Stresses quantification in structural steel bars by X-Ray diffraction technique. PART II: On site measurements

S. Sánchez Beitia [1], L. Ramos [2], P. Lourenço [2], J. Elices [3], I. Lombillo [3] and L. Villegas [3]

[1] Univ. del País Vasco, E.T.S. de Arquitectura, Plaza de Oñate, 2, 20018 San Sebastián (España)
[2] Univ. do Minho, Dpt. da Engenheria Civil. Campus de Azurem, Guimaraes (Portugal)
[3] Univ. de Cantabria. E.T.S. de I.C.C. y P. Dpt. de Ingeniería Estructural. Avda. Los Castros s/n, Santander (España)

Abstract. One of the most interesting challenges of the scientific community in the analysis structural field is the development of new on site experimental techniques absolutely non destructives. Paper deals about the X-Ray diffraction technique for obtaining real stress states in service steel bars. In this sense the paper represents an innovation for on site applications.

1 Introduction

All the elaboration processes (forming and finishing) of the metallic pieces or elements introduce a set of stresses in the materials. A part of them has thermal origin whereas another part has mechanical origin. A proportion of these stresses is remaining in the material and they are denominated the residual stresses. In some cases its level can be similar to the yield stresses of the materials. For instance Fig. 1 shows the internal profile of residual stresses into a section of a steel bar. By equilibrium conditions the area with sign under the stresses profile has to be zero. Most of the cases the residual stresses are confined very close to the surface of the element (a< 0.6 µm and b < 1 mm independently the diameter of the bar in **Fig. 1**). It must be added the value of the residual stresses to the values of the design stresses in order to know the true level of stresses of a structural element.

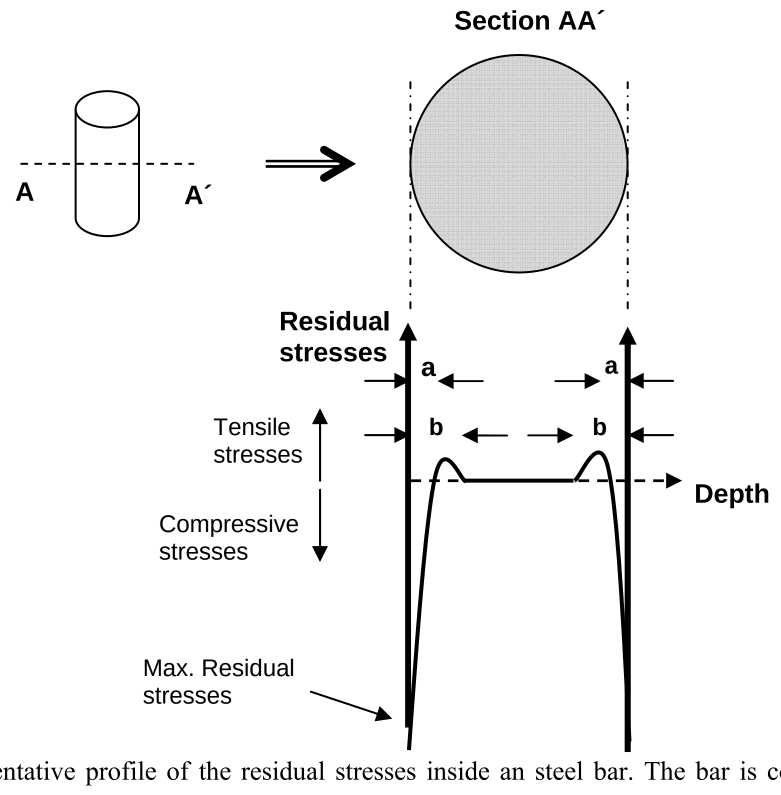

Fig.1 Representative profile of the residual stresses inside an steel bar. The bar is considered without external loads..

