GAMMA-RAY INSPECTION OF POST TENSIONING CABLES IN A CONCRETE BRIDGE

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ABSTRACT
Gamma-rays have been applied in an NDT campaign aimed at evaluating the condition and the exact location of the internal post-tensioning cables of an existing box-girder concrete bridge. Previous visual inspections to the bridge deck revealed systematic cracking patterns and localized corrosion signs in the post-tensioning ducts. In this paper, the test logistics is described as well as the main results that were obtained.

INTRODUCTION

The N. S. da Guia Bridge (Fig. 1) is a prestressed concrete bi-cellular box-girder bridge with a total length of 250m, divided by 5 spans of 38-3x58-38m. The cross-section height varies parabolically from 1.45m at the spans to 2.9m at the intermediate supports with a resulting slenderness ranging between L/40 and L/20. The deck is 11.84m width supporting one carriageway with two traffic lanes and being supported by laminated neoprene bearing pads which rest on lightly reinforced concrete piers. This was one of the first bridges designed and built in Portugal according to the segmental cantilever construction method. Although the original design dates back to 1973, the construction only began in 1978 and the bridge was opened to traffic in 1980. This bridge is located in the national road EN 201, which was once part of the main route connecting the Spanish region of Galicia with the North-western part of Portugal. In 1998 a new motorway connecting these two regions was opened and nowadays the bridge is crossed mainly by local traffic.

During a routine inspection several cracks were detected in the webs which were not reported in previous inspections. A comprehensive examination program was developed aimed at evaluating: the causes of the observed cracking patterns; the current safety level of the bridge, and; the urgency of eventual strengthening actions. As part of this program, a detailed visual inspection campaign was carried out enabling a complete mapping of the cracking patterns and other anomalies of the bridge deck. Both internal and external inspections were performed. Consistent cracking patterns were observed in the webs and in the bottom slab, exhibiting both longitudinal and transversal symmetry, as depicted in Fig. 2. The bridge was monitored both during a load test and under normal serviceability conditions during a period of one week. Although the cracks exhibited opening a closing movements, no significant deviation could be observed from the calculations performed using a linear elastic model considering uncracked concrete behaviour [8]. In a limited number of predefined locations, a covermeter was used to check if the reinforcement layout coincided with the prescribed in the original design. The agreement was found to be good. Only the most superficial reinforcements, and not the post-tensioning ducts, could be detected with this method. The concrete strength was evaluated by combining the results of NDT methods (sclerometer test and ultra-sounds) with a limited number of tests on drilled cores.

