with an unknown cross-section with a width (diameter) of min. 15 mm. Reinforcement of the mandolin and fingers with reinforcing bars of Ø 6 mm is not captured in the picture.

## 4. Conclusion

On laboratory examples, the paper presented a method which is ideal in a number of cases for determining the position of steel reinforcement in historical statues and sculptures and which can be used, without much difficulty, also directly on the objects in the field, if they are sufficiently accessible from both sides. The surveys clearly showed that it is possible to apply the methods commonly used in the diagnostics of traditional reinforced concrete structures for the surveys of historical sculptures, the radiographic method with an X-ray in particular provides ideal results. The main problem halting the spread of this method for these kinds of applications is that the equipment needed (suitable sources of radiation) is only available to a very small number institutes, e.g. in the Czech Republic practically only in the workplace of the authors of the article.

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