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Review of Robot Welding Technology in Tsu Works, JFE Engineering†

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Abstract:

Welding process utilizing robot equipment has been developed and operated at Tsu Works, JFE Engineering for the purpose of production cost reduction and quality improvement of bridges. This paper summarizes the steps taken for such robot welding technology to date from early 1990s.

1. Introduction

Full-scale application of welding robots in bridge fabrication developed at a fast pace from the second half of the 1980s. This was due to the appearance of articulated robots, which began to be adopted rapidly in the early 1980s, and the development of systems that utilized/expanded design information to production information. JFE Engineering's Tsu Works also sought the ideal form of a new works, and established a mid-term plan for modernization of works equipment at the beginning of the 1990s, with the aims of higher quality and deskilling the production process. During fiscal years 1991–1993, Tsu Works successively introduced modernization equipment from upstream to downstream in the laser cutting line, box girder panel fabrication line, I-girder panel fabrication line, lateral rib fabrication line, automatic light-chamfering line, and new paint shop[1–3]. Welding robots were also introduced at this time, marking the start of full-scale application of welding robots at Tsu Works.

Table 1 shows the transition of robot welding technology at Tsu Works. Following the works equipment modernization plan, welding robot equipment was introduced and welding processes were developed and applied corresponding to the object of application and trends of the times, with the aims of improving the quality of bridges and other products and realizing deskill-

Table 1 Robot welding technology transition in Tsu Works

1990s	1992	Box girder panel fabrication lines (Web panel welding robot system, Flange panel welding robot system)	Panel fabrication approach High speed rotating arc welding process Teaching-less CAD/CAM system	Fillet welding Arc sensor
	1994	I-girder panel welding robot system Lateral rib fabrication line	Box fabrication approach	
2000s	2002	Steel segment welding robot system Portable multi-layer welding robot "Ishimatsu"	Use positioning units Portable transverse coordinate type robot	Vertical, Lap, Groove Groove welding adaptive control
	2004	Web panel welding robot system (Renewal)	Mobile gantry type welding robot	Wave-shape web panel U-rib steel plate deck
	2006	I-girder panel welding robot system (Renewal)		Gouging-less welding process
	2007	Flange panel welding robot system (Renewal)	Transverse coordinate type robot, 10 torchs	U-rib 75% penetration
2010s	2013	I-girder panel welding robot system (Expansion)	Welding wire auto changer Simple CAM system	Flexible application Expansion of adoption

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ing. This paper introduces selected examples of efforts in connection with robot welding technology at Tsu Works from the period of works equipment modernization to the present.

2. Introduction of Robot Technology for Equipment Modernization

Although steel bridges take numerous forms, many of their main members are box type or I type. Their upper and lower members are called flanges, the lateral material is called the web, and small strip stiffeners are attached to the large rectangular main plates. A study on factory fabrication of these members was carried out, including assembly methods and welding methods, and welding robots were independently developed and introduced.

At the time, box girders were fabricated by a method in which stiffeners were temporarily attached to the web and flanges, the parts were assembled into a box shape, and all welding was then performed together. Thus, welding work was performed in the narrow, complex environment inside the box girder. In introducing welding robots, a panel method was adopted, in which both the web and the flanges take the form of panels, and horizontal fillet welding of the stiffeners and other parts is performed. In I-girder panel fabrication, a segmented assembly method was used, with the flanges and web being welded first, and the stiffeners attached in the succeeded process. However, in robotization, a simultaneous one-step assembly method (fillet welding of object joints) was adopted. This reduced the number of processes and area occupied by the equipment, and lightened auxiliary work such as applying preset distortion and distortion removal work.

Moreover, in the robot welding process used in ordinary bridge fabrication, the main stream is fillet welding by gas shielded metal arc welding, in which the torch is weaved to the right and left. In contrast to this, JFE Engineering achieved high efficiency and high accuracy by adopting the high speed rotating arc welding process[4,5], which is a unique JFE Engineering welding process. The welded joints which were the object of this process are 1-pass fillet welds.

