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APPLICATION OF WELDING FOR RESTORATION OF CAST IRON RAILING OF THE KOTZEBUE BRIDGE IN ODESSA

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The results of evaluation of real condition of cast iron railing of the Kotzebue Bridge and the opportunity of welding application for its restoration are presented. According to the instructions SRP 2007.4.1 on carrying out restoration works on the cultural heritage objects, an expert examination of the disassembled elements was carried out, the lists of defects were compiled and the complex of investigations on identification and weldability of cast iron was performed. It was established that the peculiarities of weldability of such cast iron are predetermined by its pearlite structure, carbon content, gas saturation, penetration of corrosion products deep into base metal, low ductility, as well as tendency to formation of cementite, ledeburite and welding stresses in HAZ metal. The principles of minimizing the influence of these factors on weldability were developed. The approach to selection of welding method and welding consumables was mastered. It was established that the mechanized method of welding using self-shielding high-nickel wire of grade PANCH-11 meets mostly the specified requirements. On its basis, the technology for restoring integrity of all the main architectural and decorative elements of railing (grates, emblems and cornices) was developed and implemented under the author's supervision 7 Ref., 2 Tables, 7 Figures.

Keywords: *railing, architectural and decorative elements, pearlitic cast iron, weldability, restoration, mechanized MAG welding, self-shielding high-nickel wire PANCH-11*

The Kotzebue Bridge, one of the most famous Odessa bridges, was built in 1892 (architect Landesman S.A.) over Karantinnaya ravine, now Devolanovsky descent), connecting two regions of the Politseyskaya street (now Bunin street). Its load-carrying metal structures were manufactured in France in the workshops of Gustave Eiffel, who at that time already became famous as the creator of the highest construction in the world in 1889: the Eiffel Tower with a height of 324 m. The metal structures of the bridge as well as of the tower are made of the same materials, in the similar conditions and at almost the same time, which even motivated the citizens of Odessa to call it the younger brother of the Eiffel Tower. The assembly was carried out at the mounting site in Odessa. The general view of the bridge at the end of the 19th century is shown in Figure 1. The bridge, named after Kotzebue P.E., the last governor-general of Novorossiya, is decorated with a

Figure 1. General view of the bridge at the end of the XIX century

cast iron railing. On the special grates in the center of the panel the cast emblems of Odessa are built-in: one on each side. For its originality, the railing of the bridge was awarded the status of a cultural heritage in 1985, and in 2008 the bridge was added to the state register of immovable architectural monuments.

It was managed to follow the change in the appearance of the railing over a 125-year history on the basis of analysis of photos from the thematic publications on the Kotzebue Bridge in the city mass media, since technical documents were not preserved. Figure 2 shows the general unsatisfactory condition of the railing ensemble. The poles of the railing were protected against falling by pouring the inner cavity with concrete and installing the bracings (Figure 2, *a*), which prevented the movement along sidewalk. Most of the removable railings were almost lost, except of few ones, being cast together with grates, apparently during the postwar restoration as far back as in the middle of the 20th century. As for under emblem grates, they were reinforced by the channel bars (Figure 2, *b*) at the same period, which clearly reduced the artistic component in perceiving the masterpiece of casting art. The emblems lost their curling ornaments — volutes (Figure 2, *c*).

In 2011, the load-carrying structures of the bridge floor and the cast iron railing ensemble were recognized as emergency ones and those which need the major repairs, and therefore, the bridge was decommissioned and in June 2016 it began to be reconstructed. The reconstruction project envisaged the restoration and preservation of the original arched part, without its involving in the work of bridge structures. The transport load will be now undertaken by the new span structures, meeting the modern requirements. As for railing, then after restoration it must preserve its purpose in the previous appearance.

The OJSC «ROSDORSTROY», the general contractor for reconstruction of the Kotzebue Bridge, commissioned the E.O. Paton Electric Welding Institute of the NAS of Ukraine (PWI) to fulfill the evaluation of a real condition of railing and the possibility of using welding for its restoration with the highest possible degree of preservation of its authenticity in accordance with the requirements of the instructions [1] on restoration works at the objects of cultural heritage. In the shortest terms, it was necessary to study the design, technical and artistic state of preservation, to establish the most probable factors, causes and extent of integrity loss, to prepare the lists of defects, to carry out a complex of investigations on identification and weldability of structural cast iron, to develop technical solutions and welding technology for practical restoration tasks, as well as to realize them in restoration of damaged architectural and decorative railing elements.

