

X-RAY AND BACK-WALL ECHO ULTRASONIC EXAMINATION OF WROUGHT IRON BUILDING STRUCTURES

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Abstract. *The wrought iron building structures constituting part of the architectural heritage, e. g. handrails, gate hinges, columns, arch ties and wall ties represent incorporeal value, but operate as load bearing structures as well. There are few information on their mechanical properties and quality. Due to the inhomogeneity of the material of wrought iron building structures generated during the production, the known metal testing methods, as the tensile and hardness tests or metallographic examination, are not enough to survey the properties of such structures in depth. For the further and more accurate examinations, the application of X-ray and back-wall echo ultrasonic tests are essential. The goal of our paper is the presentation of the application of the examinations used extensively in the machine industry for the testing of wrought iron building structures.*

Key words: *X-ray, Back-wall Echo, Iron Building*

1. INTRODUCTION

In the practice of the monument-restoration the application of the traditional technologies and materials and the conservation of the original structures become more and more extensive. This is the point emphasised by the Italian National Charter [20], *Aspects and methods of restoration and conservation of monuments and groups of monuments in Italy* and the Cracovian Charter of 2000 [20] presenting the newest international monument restoration principles for the application of traditional technologies and for the conservation of decorations and sculpture elements support such aspirations as well.

With this in view, the idea has arisen to examine the wrought iron building structures, as handrails, gate hinges, columns, ties, wall ties (*Fig. 1.*) representing above all incorporeal and historic value, but operating sometimes as load-bearing structures as well. The mechanical properties of the wrought iron parts used for building structures are hardly known.

The material of the iron building structures manufactured by manual forging may be ingot iron or wrought iron. According to our present knowledge, the ingot iron is a homogenous mild steel, while the wrought iron is a composite material composed of iron (mainly ferrite) and slag "filaments" [4].

The problems concerning the engineering structures and constructions made of wrought iron were analysed in several research works [4;5;8;9;16;17]. Their goal was to determine, analyse and compare the mechanical properties of the materials of large wrought iron structures (mainly bridges) generally produced in ironworks.

The mechanical properties of the structures produced by manual forging differ significantly from those of wrought irons produced in ironworks. The conditions of the manual forging (variations in the temperature and the direct connection with the smith's hearth), the features of the job (manual processing, stronger impacts on the surface) and the material consumption (secondary material consumption, spongy iron) significantly influence the structure and mechanical properties of the material.

The mechanical properties of the structural elements depend first of all on the structure of the material, i. e. the material quality and the mechanical properties can be judged by the results of metallographic examinations [4]. The disadvantages of the metallographic analysis are the slowness and labour-intensiveness of the test and the fact that it can render adequate information only on the sections tested. By X-ray examinations, however, the entire sample can be mapped quickly and non-destructively.

The other non-destructive testing method, the back-wall echo ultrasonic examination serves first of all for the completion of the X-ray tests in such cases, when the X-ray exposure is hindered or disturbed by the geometry of the test-piece. It can excellently be used for a more detailed survey, e. g. for the local examination of forge-welds and slag inclusions.

The goal of our paper is to present the X-ray and ultrasonic diagnostics of wrought iron building structures and their application to the preventive protection of the structural elements concerned.

2. WROUGHT IRON BUILDING STRUCTURES

The range of the wrought iron building structures constituting part of the architectural heritage is wide and their history can be traced back several centuries.

The ancient architects have used the wrought iron mainly for auxiliary structures, e. g. the cramps used to keep the stones of Porta Nigra at Trier together [10] or the roughly formed wrought iron grille originating from the 3rd-4th centuries exhibited in the British Museum [2].

However, only a few ancient iron building structures were found, because the iron was recycled for the production of weaponry in the stormy centuries of the history.

The first medieval building structures were the gate hinges. Later on, the locks, keys, knockers, weathercocks, window grills, door hardware, choir screens and graveyard fences (Figure 1.) were made of wrought iron [19;21]. The first wrought iron ties and rings used to reduce the arch pressure were forged in the middle ages as well [14]. The strength of the bodies of masonry was increased by wrought iron bars built in the walls of the towers around the spiral staircases.