In applying robot welding to bridges and similar structures consisting of comparatively large members with mostly different shapes, a teaching-less robot system that makes it possible to eliminate teaching work for each of the multiple welding robots is indispensable. JFE Engineering developed a teaching-less CAD/CAM system based on a lofted drawing system (NEW-BRISTLAN) that links design information to production information (member shape data and welding data can be used)[6].

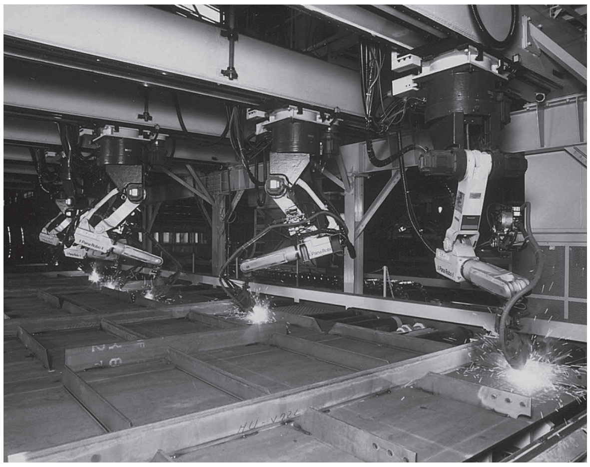


Photo 1 Web panel welding robot system

Integrating the technologies described above, the box girder panel fabrication lines (web line, flange line) and the I-girder panel fabrication line were put into operation. **Photo 1** shows the web panel welding robot system, which was the first welding robot system at Tsu Works.

3. Robot Welding Technology for Steel Segments

When constructing underground tunnels by the shield method as part of improvement of the urban highway network, large-scale steel segments are used in locations where large cross-sectional forces act on the structure. Although steel segments may be either square shaped or ring shaped, the individual segments are box shaped and one side is opened. Since it is necessary to produce a large number of blocks with similar shapes in the steel segment fabrication process, application of a dedicated welding robot system which enables repeated production with high quality and high efficiency is advantageous. In addition to horizontal fillet welds and vertical fillets welds of square structural parts, the welded joints in steel segments also include lap fillet welds of outer plate parts and groove weld joints of frame end parts. In the welding robot system, a method in which members are handled by a positioner and linked with articulated robots was adopted in order to avoid difficult welding positions and maintain quality. A dedicated CAD/CAM system is used to generate robot data, and the range of application of robot welding was maximized by checking for robot interference in narrow spaces in each segment type and size by using a robot simulator and advance study of the welding position/operating patterns on a computer. **Photo 2** shows the application of the steel segment welding robot system[7].

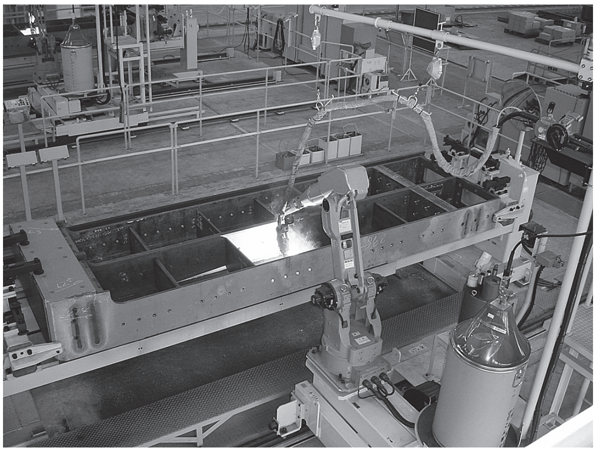


Photo 2 Steel segment welding robot system

Photo 3 Web panel welding robot system (Renewal)

4. Welding Robot Renewal and Robot Welding Technology

The beginning of the 2000s, the welding robots (web line, flange line, I-girder line) introduced at the beginning of the 1990s had been in service for more than 10 years and were due for renewal. In this renewal, the welding process and equipment system were studied corresponding to the features of the object members with the aims of further stabilizing quality and also expanding the range of application of robot welding.