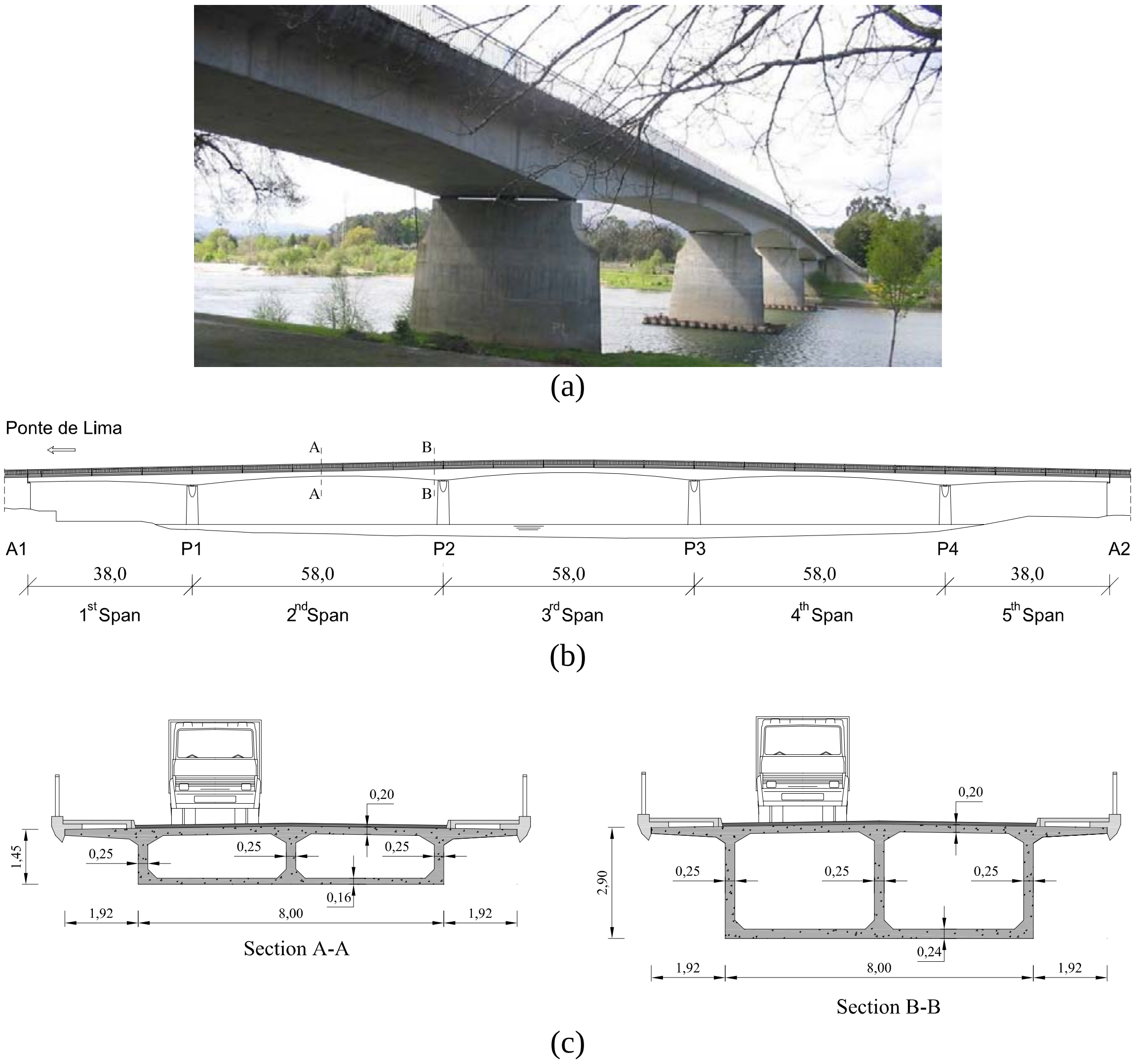


Fig. 1 - N. S. da Guia Bridge: (a) view of the bridge; (b) side elevation and notation; (c) typical cross-sections.