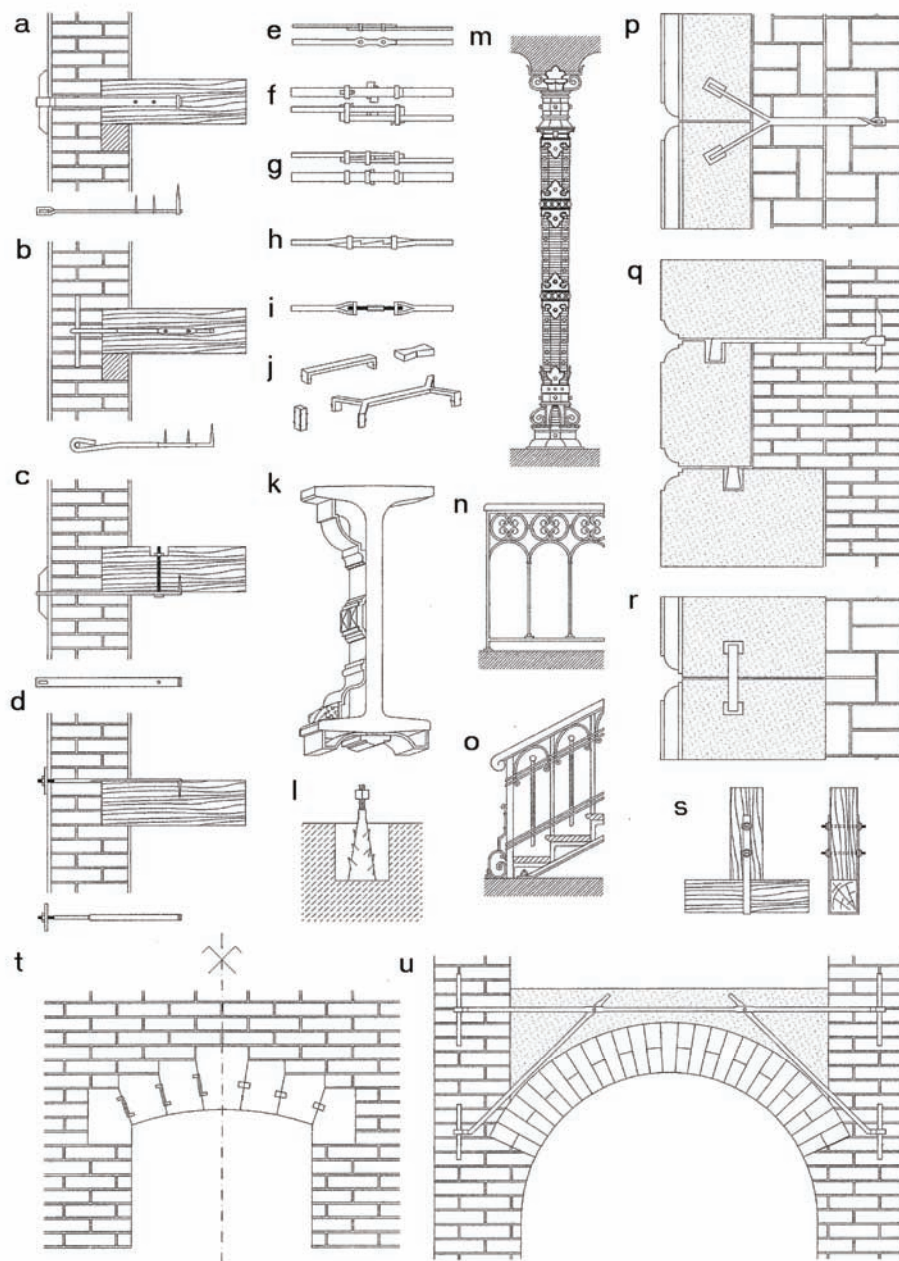


Fig. 1. Wrought iron building structures: a-d) balk irons; e) riveted-; f-g) wedged-; h) cogged-; i) turn-buckle ties; j) stone cramps; k) cornice element; l) column anchoring bolt; m) column; n) handrail; o) stairs; p-r) ashler wall ties and anchoring; s) connection of suspension columns with iron bail; t) stone dowels for arch; u) above-arch ties

There are plenty of wrought iron art remains from the 15th century. A number of staircase- and balcony balustrades, tomb railings, choir screens, wrought iron handrails of pulpits, fences and gates of the aristocratic palaces, decorated wells and window grilles have appeared [21;18] and other structural elements were manufactured as well. In terms of static solution, one of the most interesting engineering structures is the huge wrought iron ring bracing the dome of San Pietro at Rome [12].

The end of 17th century and the early years of 18th century are characterised by the appearance of a large scale wrought iron products – e. g. the fences and gates of the Belvedere in Vienna, the palace of the archbishop of Würzburg or the Palace Stanislas at Nancy [21], but there are plenty of other structural parts, e. g. above-arch ties remaining from that age (*Fig. 1./u*) [13].

In the 19th century, the static application of the wrought iron in the building structure became more and more important. In addition to the forge-welding, the iron bars were lengthened by riveted (*Fig. 1/e*), cogged (*Fig. 1/h*), wedged (*Figs. 1/f-g*), articulated and split pinned joints as well. The various mounting elements, as pins, bolts, rivets and turn-buckle connections (*Fig. 1/i*) were stressed and they had important load bearing function as well. The plate girders, the rolled C-, Z- and I-profile girders, the lattice girders the elements and joints of which were made of wrought iron as well as the various types of chain and wire ropes appeared at that time.

Some parts of the iron columns (*Fig. 1/m*) were made of cast iron, while other ones and the anchoring bolts of the columns (*Fig. 1/l*) were forged of wrought iron [7;11;14].