4.1 Web Line

In renewal of the web line, the same high speed rotating arc welding process was adopted in the welding process, and the advantages of high current, deep penetration welding and high accuracy seam tracking by the high speed rotating arc sensor were continued. For the robots, a specification in which two 6-axis articulated robots are suspended from one mobile gantry was adopted with the aim of expanding the range of operation in comparison with the conventional type, and each of the robots was given a degree of freedom that enables independent traversing, vertical movement, and traveling. These features expanded the range of applications to include not only flat plate structures, but also 3-dimensional structures. This made it possible to extend application of the system from horizontal fillet welding of simple web panels to continuous welding of vertical fillet welds after horizontal fillet welding of deck slabs and continuous welding of wave-shape webs (3-dimensional work), etc. **Photo 3** shows the application of the web panel robot welding system, and **Photo 4** shows an example of the result of application to a wave-shape web.

4.2 Flange Line

In the renewal of the flange line, the equipment composition was studied considering minimization of the risk of breakdown and simultaneous welding of a larger number of ribs. Because the panels which are welded at the flange line have comparatively simple structures, a complex robot approach position and operation are not necessary when approaching joints. Therefore, a 4-axis transverse coordinate type welding head was selected rather than an articulated robot, and a simple high rigidity structure with low risk of malfunction was adopted. The number of welding heads was also increased from 6 to 10 in order to increase production capacity.

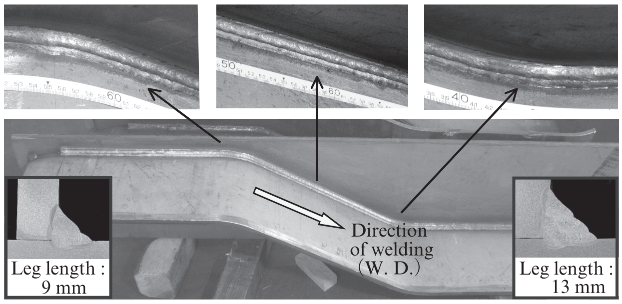


Photo 4 Wave-shape web welding bead appearance

Considering the long joint length, the same high speed rotating arc welding process as in the past was adopted, as this technology provides superior high speed welding and seam tracking performance. The main object joints are vertical ribs attached to flanges and horizontal fillet welds of deck slab U-ribs. This system enables 1-pass fillet welding up to a leg length of 11 mm. When welding deck slab U-ribs, Specifications for Highway Bridges requires that the penetration depth secure at least 75% of the plate thickness in the U-rib plate thickness direction in order to prevent fatigue cracks. Satisfactory results can also be obtained in this regard by high current, deep penetration welding by the high speed rotating arc and high accuracy seam tracking performance (securing the aimed position) by the rotating arc sensor, which are features of this system. **Photo 5** shows application of the robot to a U-rib, and **Photo 6** shows an example of the U-rib bead appearance and weld macro section.

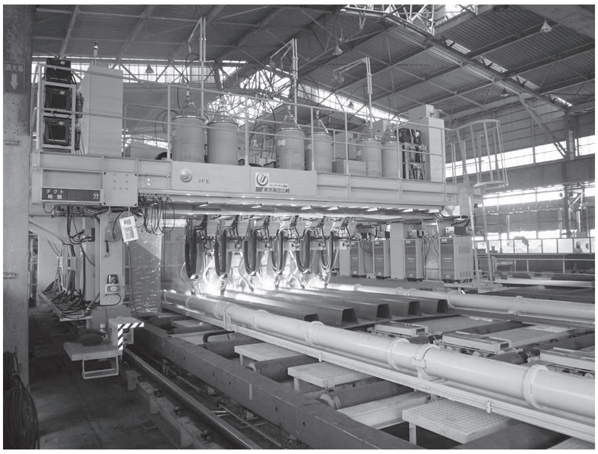


Photo 5 Flange panel welding robot system (Renewal)