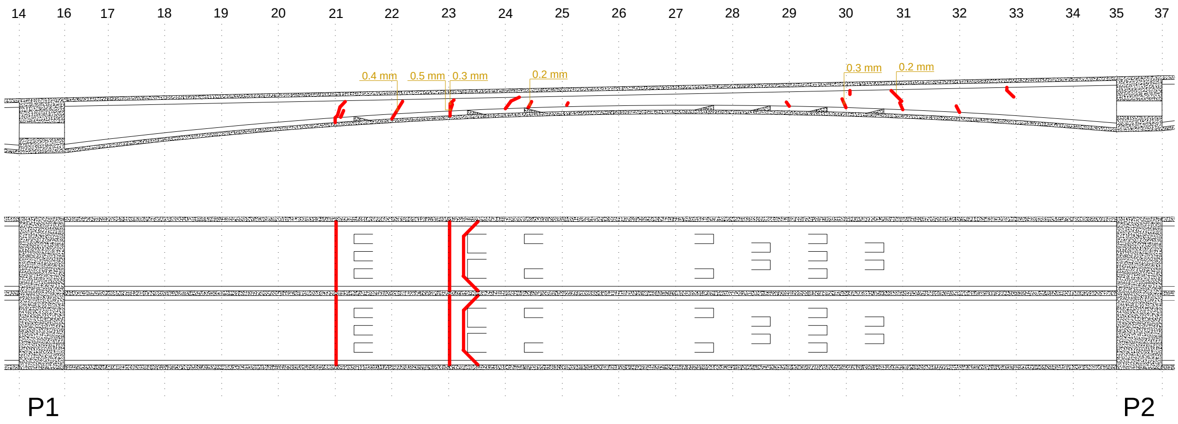
MOTIVATION

Corrosion evidence

Besides minor signs of corrosion in confined areas, mainly related with drainage problems of the deck, and some stirrups not properly protected by an adequate concrete cover, the main concern is related to the state of the embedded prestressing tendons. The holes allowing the movable scaffolding attachment to the deck were not filled with concrete and, in some of them, it is possible to observe corroded metallic ducts containing the bottom continuity tendons, as depicted in Fig. 3. It is also known that, at the time of the construction, the injection of the ducts was a problematic issue and it is likely that it was not properly executed. As these ducts were locally exposed during 27 years, the state of the prestressing tendons is, at the present time, unknown.

Uncertainty regarding the post-tensioning layout

In the original design only the long-term prestressing force required in each cross-section was specified. Definition and detail of the tendon layout were left for the contractor to draw accordingly with the adopted post-tensioning system. According to the bridge owner, the corresponding construction drawings and calculation reports were lost. Only three drawings were available corresponding to the midspan segments of the 2nd, 3rd and 4th spans. Therefore, the reconstitution of the real tendon layout and the corresponding determination of the effective prestressing force were very difficult and subject to considerable error due to the following facts:



(a)

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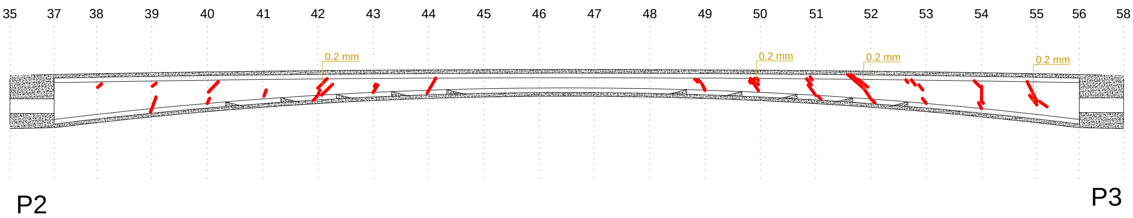


(c)

(d)

Fig. 2 -

- Apart from the bottom slab continuity tendons, the anchorages are not visible and accessible to confirm the assumptions that inevitably had to be made;
- A close observation of the formwork marks on the concrete surface inside the box-girder and the information contained in the construction log book reveal that the construction sequence defined in the original design was not strictly followed. Therefore, the prestressing forces calculated in the original design may not constitute a reliable basis;

- The use of precast concrete segments was defined in the original design. In these circumstances the time dependent alteration of the sectional forces due to concrete creep is lower than in the adopted in-situ segmental cantilever construction method. It was unclear if a re-calculation of the bridge had been made in order to account for the different construction sequence and procedure.

Fig. 3 - Prestressing ducts exposed at the bottom slab.

Owing to the corrosion signs observed in some exposed ducts, the condition of the post-tensioned tendons is uncertain and a special inspection is thought essential for clarifying this issue. Moreover, at the time this inspection work was being performed, no information regarding the prestress installed in the bridge was available due to the fact that the construction drawings with the real tendon layout were assumed to be lost. If performed with resource to destructive methods a complete examination of the tendons would be unfeasible. Therefore, the use of NDT methods was investigated.