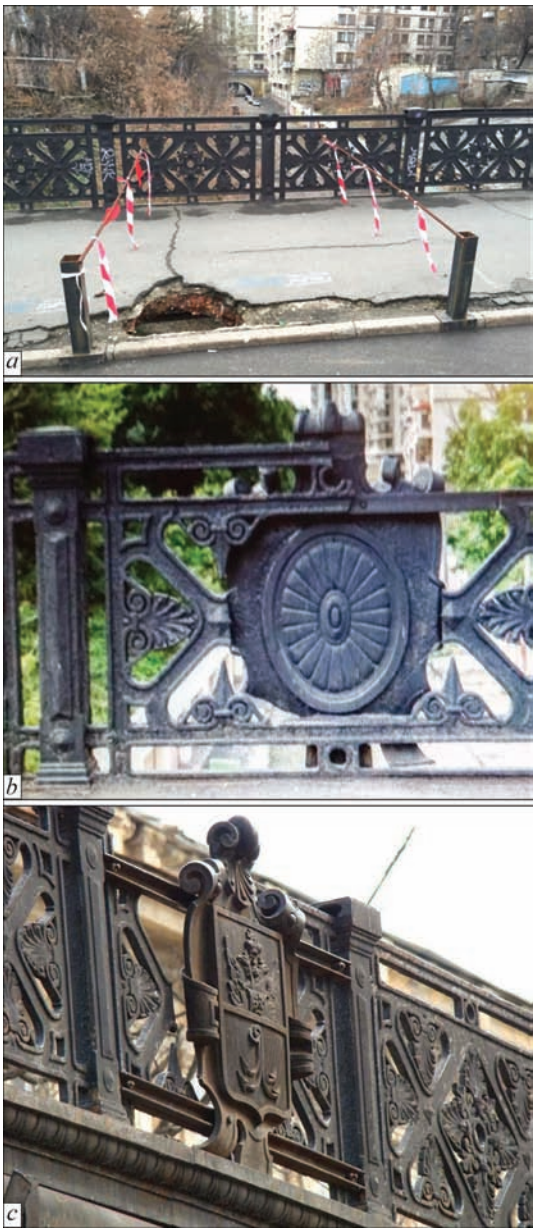

Figure 2. General view of condition of the railing of the Kotzebue bridge in 2016 (before disassembly): *a* — panoramic view; *b* — rear side of the emblem on the under emblem grate; *c* — front side of the emblem on under emblem grate

The process of disassembly of architectural and decorative railing elements was carried out manually, which did not cause a significant damage to them. The disassembled railing elements were numbered and placed in storage in the warehouse conditions of the general contractor.

In September–October 2016, under the terms of the general contractor, the first stage, an expert examination of all the architectural and decorative railing elements with element-by-element visual evaluation of a real condition and with photofixation was carried out by the specialists of the PWI (Figure 3).

To make the decisions on repairability, they were conditionally divided into two categories. To the first one the elements were attributed which are not sub-

Figure 3. Working moment of the joint expert examination of architectural and decorative elements of railing of the Kotzebue Bridge with representatives of the Department of Cultural Heritage Protection of the Odessa State Administration

jected to loading in the process of service. They are the cornices and corner elements of the decoration. To the second one the critical railing elements belong, perceiving the loads and determining the load-carrying capacity of railing: poles, grates and emblems. The applied criteria for evaluation of repairability of parts of the second category by welding were more rigid than for the parts of the first category.

During examination in both cases, a particular attention was paid to preservation of design, technical and artistic conditions. Based on the results of the examination, the lists of defects and reports of technical condition, as well as decision of repairability were drawn up. In the generalized form, the results of the examination are presented in Tables 1 and 2, and the examples of condition of some parts are shown in Figure 4.

It was established in the course of examination that the mass destruction of pillars and the loss of load-carrying capacity (Figure 4, *a*) are the results of complex cause. It consists in design features, i.e. the presence of problematic corrosion zones inside the hollow structure, low mechanical characteristics of cast iron, tight fit of grates in a standard position, vibration from transport movement, aggravated by its own weight and the weight of hinged elements, rigid action of low temperatures and water in all its aspects. The most critical for destruction is the fatigue of metal structures of the bridge in the process of long service life and corrosion. Therefore, in connection with a low degree of integrity and loss of load-carrying capacity, as well as high critical importance of these elements in the composition of the railing, it was recommended to cast all the poles anew.

