Gamma-ray imaging for void and corrosion assessment in PT girders

M.A.J. Mariscotti[a], F. Jalinoos[b], T. Frigerio[a], M. Ruffolo[a] and P. Thieberger[a]

[a]THASA.
2017 Reclus, Boulogne, BA 1609, Argentina
[b]Federal Highway Administration
6300 Georgetown Pike, Malean, VA 22101

Abstract

As an extension of the reinforced concrete tomography technique, gamma rays have been successfully applied for the assessment of voids and corrosion in concrete structures. In this paper, some examples are given that illustrate the advantages of using this technique, especially in the case of PT girders. Results obtained in the Zárate bridge in Argentina are discussed in some detail.

INTRODUCTION

Reinforced Concrete Tomography has been extensively used in recent years to determine positions and diameters of rebars with the precision required for verification of concrete structures [1, 2]. The technique uses gamma rays to illuminate sections of beams, columns, slabs, etc. and sensitive films to record the transmitted rays [3]. The 3D reconstruction of the reinforcing bars in the sections examined is obtained from the subsequent analysis of the data recorded in these gammagraphies. Since gammagraphies, like X-rays, provide "pictures" of the interior of the irradiated volume other aspects of interest, other than locating rebars, can be investigated. Of particular importance and current interest is the detection of corrosion in steel elements (rebars, wires, cables) and voids in the concrete matrix of PT ducts. The "picture" quality of a gammagraphy makes this technique superior to any other in use today for addressing these problems.

In this paper we discuss the use of gamma rays to assess corrosion and voids in general and then discuss some of the results obtained in the study of a large PT girder of the Zárate bridge in Argentina [4].

CORROSION AND VOID ASSESSMENT

The upper part of Fig. 1 shows the gammagraphy of a corroded rebar [5]. The effect of corrosion in a rebar is to change metal into oxide, the latter being of less density. The absorption of gamma rays, being sensitive to density will show the loss of metal in a gammagraphy as a change of rebar diameter. Since the amount of corrosion varies along the rebar length, the phenomenon is seen in a gammagraphy as a change of diameter at different sections.

A quantitative analysis of the extent of the corrosion in terms of loss of rebar section can be done by plotting the position of "edge" pixels along an axis parallel to the bar. Edge pixels define the bar profiles and correspond to the points of maximum slope in the gray level distribution along an axis perpendicular to the bar main axis for each section. The maximum slope can be found by software methods [6].

The plots in Fig. 1 show the edge pixel positions in terms of distance to the "average center" of the bar (upper plot) and their differences (lower plot), along the length of the bars.

The data in the lower plot correspond to the defects in the projected diameters relative to the expected value (white straight line). The accuracy of this measurement is estimated at 0.3 mm.

Likewise voids in concrete can also be precisely ascertained. The left hand side of Fig. 2 shows the gammagraphy of a concrete block with an artificially generated void of a well known shape inside, that exhibits the extension of the void in the plane perpendicular to the radiation, while the plots on the right hand side corresponds to the "depths" of the void in the different planes parallel to radiation, obtained with 1 cm^3 gamma-ray spectrometer.

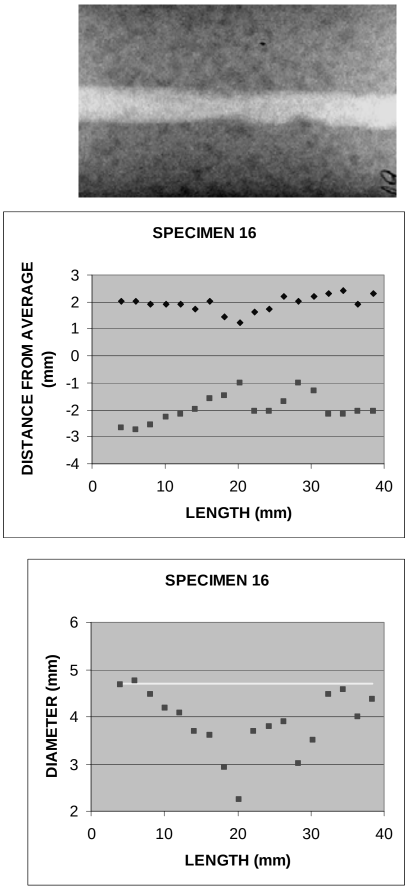

Fig. 1. Gammagrahy of a corroded bar in a concrete block [5]. The plots show the edge pixel positions in terms of distance to the "average center" of the bar and their difference, along the length of the bars.