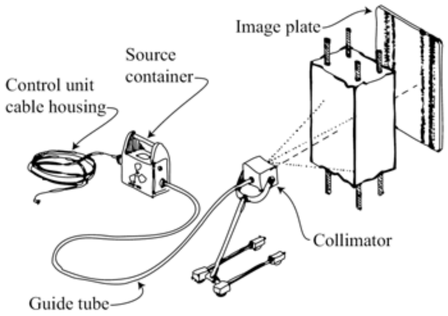
NDT USING GAMM-RAYS

When focusing on a specific case, it can be noted that in most instances NDT methods provide only partial answers. In these cases, the contribution of a second technique must necessarily uphold the diagnosis, and the use of complementary NDT techniques is advised. In the particular case of post-tensioning tendons, a set of complementary technologies have been developed which retrieve different levels of information, like the ground penetrating radar (GPR), impact-echo (IE) techniques, remnant magnetism (RM) method or magnetic leakage flux measurement [7; 9], and the radiographic methods [1; 2; 4; 5]. In this particular case, not only the evaluation of the tendons condition was required but also the characterization of the strand type, duct size and number of strands per tendon was of interest. It can be concluded that a combination of at least two techniques is advised: the GPR to locate the tendons and to define the tendons coordinates; and a gammagraphic study on selected zones in order to evaluate the tendons condition, to perform the tendons characterization and to solve eventual ambiguities regarding the tendon layout raised during the GPR inspection.

Experimental setup

A preliminary gammagraphic study on some selected spots of the deck was performed which was aimed at evaluating the logistics required for such an operation, so that a complete inspection could be planned. The work was a collaborative project of LABEST and of the Argentina based company THASA (Tomografia de Hormigon Armado, S.A.). In this preliminary campaign the field work duration was restricted to one day.

In order to meet the required safety measures, the in-situ application of gamma-rays in most practical cases is facilitated if low-energy, low-activity sources such as ^{192}Ir are used. In the present case, the maximum thickness of the cross-section elements is 25 cm, which makes it feasible to use such a source. It must be noted that recent developments in computed radiography (CR) equipment introduce new possibilities concerning the competitiveness of this technique. A CR system employs reusable phosphor image plates that are read with a scanner. The use of portable scanners allows obtaining results in-situ eliminating the chemical development process of the films. Relative to conventional radiography, CR plates provide superior range of detected gamma-ray intensities and higher detection efficiency, implying a significant reduction of the exposure times or the use of weaker sources [5]. The radiation safety measures and the time required for performing an inspection can be diminished, thus decreasing the associated costs. Moreover, CR also opens new perspectives concerning the digital treatment and analysis of the obtained images.



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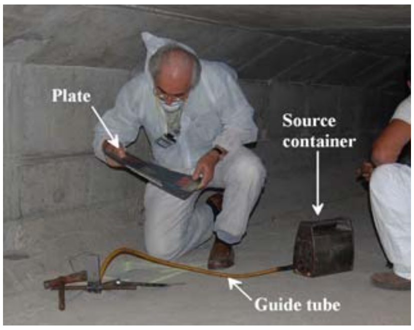


(b)

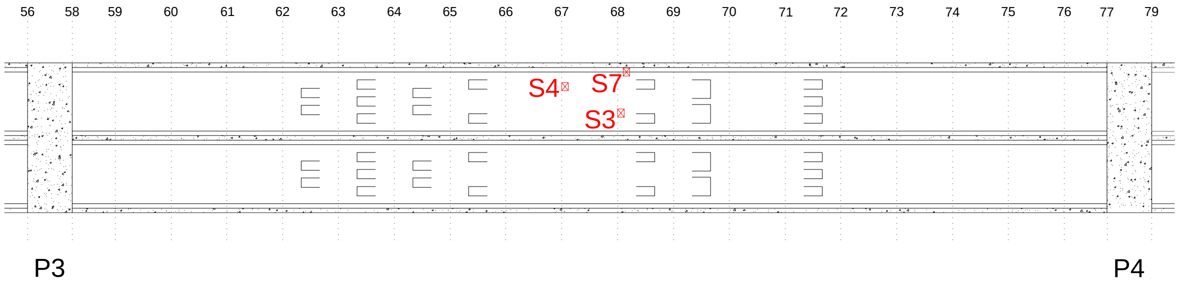

(c)

Fig. 4 - Gamma-ray testing: (a) Schematic representation of a typical experimental arrangement (b) View of the source container, guide tube and image plate during the test; (c) plate positioned in the web.