The analysis showed that characteristic defects on grates (Figure 4, *b*), emblems (Figure 4, *d*) and outer horizontal surface of the cornices (Figure 4, *d*) such as cracks, lost fragments, corrosion damages are exclusively the consequences of assembly errors, action of time and long-term service. They are associated with the absence of proper current maintenance, incorrect restoration operations, unsuccessful design solutions during creation of elements, especially of under emblem grating and a low ductility of structural cast iron.

On the basis of comprehensive analysis of the degree of defectiveness of cornices, emblems and railing grates, taking into account the high degree of integrity of structural and artistic conditions, the conclusion was made about the potentiality of restoring their fitness for further service in the designing mode and in the same appearance using welding. To eliminate the design drawbacks of under emblem grates, taking into account

Table 1. List of architectural and decorative elements of the disassembled railing, presented for expert examination

Number	Description of architectural and decorative element	Quantity, pcs (account number No.)					
		Under the project	Available	Does not require repairing	Repairable by welding	Not repairable by welding	Manufacture by casting or other
1	Railing pole	44	44	3 (1, 11, 44)	–	41 (2-10, 12-43)	44
2	Railing grate (long)	40	40	29 (2-5, 7, 8, 16-19, 21-23, 25-34, 37-41, 44)	11 (1, 6, 9-15, 20, 42)	–	–
3	Railing grate (short)	4	3	1 (43)	2 (35, 36)	–	1
4	Railing grate (under emblem)	2	2	–	–	2 (24, 45)	2**
5	Railing	42	12	6 (1, 2, 3, 4, 5, 6)	–	6 (7, 8, 9, 10, 11, 12)	36
6	Corner decor element	43	43	40	3	–	–
7	Cornice (long)	42	42	35 (1-4, 6-8, 10-18, 21-26, 28-30, 32-39, 41, 45)	7 (5, 9, 19, 20, 27, 31, 40)	–	–
8	Cornice (short)	3	3	2 (42, 43)	1 (44)	–	–
9	Emblem	2	2	–	2	–	2*

Note. * — to manufacture the missing fragment by casting; ** — to manufacture completely.

Table 2. Classification of defects and content of repair of architectural and decorative elements of subrailing

Number	Description of architectural and decorative element	Characteristic defects	Content of repair, technical solutions
1	Railing poles	Corrosion and mechanical damage, loss of elements	To cast anew from gray cast iron SCh20 GOST 1412 in the quantity of 44 pcs. specified by the Project
2	Railing grates (long)	Loss of the elements of the subrailing or support girth. Cracks in the girths	Instead of the lost elements in the girths use substitute material. To weld cracks
3	Railing grates (short)	Loss of elements of subrailing and support girth. Cracks	Same
4	Railing grate (under emblem)	General destruction, loss of elements	To manufacture a new grate according to the drawing of the combined design with preservation of the original decor elements. To cast the missing decor elements
5	Railing	General destruction or loss	To cast anew from gray cast iron SCh20 GOST 1412 in the quantity of 36 pcs
6	Corner decor elements	Damages, cracks	To reweld cracks
7	Cornices (long)	Loss of fragments in the zone of mounting cuts. Cracks on the outer horizontal surface.	To use steel inserts instead of the lost fragments. To reweld cracks.
8	Cornices (short)	Loss of fragments in the zone of mounting cuts. Cracks on the outer horizontal surface.	Same
9	Emblems	Elements of curling ornament — volutes are lost.	To cast the lost elements of gray cast iron SCh20 GOST 1412 according to the drawing and to weld-on