Various types of ties were made of wrought iron as well. The wrought iron balk iron secured the connection of the wooden floors to the walls (*Figs. 1/a-d*), the wall tie (*Figs. 1/i-e*) prevented the brick walls from separation, but ties were used also to the anchoring of ashlar walls (*Figs. 1/p-q*) [7].

Iron cramps were used as before to keep together the stones (*Figs. 1/j and 1/r*) the types of which were augmented with fork, square and other special forms in addition to the usual double dovetail and U-forms. Wrought iron wall dowels were laid into the horizontal joints of the arches and stone masonries (*Fig. 1/t*) [7].

The wrought iron binding units of the carpenter structures, the bolts, nails, cramp irons, flat-irons, shackles, rings and the iron bails of the suspension post, etc. were used in increasing numbers in the construction technology (*Fig. 1/s*) [7].

The below-arch ties were replaced by above-arch ties as early as in the Baroque age (*Fig. 1/u*). Their mechanical calculated and adjustable versions appeared by the second half of the 19th century [1].

Decorative structural parts, e. g. fences, handrails, stair and balcony balustrades, etc have been produced (*Figs. 1./n-o*). The appearance of the wrought iron cornices and architectural members (*Fig. 1./k*), however, was a novelty in the branch [3;11;14]. The major part of such structural elements was still manufactured by manual forging, while a smaller part, especially toward the end of the 19th century, was produced serially in iron-works.

The application of the artistic wrought iron reaches its summit in the eclectic "historicism" of the end of the 19th century and the secession (Art Nouveau, Jugendstil) of the early 20th century. Several wrought iron fences, gates, grilles, handrails, etc were produced for apartment buildings, public buildings and parks [18].

In second half of the 20th century, the manual forging survives in the applied arts and monument restorations in occasional applications.

3. ANTECEDENTS OF THE EXAMINATIONS

The properties of the wrought iron materials were well known from experiences of the blacksmiths of the old times. The blacksmiths and locksmiths were always careful to avoid the red-short and rigid materials (and those apt to lamellar fracture) and several methods were applied to achieve this goal [6;15;22].

By analysing bridge structures, Gordon and Knopf [4] have observed that the rigidity of the material threatened the structure even if it had an acceptable strength. The brittle fracture (less of ductility) may be caused mainly by defects, i. e. contaminations in the material (sulphur, copper, phosphorus, antimony, tin) and the slag caught in the material after the manufacturing process blocking the load-bearing cross sectional area in the material. This is expressly true for cross sections including forge-welded sections created in the course of the building of the structures and not at the production of the material itself [23].

The detrimental effects of the sulphur, as an alloying element manifest during forging [5]. The literature [15;22] reviewing the forging technologies and the steels used in the 18-19th centuries suggests that the blacksmiths knew well the detrimental effect of the sulphur and used forging tests to eliminate this problem [15].

The puddle irons are characterised before all by the presence of phosphorus. The phosphorus, as contaminant may be present up to 0.2 mass % without deteriorating significantly the mechanical properties of the wrought iron. Higher levels (0.3–0.4 mass%) will not cause brittle fracture, if a major part of the phosphorus present is contained in slag inclusions [4;15]. The presence of high quantities of phosphorus and the wrong forge welds were tested by throwing test, i. e. hurling the iron against an anvil set on the floor [6;15].

4. EXAMINATIONS

In order to decide whether a historic wrought iron structure can be retained or not, the type of the base material, its structure (ingot iron or wrought iron), its components and contaminants and the presence of flaws endangering the stability of the structure must be known.

The goal of our examinations was to filter out the material flaws, the full range investigation of the structure of the material by X-ray examinations of samples taken from wrought iron building structures manufactured in the 18-19th centuries. The X-ray examinations were completed with back-wall echo ultrasonic method at places where the X-ray examinations were hard to carry out or could not be carried out at all. The materials tested are listed in *Table 1*.

4.1. X-ray Examinations

The X-ray images paint a clear picture about the material structure, its flaws and help to decide whether the sample is composed of homogenous ingot iron or fibrous wrought iron.

The images were shot by an Yxlon 225 X-ray equipment. The wrought iron samples were put on a X-ray film laid onto a lead plate and they were exposed at a thickness dependent beam power for specified times. The adjustments are listed in *Table 2*, while the X-ray images are shown in *Figures 2-9*.