In this study a radioactive ^{192}Ir source with only 20Ci was used. The source is kept inside a special container with a Uranium shield. For performing an irradiation, the source is placed at the tip of the guide tube by remote control (Fig. 4). Conventional films were still used because no local provider for a CR system could be found. Therefore, the required exposure times led to the fact that only 7 gammagraphies could be taken in one working day, including the necessary time for their chemical development in the laboratory. The films were placed inside flexible cassettes which contained thin lead foils designed to improve image contrast by filtering the scattered radiation. Care was taken at all times to meet radiological protection and safety requirements in accordance to the International Atomic Energy Agency (IAEA) regulations. Acceptable radiation dose rates were achieved at a distance of approximately 10 meters. Outside the box-girder, dose rates well bellow the acceptable levels for general pubic were measured. It is to be noted that gamma radiation from radioactive sources induces no radioactivity on the irradiated elements nor produces any unwanted effects on these elements.

In Fig. 5 and Fig. 6 some of the sectors where the measurements were taken are identified. Each measurement covers an area of 45 x 35 cm, which is defined by the dimensions of the film. Sectors 1-4 and 7 are located in the bottom slab and sectors 5 and 6 in the central web. For the web measurements, thin wires inserted through existent holes were used as reference for the correct positioning of source and plate on each side of the web, as depicted schematically in Fig. 7 (a). In the case of the bottom slab measurements, an especially designed tool, see Fig. 7 (b), was used in conjunction with the existing 9 cm holes. This tool made it possible to position the source beneath the floor in a very inexpensive way when compared to the alternative of costly scaffoldings or other heavy machinery. It consists of two bars, joined with a hinge, which in its quasi-straight position (left hand side of Fig. 7 (b)) is moved down through the hole. By pulling a cable once the hinge is beyond the hole, the lower arm is lifted to reach the horizontal position depicted on the right side of Fig. 7 (b), so that the source is set facing the plate on the upper side of the bottom slab. Both the vertical and horizontal positions of the source are adjustable.

The application of mathematical algorithms for the quantitative analysis of the data extracted from the gammagraphies requires special hardware for a precise characterization of the relative positions of the source, object being analysed and recording means. This type of hardware has been developed and patented by THASA [6]. Due to budget constraints and to the preliminary character of this work, this hardware was not brought from Argentina. Therefore, the relative positions were hand measured, which increases the error involved in the determination of the coordinates of the observed elements.



(a)

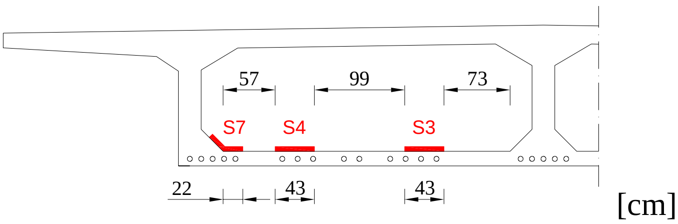


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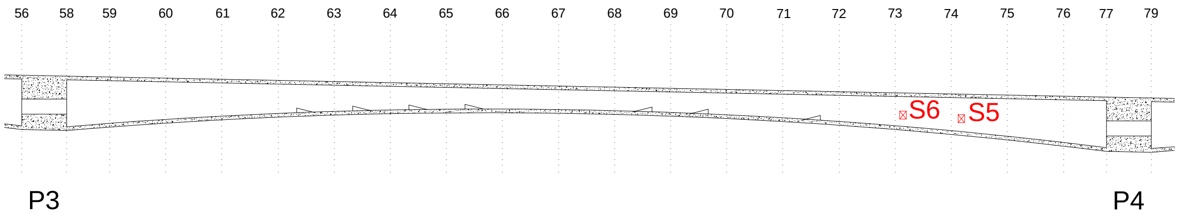
Fig. 5 - Sectors where measurements were taken: (a) sectors 3, 4 and 7 in the bottom slab of the 4th span; (b) corresponding positioning in the box-girder with the expected cables location.