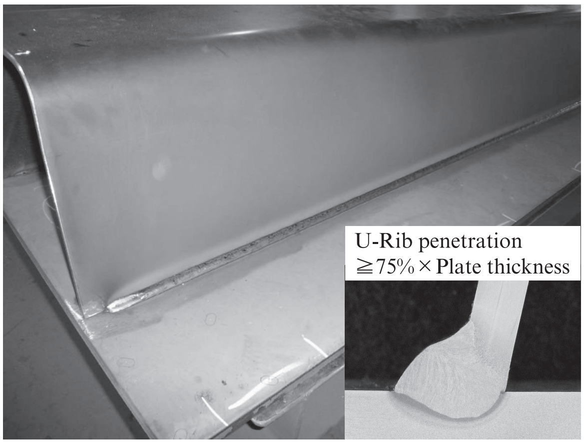


Photo 6 U-Rib bead appearance and macro section

4.3 I-girder Line

The I-girder line is a main facility which was introduced continuing on the box girder panel lines (flange, web). As mentioned previously, a simultaneous one-step assembly method was adopted in robotization. This renewal was carried out using the same mechanism and functions as the above-mentioned web robot system, giving the line higher generality.

The applications of robot welding were expanded to include not only conventional fillet welding, but also groove welding. A new robot welding process (gouging-less full penetration welding process) which does not require gouging when performing groove welding was developed and applied. Although it is essential to control the groove accuracy of the welded joint, this is a revolutionary welding technology that makes full use of the advantages of the high speed rotating arc welding process. **Photo 7** shows examples of the macro section of gouging-less full penetration welds.

Furthermore, in 2013, the number of I-girder welding robots was increased in order to expand production capacity in response to increased I-girder construction. In addition to the same mechanism and functions as described above, these robots were also equipped with a

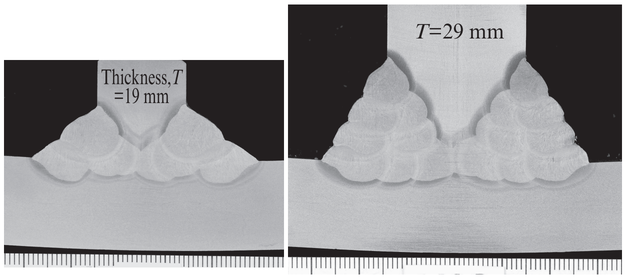


Photo 7 Gouging-less welding process macro section

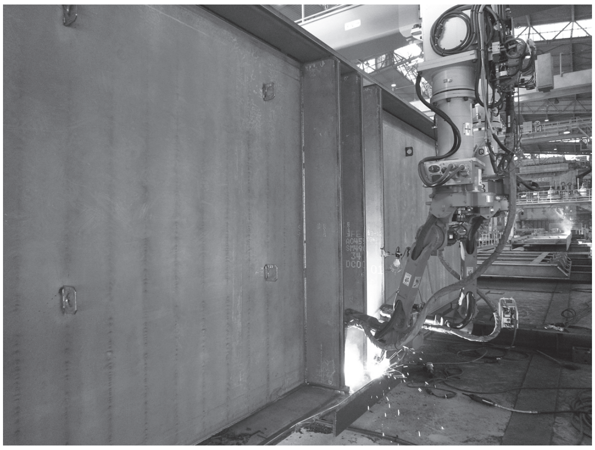


Photo 8 I-girder panel welding robot (New)

wire auto-changer, which automatically switches between solid wire and flux cored wire, and a state-of-the-art digital power source was adopted to enable more flexible operation. A compact version of the high speed rotating arc welding torch was applied, making it possible to enter narrower spaces. **Photo 8** shows application of this new robot to full penetration groove welding of the supporting point of an I-girder panel in a vertical position. We aim at greatly improving the robot welding application rate by these measures at Tsu Works.