Table 1. Samples for X-ray examinations

	Material	Sign	Shape of the sample	Size of the sample (mm)
1.	Budapest, Forgách-Walla mansion ¹ , window-grille element	F1	Square bar, partly twisted	13x 13x 470
2.	Gyula fortress, pieces of ties to hang brown meat ²	Gy1/1	rectangular bar	27x 65x 1015
3.		Gy1/2	deteriorated prism	25x 40x 220
4.	Budapest, Sándor-palace ³ , wall tie	Sp1	deteriorated prism	10x 10x 53
5.	Sugarworks at Hatvan ⁴ , wall tie	H1/1	looped back, welded, of rectangular bar	7x 50x 370
6.		H1/2	rectangular bar	10x 55x 520
7.	Gate hinge from an unknown place in Hungary	un1	flat iron, decorated	3x 35/40 x 700
8.	Máriabesnyő (Gödöllő), Roman catholic parish ⁵ , altar-screen element	M1	flat iron, with fitting holes	8x 28x 630
9.	Gate hinge of the Lutheran church at Pilis ⁶	P1	flat iron, cross shaped, decorated	360x 35x 3mm and 200x 35x 3mm
10.	Zsámbék, building of the Apor Vilmos Catholic College (former Zichy-castle), balk iron ⁷	Zs 1/1	looped back, of cylindrical bar, hooked	24(110)x 24(30) x 810
11.		Zs 1/2	cylindrical bar	d=24 l=410
12.	Zsámbék, building of the Apor Vilmos Catholic College (former Zichy-castle), arch tie ⁸	Zs 2/1	square bar	25x 25x 850

1 – The Forgách-Walla mansion (Budapest, II. district), built in the 19th century, presently the building of the Klebelsberg Cultural and Art Centre.

2 – The Gothic fortress at Gyula built in the 15th Century (Hungary, Békés County) was rebuilt in the 18th century. The pieces of ties to hang brown meat originate from this age.

3 – The Sándor-palace (Budapest, I. district) was finished in 1806. Since its last restoration (2002), it houses the presidential office of the President of State.

4 – The first building of the sugarworks at Hatvan (Hungary, Heves County) was built in 1889.

5 – The Roman catholic parish-church at Máriabesnyő belonging to Gödöllő (Hungary, Pest County) was built as the family temple of the Grassalkovich family between 1768 and 1771.

6 – The Lutheran church at Pilis (Hungary, Pest County) was built in 1784.

7 – The castle of the Zichy family was built at the place of the medieval fortress at Zsámbék (Hungary, Pest County) in the early 18th century. The castle was completed with a new floor in the first years of the 20th century. Before the present restoration, the building was used by the Apor Vilmos Catholic College. The balk iron was manufactured at the time of its rebuilding in the early 1900's.

8 – The arch tie was manufactured at the time of the building commenced in the early years of the 18th century (around 1710).

Table 2. Radiation parameters set for the X-ray imaging

	Material	Sign	Voltage [kV]	Current [mA]	Time	Remark
1.	Budapest, Forgách-Walla mansion, window-grate element	F1-X1	185	3	50"	no remark
2.	Gyula fortress, pieces of ties	Gy1/1-X1	200	4	4'30"	no remark
3.	to hang brown meat	Gy1/2-X1	200	4	4'30"	no remark
4.	Budapest, Sándor-palace, wall tie brace	Sp1-X1	170	3	60"	no remark
5.	Sugarworks at Hatvan, wall tie brace	H1/1-X1	200	4	3'50"	X-rayed set on edge
6.			170	3	40"	X-rayed in flat position
7.	Gate hinge from an unknown place in Hungary	H1/2-X1	185	2,8	50"	no remark
8.	Máriabesnyő (Gödöllő), Roman catholic parish, altar-screen element	un1-X1	170	3	20"	no remark
9.	Gate hinge of the Lutheran church at Pilis	M1/1-X1	170	3	50"	no remark
10.	Zsámbék, building of the Apor	P1-X1	170	3	25"	no remark
11.	Vilmos Catholic College (former Zichy-castle), balk iron	Zs1/1-X1	185	3	50"	no remark
12.	Zsámbék, building of the Apor Vilmos Catholic College (former Zichy-castle), arch tie	Zs1/2-X1	195	4	2'10"	no remark

The material of the bar *F1-X1* taken from the window-grille of the *Forgách-Walla mansion* seems to be homogenous on the X-ray image (*Fig. 2.*).

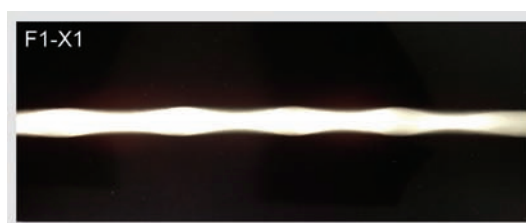


Fig. 2. X-ray image of the window-grate elements originating from the Forgách-Walla mansion at Budapest.

On the image *Gy1/1-X1* of the ties originating from the *Gyula fortress* (Figs. 3-4.), a conspicuous, repeatedly broken line 60 cm away from the measuring point 0 marks the place of the longitudinal weld. Smaller lines indicating the places of welds can be seen at many locations. In the lower 1/3 of the sample along the first 10 cm from the measuring origin, at the 20th centimetre at the upper sixth of the height (Fig. 3. – arrow 2.) and between the 20th and 28th centimetres from the origin (Fig. 3. – arrow 1.), furthermore, at the 36th centimetre approximately at half of the height, a virtually continuous line appears. Between the 60th and 70th centimetre from the origin, at several locations, various patterns, straight and branching, dark lines can be observed (Fig. 4. – arrows 1-3.) showing the location of the welded lengthening. Again, at the 90th centimetre, a material flaw of complicated pattern can be seen (Fig. 4. – arrow 4.) showing presumably the location of another weld.