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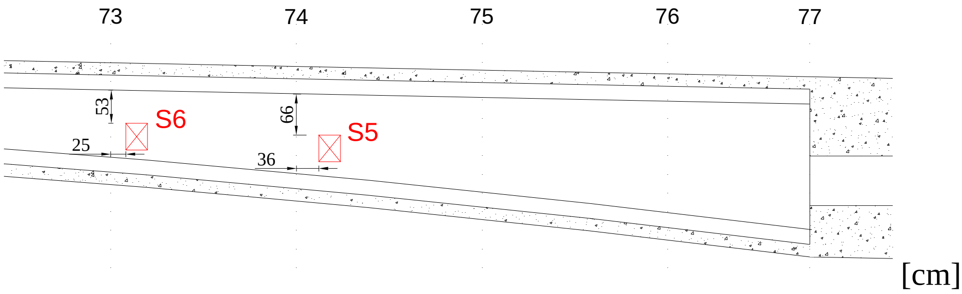

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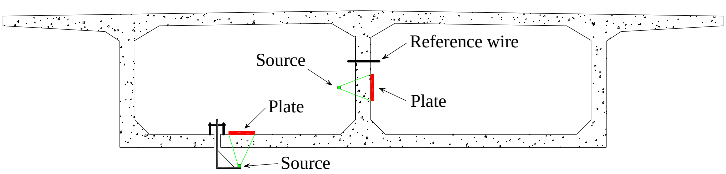
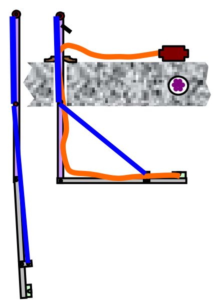
Fig. 6 - Location of the sectors where measurements were taken: (a) sectors 5 and 6 in the central web; (b) corresponding positioning in the box-girder.





(a) (b)

Fig. 7 - Experimental setup: (a) Bridge cross section showing the two source-plate arrangements used in this work; (b) Sketch of the tool designed to position the source beneath the bottom slab using pre-existing holes.

Results

All the obtained gammagraphies show one or more ducts with cables inside plus various ordinary reinforcing bars. The quality of the images makes it possible to see details such as the duct edges, individual strands and even individual wires. The image quality of the photographs shown here is necessarily reduced with respect to the original gammagraphies. These photographs were obtained with a pocket digital camera and with the gammagraphies placed on back lit translucent plates. Image parameters have been adjusted to improve some features of these photographs at the expense of others, to improve image contrast.

In all the 7 gammagraphies no grouting defects were observed nor signs of wire breaks or section loss due to corrosion. According to the THASA report [3] where the quantitative analysis of the obtained gammagraphies is performed, the ducts have 55 mm diameter and the strands were confirmed to be 0.5''. Regarding the number of strands per duct, not all the strands could be identified due to their relative positioning in the duct. In Fig. 8 the gammagraphy corresponding to sector S3 is depicted. Three tendons can be identified together with upper and bottom reinforcement grids. In Fig. 9 the gammagraphies of the web sectors are depicted and cantilever tendon is identified in each gammagraphy. The bright rectangle near the centre of the gammagraphies corresponds to the image of an external element used for ID purposes.