X-Ray diffraction technique is widely applied for residual stresses measurements in metallic materials within several scientific fields. In many situations they represent great benefits for the material behaviour because superficial compressive residual stresses delay the crack initiation process due to corrosion or fatigue. In the nuclear power plants or chemical factories it is imperative the quantification of the residual stresses in all the critical elements or pieces. Since many years ago (twenty five at least) the level of residual stresses in metallic materials can be controlled by means of appropriate treatments (shot peening for instance). X-Ray diffraction technique is in these fields the most proven non-destructive method to obtain the exact level of residual stresses. Nowadays the technique has not been very applied in building construction or civil engineering. Within these industrial sectors one of the most important applications of X-Ray diffraction technique is the evaluation of the residual stresses in prestressed steels. The hydrogen embritlement of the prestressed steel bars (rounds of 7 mm in diameter) in construction is strongly affected by the value of their residual stresses. Compressive residual stresses of 500 Mpa (0.3 times the yield stress) are normal values in these kinds of steel.

The X-Rays do not make distinction between the residual stresses or the external stresses. They detect the parameter that identifies the stresses state; the variation of the distance "d" between the crystallographic planes (Ref. [1]) of the material is detected. Obviously it will be registered the sum of the residual stresses and the external stresses. There are several on site experimental procedures to eliminate the residual stresses allowing the deduction of the external stresses acting on the element under analysis. Ref. 2, 3 and 4 contain thousand of works dealing the problems involved in the experimental procedures of X-Ray diffraction technique whereas Ref. 5, 6 and 7 show three case studies. Some years ago colleagues of the first author have analysed the stresses that support some bars of the Eyffel Tower in Paris. The work is unpublished.

2 Experimental works

In the past months authors are trying to introduce the X-Ray diffraction technique in different applications for the construction sector (buildings and elements of civil engineering). Potential applications for industrial heritage constructions are evident. Even more many ancient constructions in masonry contain recent metallic elements acting as reinforcement. The exact level of stresses in these elements is not well known or at least there exists a lack of knowledge about their exact role.

It has been carried out two experimental works. Firstly the stresses in a reinforcement bar of one of the towers in the Oporto Cathedral have been quantified. The fixing system of the bars has allowed the application of several external loads which has made possible to compare them with the results obtained by using X-Ray diffraction technique. After this experimental work two corrugated 10 mm diameter steel bars have been tested at laboratory. The bars were loaded to several well known stresses controlled by conventional compression machine. Again the objective was the comparison between the known applied loads and the results obtained by using X-Ray diffraction technique. Fig. 2 to 17 show several experimental details.