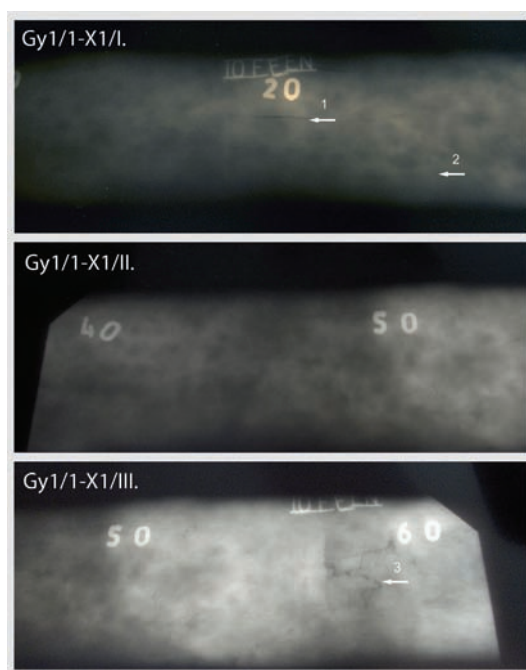


Fig. 3. X-ray image of the pieces of ties to hang brown meat originating from the Gyula fortress. Narrow horizontal lines indicating the location longitudinal welds (arrows 1-2.) and broken lines showing the locations of lengthening forge-welding (arrow 3.) can be observed

The examination of the sample *Gy1/2-X1* revealed similar phenomena, i. e. a longitudinal path running along the entire sample at the lower third of the height indicating a weld as well (Fig. 5. – arrow 1.).

In the X-ray image of the sample (*Sp1-X1*) originating from the *Sándor palace*, longitudinal slag inclusions are depicted running through the sample continuously at the half and the lower sixth of its height (Fig. 6. – arrows 1-2.).

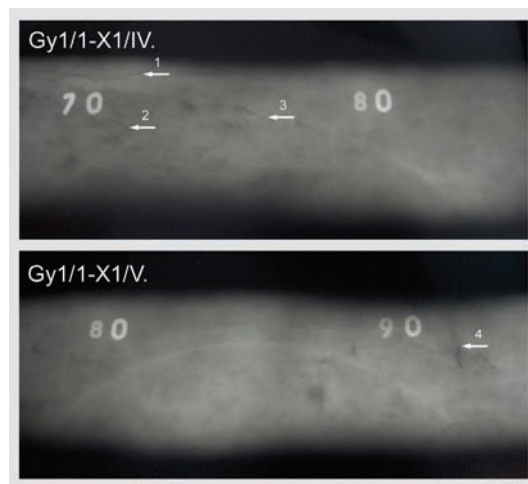


Fig. 4. X-ray image of the pieces of ties to hang brown meat originating from the Gyula fortress. Narrow horizontal lines indicating the location longitudinal welds (arrows 1-3.) and broken lines showing the locations of lengthening forge-welding (arrow 4.) can be observed.

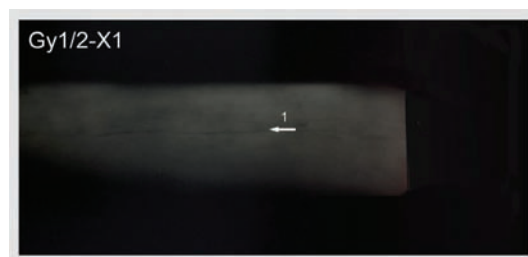


Fig. 5. X-ray image of the pieces of ties to hang brown meat originating from the Gyula fortress. At the middle of the sample, the characteristic horizontal line of a longitudinal weld is visible (arrow 1.).



Fig. 6. X-ray image of the pieces of the wall tie brace originating from the Sándor palace at Budapest. The horizontal lines indicating the locations of the longitudinal welds are visible at several locations in the sample; at the half (arrow 1) and at the lower fifth (arrow 2.).

The image of the pieces *H1/1-X1* taken from the wall tie of the *sugarworks at Hatvan*, the location of the forge-weld at the loop-back is discernable (*Fig. 7. – arrow 1.*). Disregarding this fact, the material of both samples - *H1/1-X1* and *H1/2-X1* – seems to be totally homogenous, i. e. it is ingot iron.