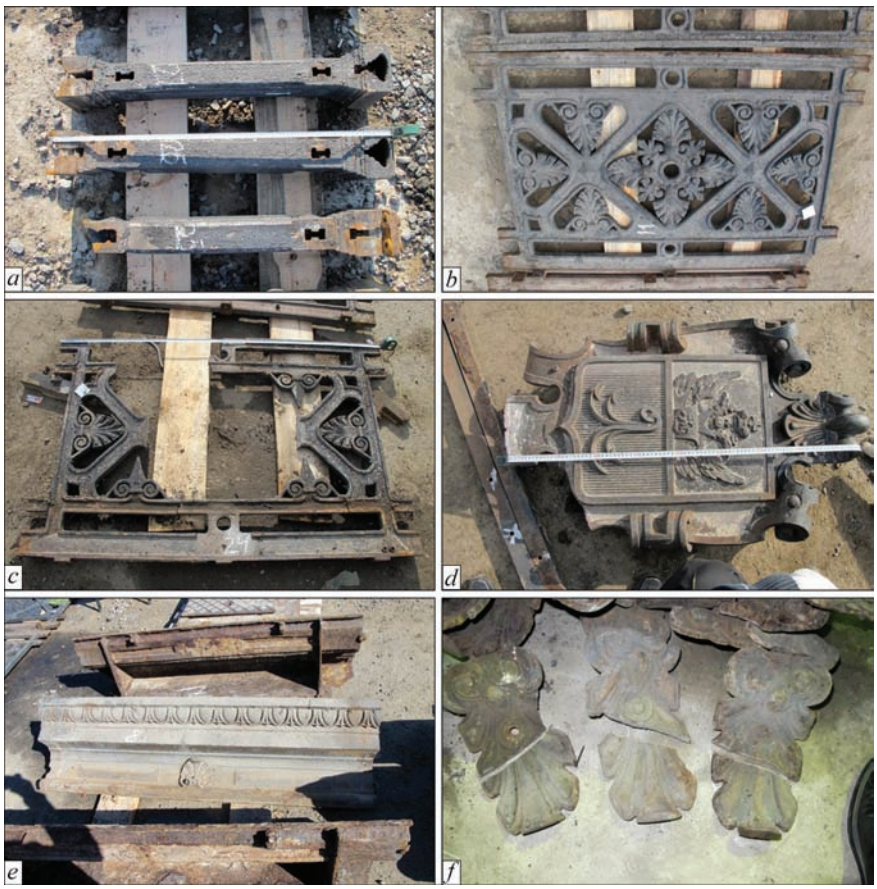

Figure 4. Examples of condition of characteristic parts of railing, established during expert examination: *a* — poles Nos 25, 26, 27; *b* — grate No. 11; *c* — under emblem grate No. 24; *d* — emblem No. 1; *e* — cornice No. 8; *e* — corner elements of decor Nos 1, 2, 3

their loading, it was suggested to restore them in the form of a combined welded-cast structure. The decision making was also contributed by the research experience in welding of gray and high-strength cast irons and participation in the restoration of cast iron pillars of the Kiev Philharmonic (19th century), pilasters of the Cabinet of Ministers building (the first half of the 20th century), as well as the load-carrying parts of technical equipment (20th century) [2].

In practice, the specialists on fracture structure determine the grade of cast iron and evaluate its weldability. In our case, fresh fractures had a fine-grained structure of light-gray color, which previously positively characterized the «French» cast iron from the point of view of weldability.

The investigation of metal samples, selected for its identification, was performed in the analytical laboratory of the Institute (Certificate of Accreditation of the National Accreditation Agency of Ukraine No. 2N362 of 14.01.2014). The composition of cast iron was determined in the X-ray spectrometer «Spectrovak-1000», the model DV-4 (Baird Company, USA), the metallographic examinations of the microstructure were performed in the optic microscope «Neophot-32» [3], the hardness was measured in the Vickers device [4]. It was established that the railing parts are cast from the cast iron of the following chemical composition, wt.%: 3.10–3.35 C; 0.37–0.40 Mn; 1.40–1.58 Si; S <0.2; P <0.15. The microstructure of cast iron of such a composition is the main factor determining the properties, as a rule it should be ferritic-pearlitic or pearlitic. According to the results of metallographic examinations, it was established that this is a typical pearlite structure in which a phosphide eutectic is present, characterized by increased hardness and brittleness. The integral hardness is not more than HV 300. As far as the decision was made to pour all the pillars and also to manufacture the railings and fragments of emblems decorations using casting anew in return for the lost ones, it was necessary to select the appropriate grade of domestic cast iron. From those, which are the closest to the original ones, a gray cast iron of grade SCh 20 meets the necessary requirements [5].

The properties of cast iron as a complex polycomponent structural material can be changed dramatically by welding process. Therefore, the technological process of welding should take into account the factors affecting weldability. All the main elements of technological process like input energy, degree of heating, cooling rate and sequence of producing joints were determined taking into account the peculiarities of the «French» cast iron and its structural transformations within the requirements [6].