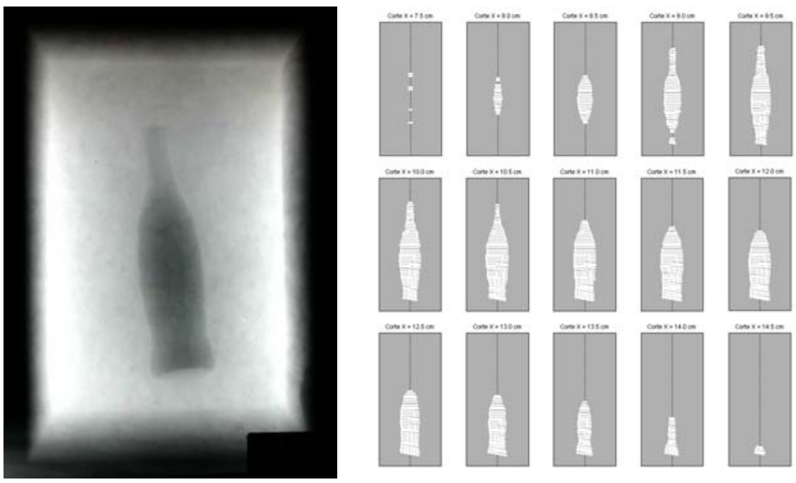

Fig. 2. Example of void determination with gamma-rays. The left hand side shows a gammagraphy of an empty Coca Cola bottle (a universally recognized shape) which exhibits the extension of the void in the plane perpendicular to the radiation, while the plots on the right hand side corresponds to the "depths" of the void in the different planes parallel to radiation, obtained with 1 cm^3 gamma-ray spectrometer.

RESULTS OF GAMMA-RAY MEASUREMENTS IN A PT GIRDER

An inspection of a PT girder was carried out in the Zárate bridge (Fig. 3). This is a two cable-stayed road and railway bridge in Argentina, crossing the Paraná River between the Buenos Aires and Entre Ríos provinces. The bridge has a suspended length of 550 m (1,804 ft), with a main span of 330 m (1,083 ft). Its pylons are 110 m (361 ft) high, and its deck depth is 2.6 m (8.5 ft). It was built between 1972 and 1978 on a design by Italian engineer Fabrizio de Miranda, and refurbished in 1998. The road link has four lanes. The main span is 50 m (164 ft) over the water level of the Paraná, which allows the passage of very large ships

Fig. 3. View of the Zárate Bridge in Argentina

One of the 30 cm (1ft) thick girders at the West end of the bridge (left in Fig. 3) with a total of 6 ducts was inspected for voids in the grouting using gamma-rays from a 93Ci ^{192}Ir source. Gammagraphies were taken in the positions indicated in Fig. 4. As a reference, distance between 1 and 2 is 70 cm (2.5 ft).