5. Application of Portable Welding Robots

Application of robot welding at Tsu Works is not limited to large-scale fixed line-type robot welding systems; portable welding robots are also applied, depending on the object. For example, the corner joints of bridge piers are fabricated by groove welding of heavy plates, and this is difficult welding that requires not only cutting and fitting accuracy, but also adjustment of the welding parameters for joint deformation due to thermal deformation during welding, etc. Commercially-available portable multi-layer welding robots[8)] are applied to this kind of welding. This type of robot has an automatic welding parameter generating function in which the welding parameters are preset for each thickness, joint type, and welding position, and groove sensing teaching is only necessary at the starting and end positions (arbitrary number of intermediate position, depending on the

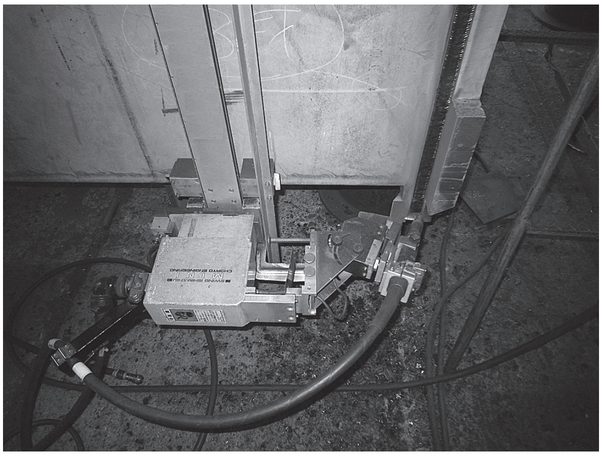


Photo 9 Portable welding robot

joint length). A multiple welding robot system with one operator has been implemented with the aim of achieving more effective operation. **Photo 9** shows the condition of installation of a portable welding robot.

6. Improvement of Welding Process

From the viewpoint of easy response to large leg length fillet welds, elimination of the need for slag removal, etc., the wire used in robot welding was generally a solid wire. However, use of flux cored wire (FCW) is also increasing in order to further stabilize welding quality, including stabilization of bead appearance, reduction of spatter, reduction of blowholes, etc. **Figure 1** shows an example of the results of robot welding using FCW; extremely good welding results were obtained. Recently, in combination with progress in welding wires, 1-pass fillet welding of a large leg length up to 8 mm has become possible, and solid wires and FCW are used properly in respective applications, depending on the welding object.

Moreover, conventional robot welding had centered on fillet welding, a general 1.2 mmφ welding wire diameter was used, but the joints to which robot welding is applied are no longer limited to simple fillet welds. Due to the increasing number of joints in which greater penetration depth stability is required, such as partial penetration groove welding, full penetration groove welding, and the like, the welding wire diameter used in robot welding has changed to 1.4 mmφ. Stable penetration

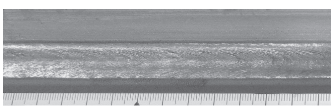
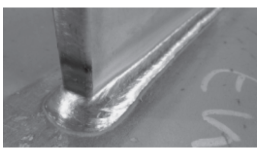
Leg length : 8 mm	Cornering bead (Start end)
	

Fig. 1 Example of bead appearance (FCW)

(weld quality) can be obtained, as stable welding with a higher welding current is possible.

7. Response to Product Diversification

Fillet welding (and some groove welding) of standard-shape members such as box girder panels (flange, web) and I-girder panels is linked to a teaching-less CAD/CAM system, and robotization of this type of welding has taken firm root. However, in recent years, there has been an increase in the number of members that have comparatively simple shapes but are not ordinary bridges panels, such as composite deck slab bridges, steel sea walls, etc. With these types of members, preparation of the data for operation of welding robots by the normal routine would require much time and labor. To enable faster and more flexible operation, a quick, simple technique for preparing NC programs for robots using only 2-dimensional design information was developed, and I-girder welding robots and web welding robots were applied to various types of actual projects. This has improved the robot working ratio and is also contributing to stabilization of quality. **Photo 10** shows application of a welding robot system to a com-