Fig. 2 General sight of Oporto Cathedral

Fig. 3 General sight of the reinforcement system

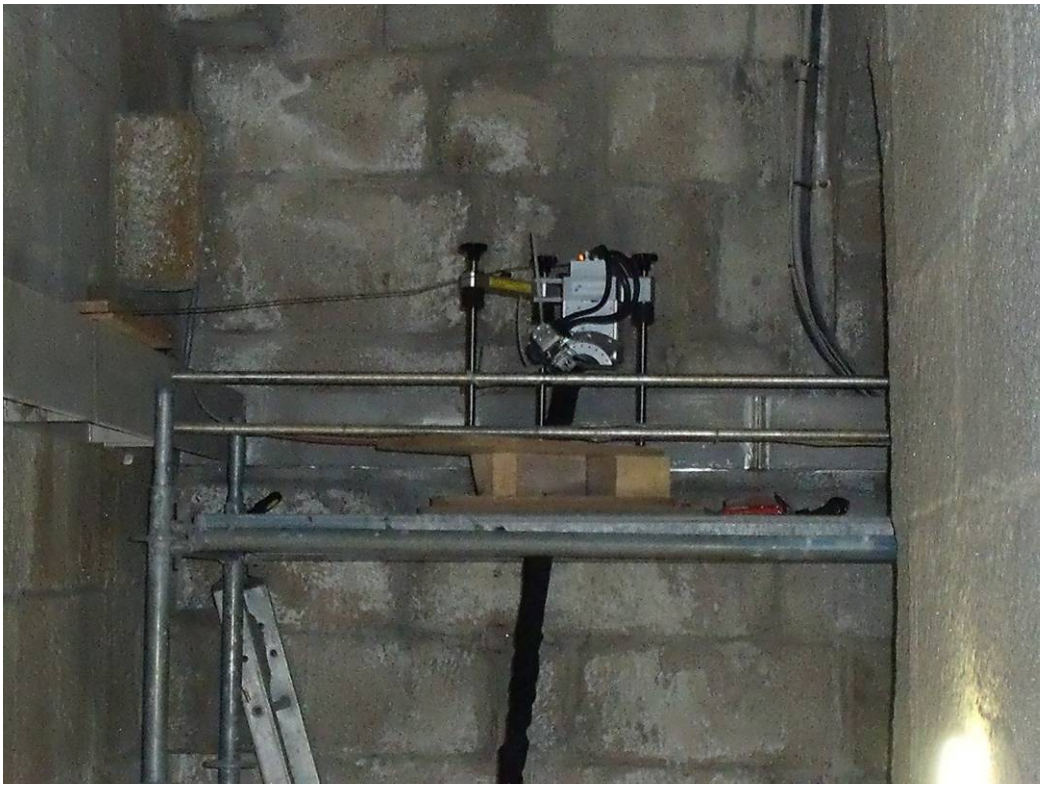

Fig. 4 Disposition of the zone of measure

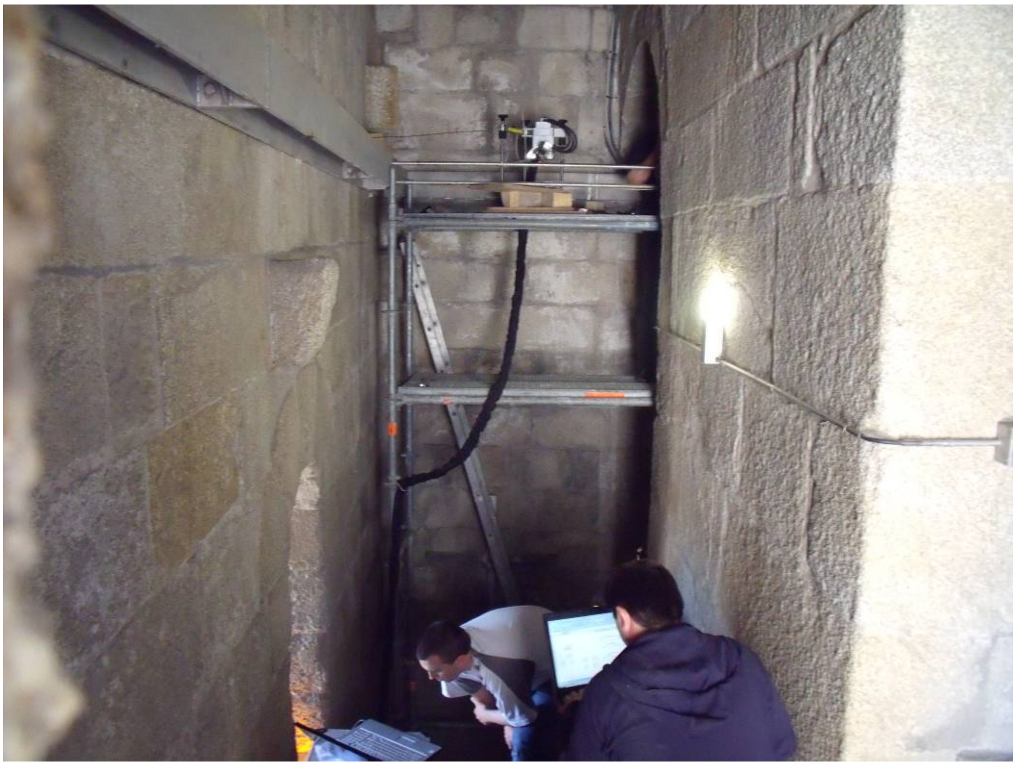

Fig. 5. General sight of the equipment on the analysed bar

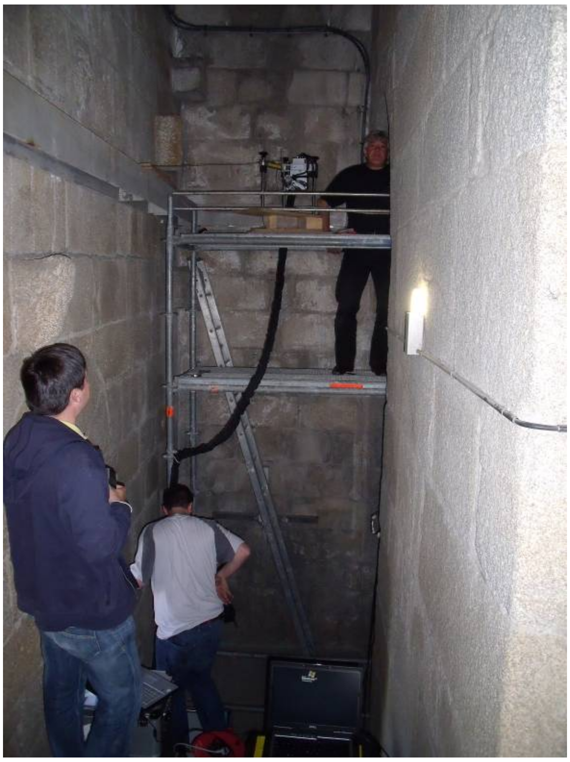

Fig. 6 Adjustment of the experimental equipment

Fig. 7 The equipment disposed on the bar

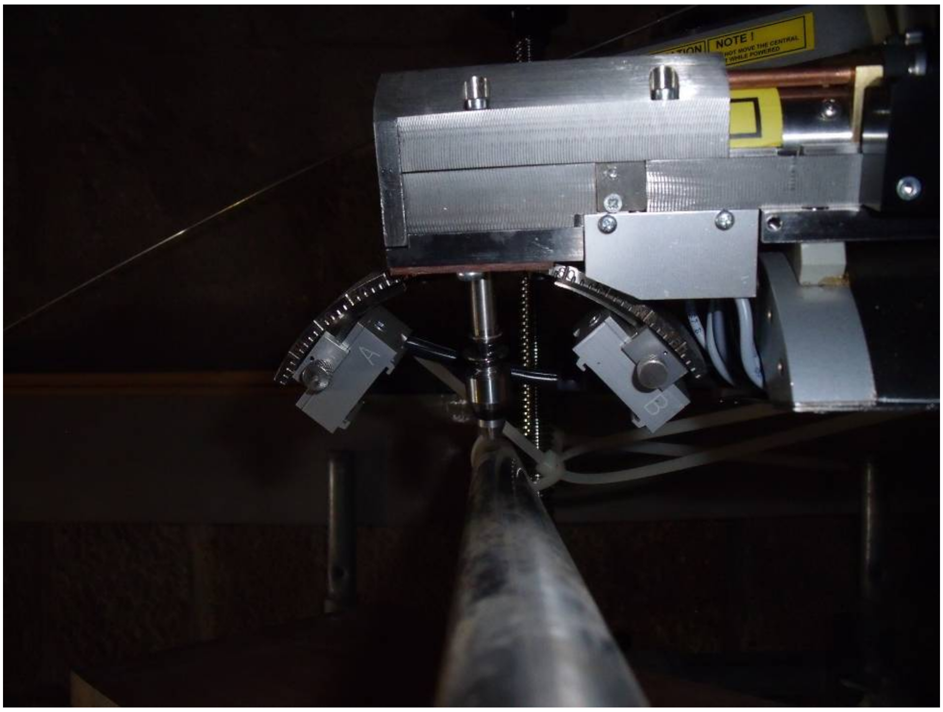

Fig. 8 The equipment placed on the bar in the process of measure

Fig. 9 Instant of the external load application

Fig. 10 Sight of the all elements of the experimental equipment

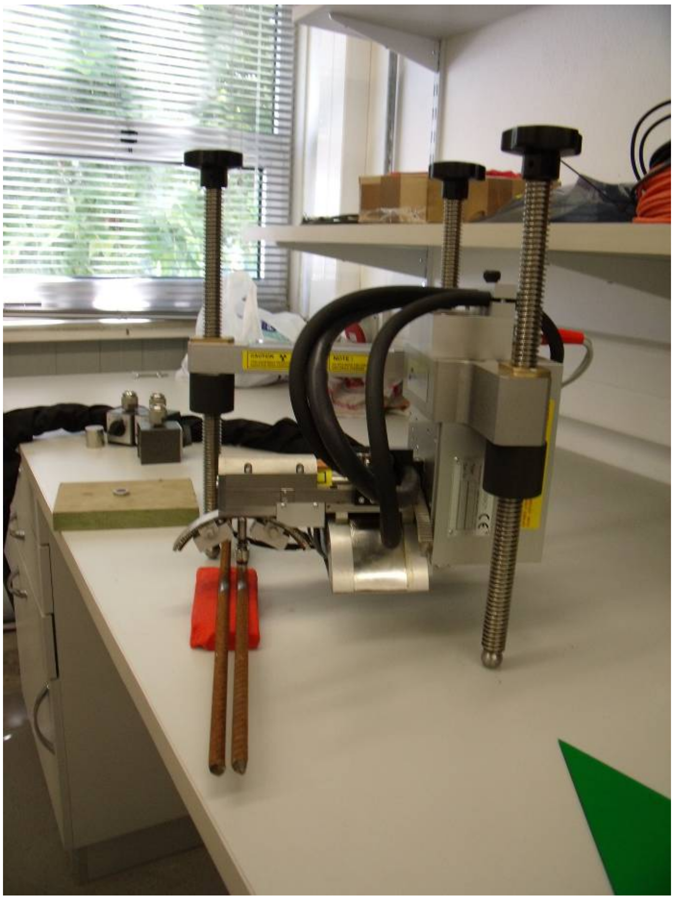

Fig. 11 The detection unit of the equipment on the two corrugated steel bars

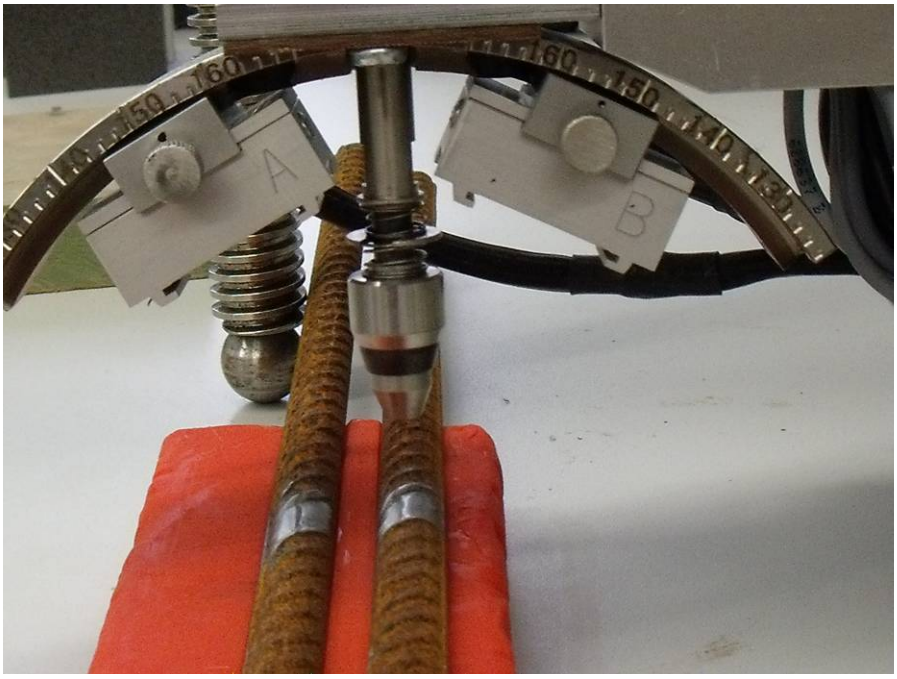