Figure 5. Fragments of restoration works: *a* — restoration of under emblem grate by welding; *b* — final cleaning of welds; *c* — type of repaired joint on short cornice; *d* — type of repaired joint on grate No. 13; *e* — type of emblems before restoration (in the foreground, newly cast fragments of lost decorations — volutes); *f* — type of emblem No. 1 after restoration

The complex of investigations, carried out at the PWI, showed that the peculiar features of weldability of the «French» cast iron are predetermined not only by its structure in the fracture, but also by pearlite microstructure, carbon content, gas saturation, penetration of corrosion products into the base metal, low ductility, as well as tendency to formation of structures of cementite, ledeburite and welding stresses in the HAZ metal. For practical tasks of parts restoration, the principles were developed minimizing the influence of these factors on weldability. They consist in the fact that welding should be carried out in multilayered welds of a small length with a significant limitation of heat input and the use of welding consumables, as a rule, high-nickel ones, impeding the carbon diffusion from base metal into weld. The welding should be carried out in a narrow gap, keeping a certain sequence of its filling, without transverse electrode oscillations and it should be accompanied by layer-by-layer peening of the welds. The approach to selection of rational welding method and welding consumables was practiced. The several variants of modern welding wires and electrodes of domestic and foreign production were tested, which are necessary for welding of gray cast iron. It was established that for welding of «French» cast iron only the mechanized method of welding by self-shielding high-nickel wire of grade PANCH-11 [7] of 1.2 mm diameter (TS48-21-593–85, and only of 1987 year of production) meets mostly the specified requirements. The welded joints produced by PANCH-11 are characterized by higher resistance against near-weld cracks as compared to the joints produced by the analogues of this wire and by electrodes for manual welding with identical chemical composition of weld metal. The wire composition allows carrying out welding without preheating. At the same time, the producing of plastic austenitic weld with a hardness of not more than *HV* 200 is provided. The properties of welded joint are generally determined by the properties of base metal. In the fusion zone, a noticeable amount of ledeburite and structurally-free cementite is not observed. In the HAZ metal, there are products of non-equilibrium decay of austenite (troostite, martensite), which slightly increase the hardness to *HV* 350. Since the width of HAZ does not exceed 150 μm, its effect on properties of joints is insignificant. The composition of the wire PANCH-11 also provides a high resis-

Figure 6. General view of railing ensemble (August-September 2017): *a* — appearance of renovated panel of railing grates; *b* — under emblem grate with emblem (view from the sidewalk); *c* — view from the outside of the bridge

Figure 7. General view of the reconstructed bridge with the restored architectural and decorative railing elements (November, 2017)

tance of welds to hot cracks formation as a result of neutralizing harmful impurities and imparting a globular shape to non-metallic inclusions.

The stable process of welding using the wire PANCH-11 is easily carried out at the direct polarity and at the mode: I_w = 110–140 A, U_a = 16–18 V, which is necessary for the aims of low heat input into the base metal. The penetration depth of the base metal is 1.5–2.0 mm. The welding can be performed in all spatial positions, but the priority is given to flat and inclined positions. The weld metal is characterized by such indicators of mechanical properties as: σ_y = = 350 MPa, σ_t = 450 MPa, δ = 15 %. The specimens for static tension are fractured outside the weld metal. A significant advantage is the possibility of welding into a narrow gap in the form of a slot, which greatly facilitates the producing of joints without longitudinal and transverse cracks, as well as combined joints with steel.

Based on the results of investigations, an optimal welding repair technology was developed, applied for all architectural and decorative elements of railing, requiring restoration and a detailed plan for their restoration was elaborated, taking into account the real condition. The features of the technology are reflected in the instructions for each repair case (WPS) according to the requirements of GOST 30430–96 to the process of welding cast iron. The results of restoration works are shown in Figures 5, 6. In August 2017, after primer painting, the restored railing was installed on the Day of the City, celebrated in September, on the reconstructed Kotzebue Bridge, and subsequently in November, after the completion of the entire complex of finishing works at the adjacent territory and installation of lanterns, all the metal structures were repeatedly sand blasted and painted in the color specified by the Project (Figure 7).

Finally, it should be noted that during preparatory and restoration works of the entire set of architectural and decorative railing elements of the bridge, a number of errors and omissions were eliminated, committed during creation as well as during restoration in the past years and, applying the appropriate design and technical solutions as well as modern welding technologies and consumables, they were made as very reliable railing elements. The main principle followed by the specialists was the maximum preservation of authenticity and load-carrying capacity of the restored elements. The desired result was achieved due to the business and constructive cooperation of the organizer and the participants of the Project, as well as the advisory support of the Department of Cultural Heritage Protection of the Odessa State Administration.

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