Photo 10 Composite deck slab bridge

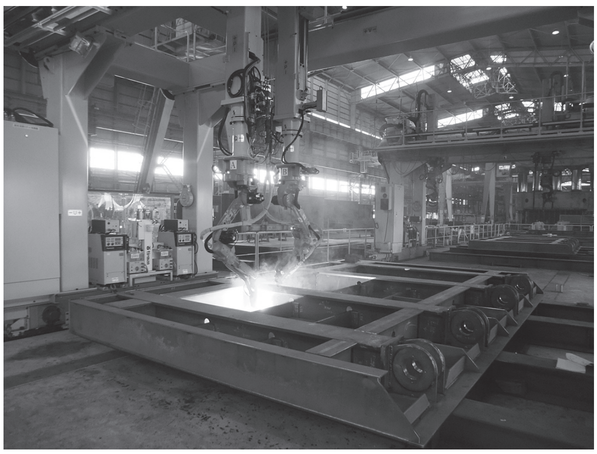


Photo 11 Steel sea wall

posite deck slab bridge. **Photo 11** shows application to a steel sea wall.

8. Future Outlook

Full-scale application of welding robots to bridge fabrication began in the second half of the 1980s and now has a history of more than 20 years. At the time, annual increases in the application of welding robots and progress of large-scale computer integrated manufacturing (CIM) were predicted (expected). At present, however, even after 20 years, there has been no large increase in the welding robot application ratio. **Figure 2** shows the ratios of automatization and robotization of MAG/MIG welding in various industries, as estimated from the results of a survey of the use of welding consumables. In the bridge field, automatization of welding is somewhat more than 20%, but robotization is limited to only about 10%[9]. This is attributed to the special features of the members in bridge fabrication (small lot/multiple type production, large scale, comparative complexity, closed structure, etc.), the high level of inspection requirements, and similar factors.

As described above, at JFE Engineering's Tsu Works, flat panel fillet welding (and some groove welding) is linked to a teaching-less CAD/CAM system and robot welding is now firmly established. Moreover, thanks to efforts to utilize robots more generally and progress in the welding process, application is gradually expanding to non-standard-shape members and joints, and use of the proper material in the proper place, as exemplified by application of portable robots, is also progressing. As a result of these efforts, Tsu Works has achieved a comparatively high level of welding robotization, at approximately 20%.

In the future, it will be desirable to expand application from flat panel structures to more structurally complex 3-dimensional structures, as represented by welding the inner sides of box girders. To realize this, it will be necessary to develop a robot mechanism and composition which are capable of entering closed and narrow spaces, sensor technology, technology for simplification of the preparation of robot operating programs, etc. Study of design and fabrication methods for structures which robots can easily approach will also be an important issue. In addition, innovation of revolutionary welding processes that utilize new welding methods (laser welding, laser-arc hybrid welding, etc.) is a challenge that should be addressed in the future.

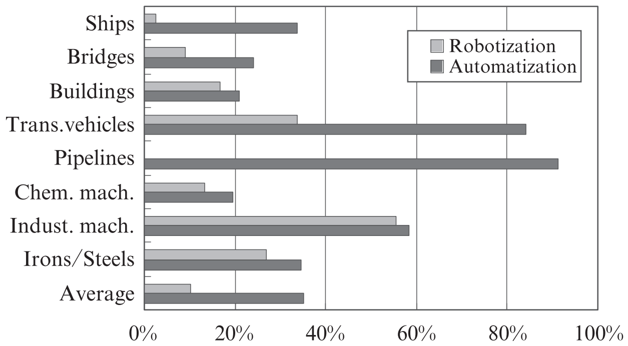


Fig. 2 Ratios of automatization and robotization in MAG/MIG welding[9]

9. Conclusion

This paper has introduced selected examples of robot welding technologies that have been applied at Tsu Works, JFE Engineering, from the beginning of the 1990s up to the present with the aims of reducing fabrication costs and improving the quality of bridges and similar structures. Results which fully satisfy the predicted effects when introduction was planned have been obtained with the robot welding technologies applied to date. Because increasing high demands for quality stabilization and deskilling are assumed in the future, heightened expectations will also be placed on welding robots. In the future, the authors will continue to explore and promote the optimum robot welding technologies corresponding to the object of application.

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