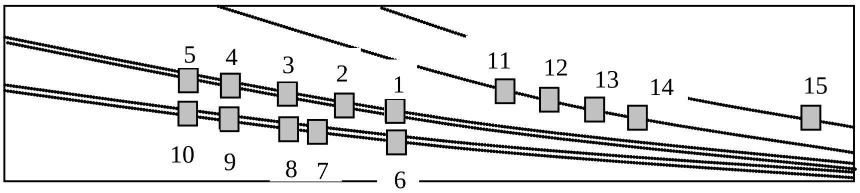

Fig. 4. Schematic location of the gammagraphies taken in this work

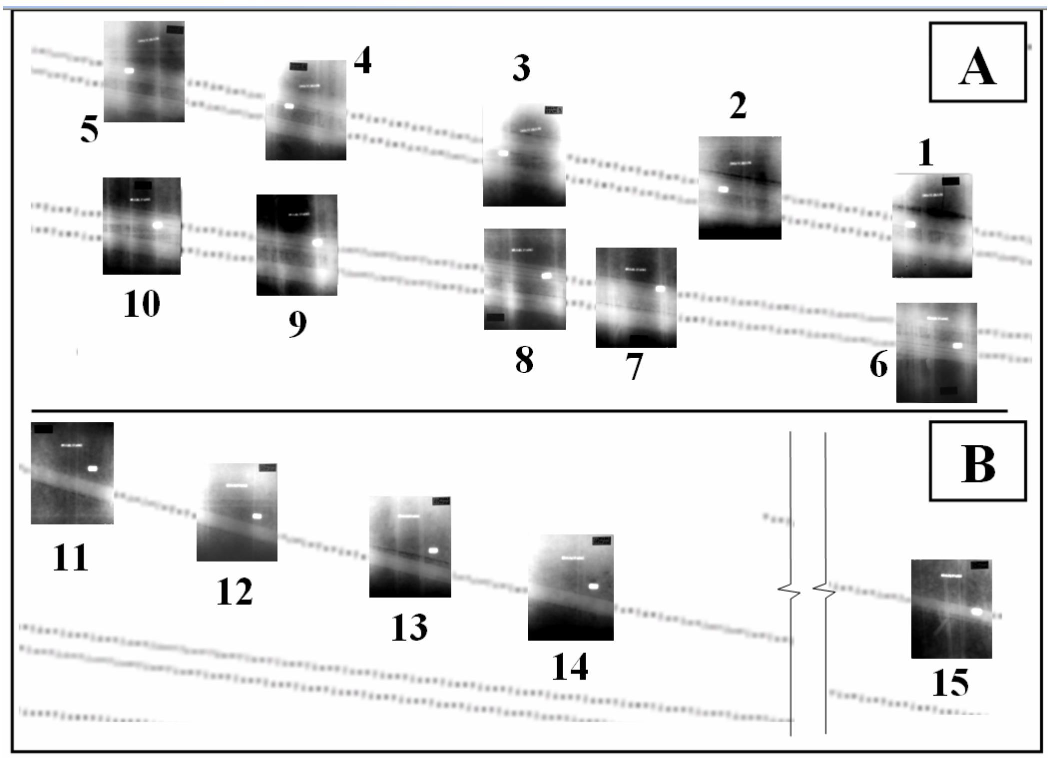

Fig. 5. Overview of the gammagraphies obtained in this work. Frame B corresponds to the right part of the girder (see Fig. 4). As discussed in the text, gammagraphies 1, 2, 3 and 13 exhibit defective grouting, most notably in 1.