The examination of the sample *P1-X1* from *Pilis* and the gate hinge *un1-X1* of unknown origin has rendered virtually identical results. The image of the cross shaped hinge of *Pilis* shows clearly the location of an assembling forge-weld at the intersection point of the two tails (*Fig 8. – arrows 1-2.*), while for the hinge of unknown origin the dots indicating the places of the slag inclusions characterising a wrought iron material (*Fig. 8. – arrows 3-4.*). Disregarding these facts, both materials seem to be homogenous. It must be noted, however, that due to the small thickness of the samples (3 mm), the fibrous properties of the wrought iron cannot dominate strongly. Comparing the outer signs (e. g. platy fractures) to the images, the conclusion can be drawn that the material under review is wrought iron.

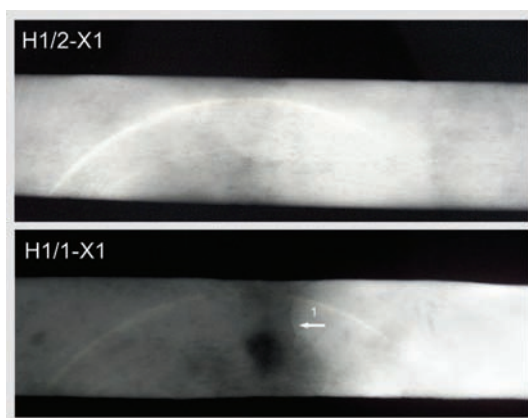


Fig. 7. X-ray images of the wall tie brace originating from the sugarworks at Hatvan. The lower picture shows clearly the traces of the weld on the back folded part (arrow 1.).

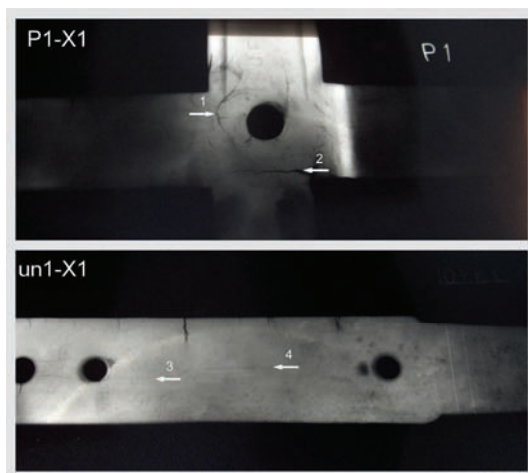


Fig. 8. X-ray images of a gate hinge originating from the Lutheran church at Pilis and the one of unknown origin. Arrows 1. and 2. in the upper figure show the traces of a lengthening forge-weld, while the arrows 3. and 4. point at the slightly visible location of the lengthening.

The X-ray image of the altar-screen of *Máriabesnyő M1/1-X1* (*Fig. 9 – arrows 1-3.*) the structure characterising the wrought iron structure is clearly visible. The material of

the sample is constituted by three or four well separated fibres along the entire length with some breaks.

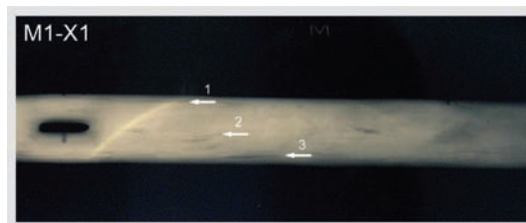


Fig. 9. X-ray image of the altar-screen originating from the Roman catholic church at Máriabesnyő. The arrows 1-3. point at the most characteristic locations of the longitudinal weld.

The images of the samples *Zs1/1-X1* and *Zs1/2-X1* taken from the balk ties of the late *Zichy-castle at Zsámbék* show homogenous structure (*Fig. 10.*).

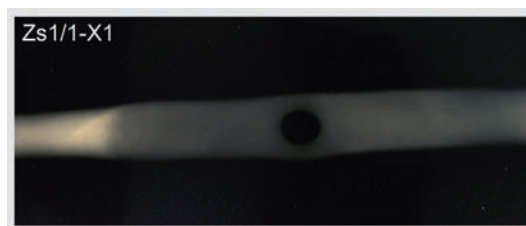


Fig. 10. X-ray image of a balk iron from the late Zichy castle at Zsámbék.

The arch tie *Zs2* was exposed from both sides. The images show clearly the fibrous structure of the material, i. e. this tie was made of wrought iron. Looking at it from the first direction three (sometimes four), while from the second one, two fibres can be distinguished (*Fig. 11. – arrows 1-6.*).

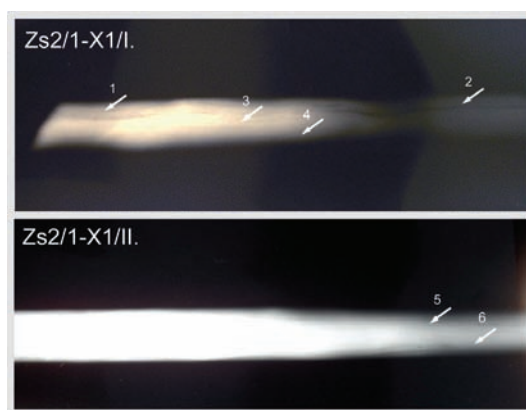


Fig. 11. X-ray images of the arch tie originating from the late Zichy castle.