Fig. 11 Sight of the calibration process before loading the bars

Fig. 12 Sight of the loading machine at the laboratory

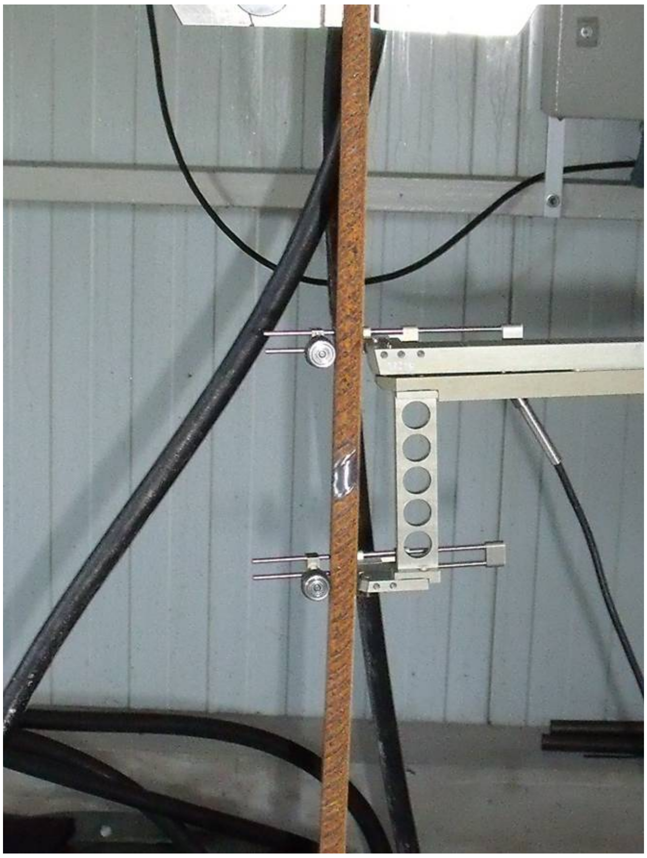

Fig. 13 One of the bars placed in the compression machine

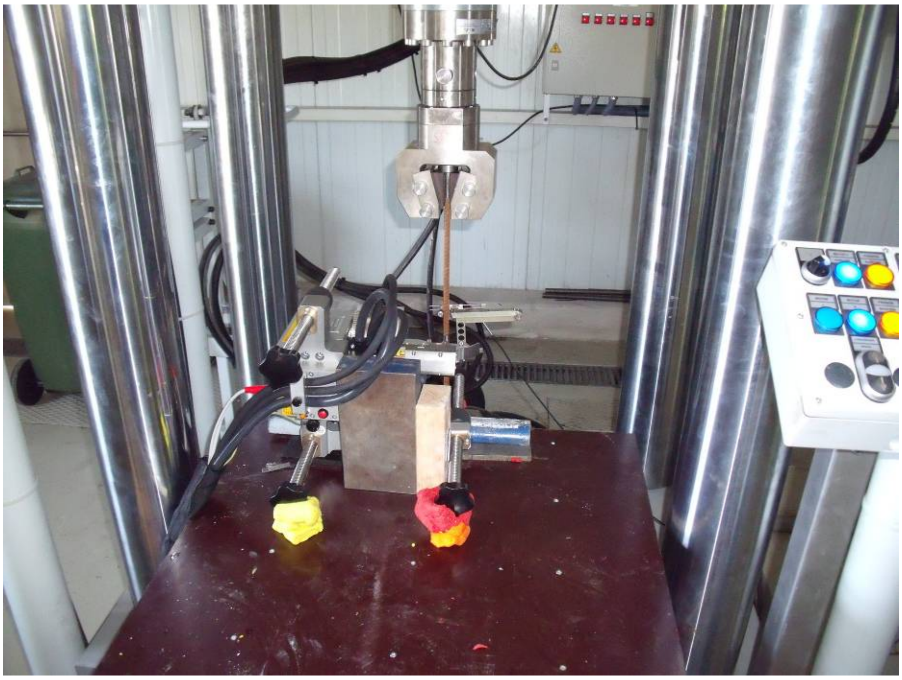

Fig. 14 Disposition of the detection unit

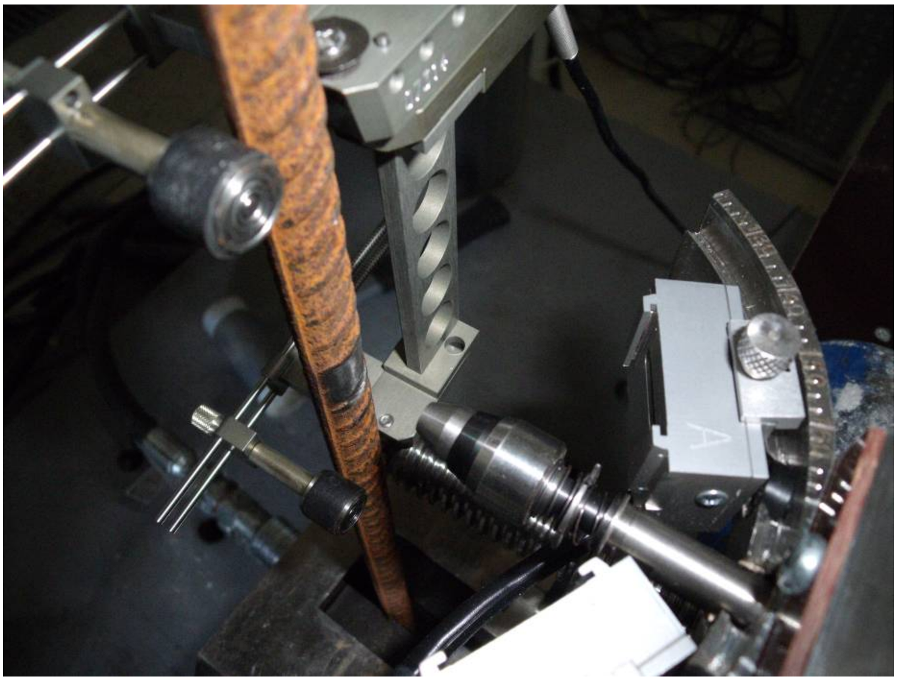

Fig. 15 Measurement process

Fig. 16 Measurement process

Fig. 17 Measurement process

3 Results

The results obtained in the experimental works have to be considered as excellent. This conclusion is expected because X-Ray diffraction technique is currently applied around the international scientific community for residual stresses identification. The innovation of this paper consists on the applicability of the technique for the on