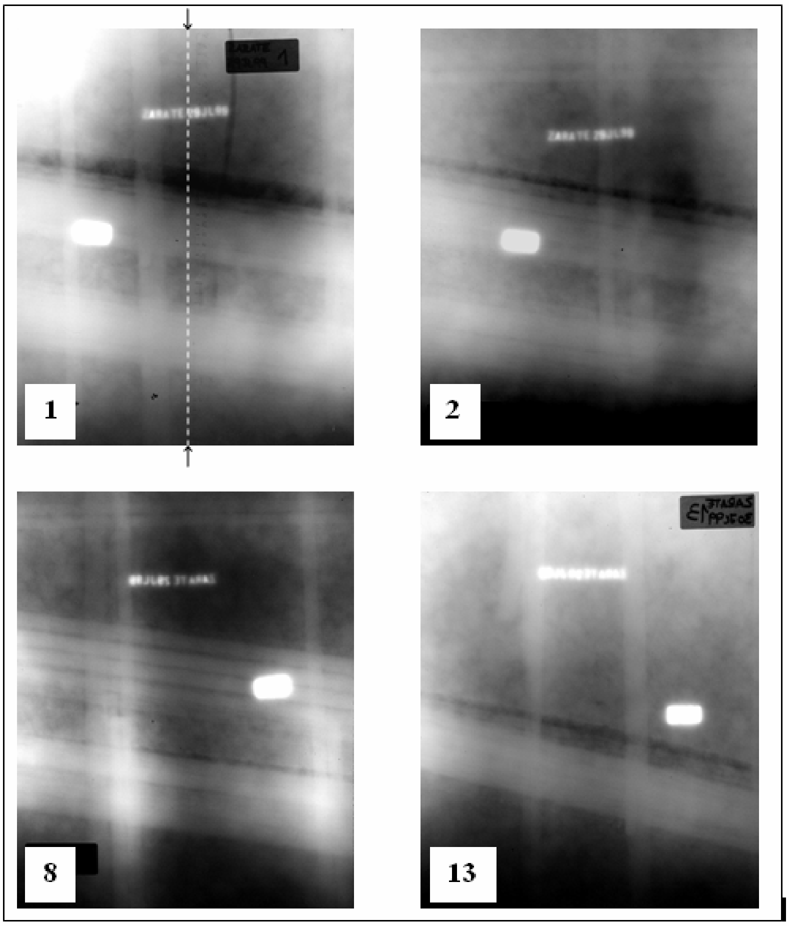

Fig. 6. Illustrative examples of the measurements carried out in Zárate bridge. Gammagraphy 1 shows a severe case of void in the grouting of the upper duct. In 2, which is the next gammagraphy towards one of the ends of the girder, this defect is still present but diminished. In the upper duct in 8 the different bundles of wires can be appreciated and in both the lower duct of 8 and upper duct of 13 thin black lines show slight voids. These gammagraphies also show stirrups as white vertical bands. The cables and ducts diameters are ~2" and 3", respectively.

Fig. 5 gives an overview of the 15, 35 x 43 cm (14"x 17") gammagraphies obtained in this work and Fig. 6 exhibits enlargements of four of these gammagraphies for the purpose of the following discussion.

Gammagraphy 1 shows a severe case of void in the grouting of the upper duct. In 2, which is the next gammagraphy away from the center of the girder, this defect is still present but less marked than in 1. Also minor voids in the upper part of ducts in gammagraphies 8 and 13 are discernible.

These voids can be analyzed quantitatively in order to assess their size. As an example, we shall discuss the case of gammagraphy 1.

Fig. 7 shows the photographic density along the vertical dotted line in Fig. 6 (plate 1). The coordinate Z goes from the bottom up in the gammagraphy as shown in Fig. 6. “Valleys” in this plot at Z ~ 10 and 22 cm correspond to the lower and upper ducts, respectively and the peak at ~ 27 cm correspond to the void in the grouting of the upper duct.

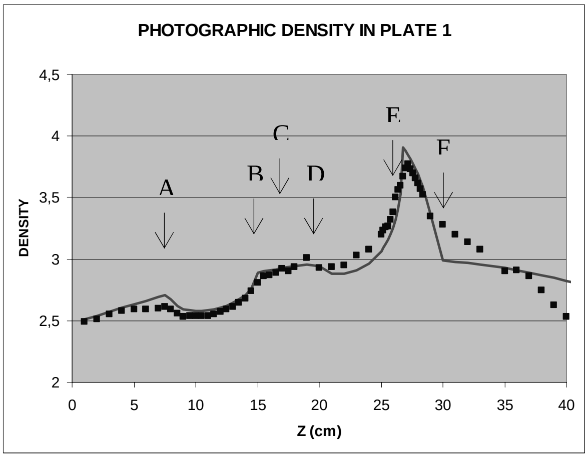

Fig. 7. Photographic density along dotted line in plate 1. A-B: lower cable; A-C lower duct; D-E: upper cable; D-F: upper duct (see Fig. 6)

These data were fitted (gray line) to the mathematical expression that describes the experimental arrangement used in these measurements: Gamma-rays from an ^{192}Ir source at 60 cm from the plate traversing a 2.5 g/cm^3 concrete block with two 7.2 cm internal diameter ducts in the center of the block, both with 5.2 cm diameter cables inside. The only significant adjustable parameters in this calculation were: the grouting density in the upper duct (0,3 g/cm^3) and the density of both cables (set to 3.5 g/cm^3). The grouting density in the lower duct was assumed equal to that of concrete.

The following conclusions can be drawn from these results: a) At the maximum photographic density, the depth of the void is a little more than 6 cm equivalent to about 5 cm of air since the fitted density in this volume is 0.3 g/cm^3; b) Considering that the maximum density of a cable composed of bundles of steel wires is about 80% of steel density, then the fitted density of 3.5 g/cm3 indicates that the cables packing factor is about 55%; c) The difference between calculated and measured values at Z ~ 25 cm corresponds to a steel thickness deficiency in the top wires of the upper duct of up to 7 mm.

In the other gammagraphies shown in Fig. 6 no steel thickness deficiency signaling corrosion has been observed beyond the measureement uncertainty of 0.3 mm.

SUMMARY AND CONCLUSIONS

This paper describes the application of the RCT technique, based on gamma rays, to the detection of corrosion and voids in reinforced concrete structures. In particular results obtained in the inspection of PT girders in Zárate bridge are presented and discussed. It is shown that gamma-ray imaging is a very useful tool for this type of studies in bridges and other large concrete structures.

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