Summarizing, one can say that the ties (Gy1, Gy2), coming from the Gyula fortress, the samples (Sp1) originating from the Sándor-palace, the gate hinge (un1) of unknown origin, the altar-screen (M1) of Máriabesnyő, the gate hinge (P1) from Pilis and the arch tie of Zsámbék (Zs2) were made of wrought iron. The material of window-grille (F1) of the Forgach-Walla mansion, the wall tie (H1, H2) taken from the sugarworks at Hatvan as well as balk tie of Zsámbék (Zs1) is ingot iron. The local inhomogeneity of the latter ones is the consequence of the subsequent processing, forge-welding and forging.

4.2. Ultrasonic tests

On one hand, the back-wall echo ultrasonic test was used to examine the forge-welds on the samples. On the other hand, we were able to get picture on the structure of the material concerned and the position and extension of the slag inclusions by ultrasonic waves reflected from the planes containing the slag inclusions in inhomogeneous materials. The principle of the examination is presented by *Fig. 12*.

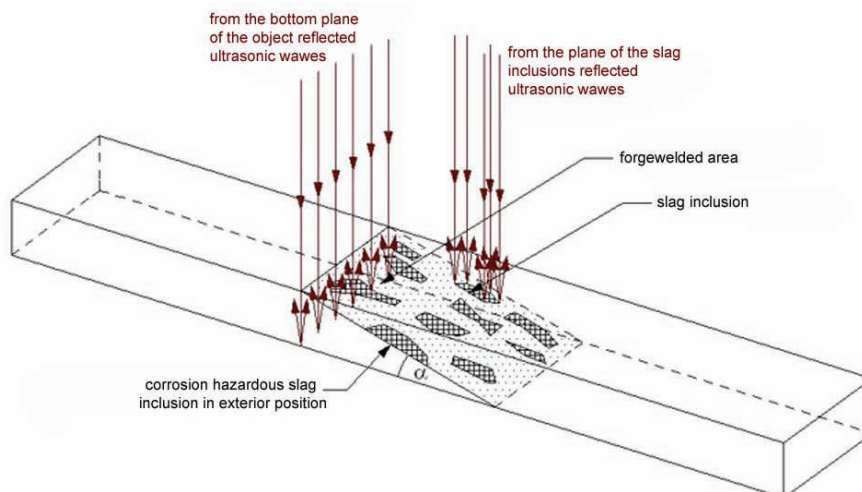


Fig. 12. Back-wall echo ultrasonic examination of a forge welded joint.

The method can be used to the bi-directional testing of the material, if the geometric properties (e. g. narrow, high pieces) exclude the bi-directional exposure at the X-ray test. In case of connecting forge welds the goal of the examination is to determine the ration of the bonded areas.

Of the pieces X-ray tested, the ones at which the bi-directional X-raying was problematic due to geometric reasons or where lengthening forge welding was assumed in the structure were tested with ultrasonic as well.

The testing of the materials specified in *Table 3*. was carried out with a Krautkramer USM 25-equipment. The surfaces of the material tested – where it was needed - were prepared by polishing to obtain the adequate quality. The testing took place in the characteristic direction or in two, to each other orthogonal planes. For the examinations KBA 5MHz testing head and MWB 70 - 4MHz angular testing head were used. For the pre-

liminary calibrations a high-grade steel gauge of 1" thickness and a staggered calibration test piece of 1 – 8 mm were used.

Table 3. Parameters of the back-wall echo ultrasonic test

	Material	Sign	Testing head	Remarks
2.	Gyula fortress, pieces of ties to	Gy1/1-U1	KBA 5MHz	no remark
3.	hang brown meat	Gy1/2-U1	KBA 5MHz	no remark
4.	Budapest, Sándor palace, wall tie brace	Sp1-U1	KBA 5MHz	no remark
5.	Sugarworks at Hatvan, wall tie	H1/1-U1	KBA 5MHz	no remark
6.	brace	H1/2-U1	KBA 5MHz	no remark
7.	Gate latch from an unknown place in Hungary	un1-U1	KBA 5MHz	no signal received
9.	Gate latch of the Lutheran church at Pilis	P1-U1	KBA 5MHz	no signal received
11.	Zsámbék, building of the Apor Vilmos Catholic College (former Zichy-castle), balk iron	Zs1/1-U1	KBA 5MHz	no remark
13.	Zsámbék, building of the Apor Vilmos Catholic College (former Zichy-castle), arch tie	Zs2/1-U1	KBA 5MHz; MWB 70 – 4MHz angular head	no remark

The ultrasonic test of the sample (*Gy1/1-U1*) originating from the *Gyula fortress* has indicated the remains of the longitudinal welding observed on the X-ray image as well. The welds parallel to both the narrower and wider side were observed. The ultrasonic test has detected diagonal form of the connecting welding on the narrower side; 60% of the reflected signal was reflected from the opposite plane of the wall tie, while 40% from the intermediate plane (*Fig. 12.*). In the light of this result, the weld is bonded on 60% of the welded cross section, while 40% of the former bonded area is covered with slag inclusions.