site works in order to obtain the real stresses on structural elements. First author worked during ten years at the Civil Engineering Fac. (Pol. University of Madrid) developing new uses and applications of X-Ray diffraction technique in many situations. Fig. 18 shows a copy of the results (text format) generated by the equipment. The copy corresponds to one of the results obtained for a bar. The most important results will be presented orally at the Conference.

No 145, Jul 28, 2009, 17:36:35 , Untitled

Prueba a 25 Kv	y 5 mA
Mode:	Psi
Peak shift:	Peak fit
Background:	linear
Background level:	0
Ka2:	Rachinger
Smoothing:	Yes
Smoothlevel:	5
LP correction:	Yes
Radiation:	CrKa
Exp.time:	5.0 s
E:	211000

v: 0.300
Rotation(phi) = 0.0° 2theta: 155.96°

psi	shiftA	shiftB	d	fwhm	Im
0.0	0.00	0.00	0.117118	3.01	69.18
-14.5	-0.59	-0.39	0.117115	3.07	68.68
-20.7	-1.94	-0.92	0.117109	3.16	68.28
-25.7	-2.15	-1.15	0.117108	3.21	66.60
-30.0	-3.46	-1.82	0.117101	3.31	64.84
0.0	0.00	0.00	0.117118	3.01	69.18
16.7	-0.01	-0.99	0.117115	3.07	67.34
23.9	-0.95	-1.26	0.117111	3.15	65.77
29.8	-1.54	-2.53	0.117105	3.27	63.63
35.0	-1.55	-2.01	0.117107	3.36	62.15

Stress = -74.1 +/- 10.0 MPa
FWHM = 3.179 +/- 0.039 deg

Fig. 18 Exemple of the results generated (text format) by the equipment

References

1.- S. Sánchez Beitia *Stresses quantification in structural steel bars by X-Ray diffraction technique. PART I: Concepts*. Proc. of REHABEND 2009 Congress. October 2009, Bilbao (Spain)
2.- Proceedings of the ICRS 2 (Int. Conf. on Residual Stresses). Nancy (France), 1989
3.- Proceedings of the ICRS 3 (Int. Conf. on Residual Stresses). Tokushima (Japan) 1991
4.- Proceedings of the European Conf. on Residual Stresses 1 to 7
5.- F. Artaraz and S-. Sánchez-Beitia. *An unsuitable residual stresses state in train springs originated by shot peening.* Int, Journal on Fatigue. 1991
6.- F. Artaraz, A. Gil, A. Irisarri and S. Sánchez-Beitia. Residual Stresses generated in welded joints of SA CL1 steel. Proc. of the IAEA (Int. Agency of Atomic Energy), Meeting of specialists of nuclear power plants. October 1989, Buenos Aires (Argentina)
7.- S. Sánchez-Beitia and M. Elices. *Influencia de las tensiones residuales superficiales sobre la fragilización por hidrógeno en aceros eutectoides trefilados (in spanish).* Rev. Iberoamericana de Corrosión y Protección. Vol XVII (1), Enero 1986.