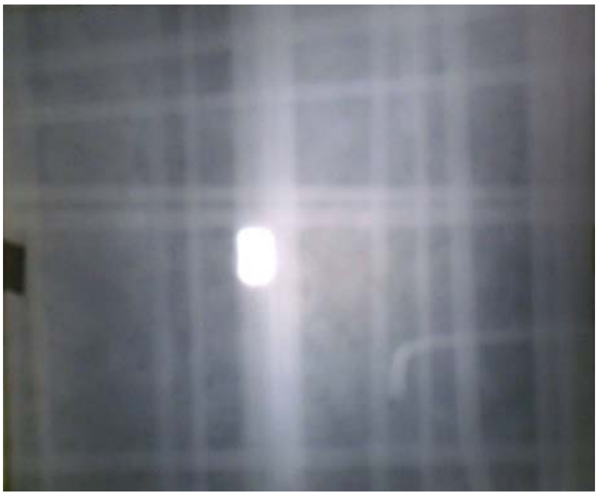


Fig. 8 - Gammagraphy of sector S3

(a) Sector S5

(b) Sector S6

Fig. 9 - Gammagraphies of the web sectors.

CONCLUSIONS

This paper discusses work undertaken to inspect the N.S. da Guía bridge near the town of Ponte de Lima in northern Portugal. Owing to the corrosion signs observed in some exposed ducts, the condition of the post-tensioned tendons was uncertain and a special inspection was thought essential for clarifying this issue. In this particular case, not only the evaluation of the tendons condition was required but also the characterization of the strand type, duct size and number of strands per tendon was of interest. Following the application of GPR to locate the tendons and to define the tendons coordinates; it was decided to use the gammagraphic method to study selected zones in order to evaluate the tendons condition, to perform the tendons characterization and to solve eventual ambiguities regarding the tendon layout raised during the GPR inspection. The results show that this method is an appropriate tool to obtain the type of details whose resolution was the motivation for this work including the precise location and size of the metallic elements such as the internal post-tensioning cables of this box-girder concrete bridge.

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REFERENCES

[1] Dérobert, X., Aubagnac, C., and Abraham, O. (2002). "Comparison of NDT techniques on a post-tensioned beam before its autopsy." *NDT&E international*, 35, 541-548.

[2] Frigerio, T., Mariscotti, M. A. J., Ruffolo, M., and Thieberger, P. (2004). "Development and application of computed tomography in the inspection of reinforced concrete." *Insight*, 46(12).

[3] Mariscotti, M. A. J. (2008). "Gammagraphic Study of the N.S. da GUIA bridge." THASA, Buenos Aires.

[4] Mariscotti, M. A. J., Jalinoos, F., Frigerio, T., Ruffolo, M., and Thieberger, P. (2008). "Gamma-ray imaging for void and corrosion assessment in PT girders." *NDE/NDT for Highways and Bridges - Structural Materials Technology (SMT)*, Oakland.

[5] Mariscotti, M. A. J., Jalinoos, F., Frigerio, T., Ruffolo, M., and Thieberger, P. (2009). "Gamma-Ray Imaging for Void and Corrosion Assessment " *Concrete International*(November 2009), 48-53.

[6] Mariscotti, M. A. J., Thieberger, P., Frigerio, T., and Ruffolo, M. (2007). "Method and device for improving tomographic determinations, particularly suitable for inspection of steel reinforcement bars in concrete structures." Tomografia De Hormigon Armado S.A., US patent office, application number PCT-US2007/2286.

[7] Mietz, J., and Fischer, J. (2007). "Evaluation of NDT methods for detection of prestressing steel damage at post-tensioned concrete structures." *Materials and Corrosion*, 58(10), 789-794.

[8] Pimentel, M., Santos, J., and Figueiras, J. (2007). "Monitoring and Detailed Modelling for extending the Lifespan of a 30 years Old Prestressed Concrete Bridge." *Structural Faults & Repair 2008: 12th International Conference*, Edinburgh.

[9] Walther, A., and Hillemeier, B. (2008). "Fast NDT localisation of prestressing steel fractures in post-tensioned concrete bridges." *Structural Faults & Repair - 2008*, Edinburgh.