On the test-piece *Gy1/2-U1* the traces of the longitudinal lengthening shown on the X-ray image were observed in one direction, while in the other direction the location of the connection welding causing serious corrosion on the surface was found.

The examination of the material (*Sp1-U1*) originating from the *Sándor-palace* has expressly shown traces of the horizontal lengthening welding indicated by the X-ray image as well. Furthermore, the ultrasonic test has shown that the discontinuity had become narrower toward the edge of the material. The welding line near to the side opposite to the examination side shown on the X-ray image could not be detected due to loss of the signal.

In case of the sample pieces (*H1/1-U1*, *H1/2-U1*) coming from the *sugarworks at Hatvan* the ultrasonic test has detected no lamellar structure either. For the forge-welded joint on the sample *H1/1-U1* more than 90% of the reflected signals were reflected from the opposite side of the sample indicating 90% of bonding on the surface representing an exceptionally excellent forge-welding.

The gate hinge from the *Lutheran church at Pilis* and the one of unknown origin (*P1-U1*, *un1-U1*) have rendered no results, because the thickness of 3 mm excluded the reception of adequate signals.

The test was carried out on the flattened part of the sample *Zs1/1-UI* taken from the building of the former *Zichy castle at Zsámbék*, where no lamellar structure was explored. The lamellar structure of the wrought iron was obvious in the sample *Zs2/1-UI* of Zsámbék. Based on the external form of the sample has suggested a lengthening by forge-welding, but the signs of such operation could be detected neither by the upright nor the angular head.

5. OBSERVATIONS

The testing tools and methods of steel structures are adequate for the examination of homogenous material structures. There are several reasons why the manually forged building structures can not be considered as homogenous materials. A major part of such building structures is inhomogeneous wrought iron and the subsequent forging may generate further inhomogeneities in the structure.

In case of wrought iron structures the tensile strength measured by the known methods is only of informative value, because the strength may drop significantly at the locations of the material flaws or damages caused by corrosion [23].

For monument restoration projects, the condition of the structure and the survey of the future potential dangers are the main points instead of the theoretical strength of the material. In case of existing structures, if they were able to resist the loads imposed, this situation will not change, if the load will not be increased, no negative changes in the environment take place or the deterioration of the structure occurs.

The structural character and type of the base material (wrought iron or ingot iron) can be determined by X-ray or back-wall echo ultrasonic tests being able to identify the flaws in the structure and determine their positions. The observations made during the examinations of the samples concerned may be used for the preparation of the future examinations to be carried out on similar building structures as well. They may provide useful information to identify the optimal locations of the non-destructive (hardness tests) and the destructive strength tests.

Contrary to the metallographic tests, the X-ray examinations provide no information on the microscopic properties or composition of the material, but all flaws endangering the soundness of the construction can be detected in non-destructive manner along the entire length. The ultrasonic examinations enable the specification of the material flaws mapped by X-ray tests and the good estimation of the ratio of the bonded areas in materials lengthened by forge-welding.

6. SUMMARY

In summary, the inhomogeneity of the materials of structures manufactured by manual forging significantly influences the results of the examinations accomplished on such structures, i. e. the examination of their state can be accomplished by surveying the factors generating the inhomogeneity and considering their possible consequences. When examining the building structures manufactured by manual forging, the completion of the usual tensile tests with X-ray and ultrasonic tests is recommended by which the type of the base material, the local changes (slag inclusions), the forging induced inhomogeneities and the locations of the internal corrosion can accurately be identified.

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X-ZRACI I POVRATNI EHO ULTRASONIČNOG ISPITIVANJA KONSTRUKCIJA ZGRADA IZVEDENIH SA GVOZDENIM OKOVIMA

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Gvozdeni okovi čine deo arhitektonskog nasleđa, u šta spadaju, ograde, šarke, stubovi, veze lukova i zidova, i predstavljaju neprocenjivu vrednost, ali takođe imaju funkciju nosećih elemenata. Imalo je malo podataka o njihovim mehaničkim svojstvima i kvalitetu. Usled nehomogenosti materijala u elementima od kovanog gvožđa do kojeg je došlo u toku proizvodnje, standardne metode ispitivanja metala kao što su testovi na istezanje i testovi čvrstoće, kao i metalografska ispitivanja nisu dovoljne za dubinsko ispitivanje ovih elemenata. Dalja i preciznija ispitivanja zahtevaju upotrebu X zraka i povratnog eha u te svrhe. Cilj ovog rada je prikaz primene ispitivanja koja se koriste u mašingradnji za testiranje struktura i elemenata od kovanog gvožđa.