NIPPON STEEL TECHNICAL REPORT No. 82 JULY 2000

UDC 624 . 1 : 621 . 791 - 52

Steel Welding Technologies for Civil Construction Applications

Hiroshi TACHIKAWA*1 Takeshi UNETA*1
Hidetaka NISHIMOTO*1 Yasuo SASAKI*1
Jun YANAI*1

Abstract

Despite the recent economic slump, particularly in the construction industries, demands for automation in the field of civil construction are very strong. Those demands are for new automatic welding apparatuses incorporating quality assurance techniques, such as joint monitoring have become especially strong after the big earthquake in the Hanshin-Awaji area in January, 1995. Nippon Steel Corporation has developed various automatic welders and welding methods for civil construction applications in response to those demands. This paper deals with the technical features and actual field use of the following welding technology products: "NS Stud Method" which has already been widely used for instantaneously welding deformed bars with pipe pilings or plates incorporating a high performance level quality assurance system; "NS-MAG Method" for welding large diameter reinforcing bars for the same application as above; "NS Robot 51" for automatic butt welding of reinforcing bars; "Plate Welding Robot" with the same technical principle of NS Robot 51 applied for butt welding of plates which proved its high performance in concrete bridge pillar reinforcing works as countermeasures against earthquake and; "Automatic Rail Welder" capable of quickly joining rails without being affected by a welder's skill.

1. Introduction

In response to the recent great expectations for automatic welding methods independent from the skill of individual welders in the fields of civil engineering and building construction, Nippon Steel has developed a wide variety of automatic welding machines and applied them to field construction work. But automation is not very popular among field workers in general: if a new automatic welding machines do not soon find acceptance in the field, they will soon be thrown aside and forgotten. We have always kept this fact in mind when developing new welding processes. This paper describes automatic welding machines Nippon Steel developed for the civil engineering use and their field application examples.

2. Development of Reinforcing Bar Welding Techniques

2.1 NS Stud Method

Nippon Steel developed a stud welding technique - NS Stud Method - to weld long and large size deformed reinforcing bars used in civil construction work horizontally to steel materials such as pipe pilings and then, as an extension to the NS Stud Method, a multi stud welding machine applicable to the construction of composite struc-

*1 Civil Engineering & Marine Construction Division tures such as concrete connections of pier footings for roadway bridges. The company also developed a monitoring device for welding quality control at construction sites. Actual field applications of these technologies are described hereafter.

2.1.1 Characteristics of NS Stud Method

The NS Stud Method has the following advantages:

(1) High reliability joint: highly reliable joints are obtained by welding of newly developed highly weldable deformed reinforcing bars with a new type high responsiveness stud gun, directly to steel pipe pilings.

(2) Horizontal stud welding of long and large size deformed bars: 19 or 22 mm diameter deformed bars of any given shape and length can be stud-welded with the newly developed servo-motored stud gun.

(3) Automatic multiple stud welding machine: High efficiency work is made possible, safely and reliably, due to the use of an automatic multiple stud welding machine capable of welding 4 to 10 bars in sequence either horizontally or vertically.

(4) Welding quality control of all the studs by a monitoring system: Welding quality of all the studs is controlled through monitoring of the welding conditions during the stud welding of the bars.

(5) Steel-concrete composite structure: In the concrete structures, conventionally, it was not practicable to use the same deformed bars for both the concrete reinforcement and the steel-concrete connection purposes. As the NS Stud Method can weld long deformed bars, however, the steel-concrete connection members (studs) can be used also as the concrete reinforcing members.

2.1.2 Quality control in NS Stud Method

By the stud welding, the welding process is completes within 1 sec. For the purpose of clarifying various phenomena involved in the quick stud welding, we recorded and analyzed welding current, voltage and the forward/backward movements (draw/ thrust) of the bar to be stud-welded and, as a result, discovered important factors of the stud welding quality. The discovery included things such as that no short circuit should occur to the welding voltage before the stud bar is thrust in, and that any one of the welding current, the welding time, and the strokes of the backward (draw) and forward (thrust) movements of the bar should be controlled within respective permissible ranges. On these bases, we measured various welding phenomena at each stud welding with the monitoring device shown in **Fig.1** and worked out a monitoring screen shown in **Fig.2** using a computer. In parallel, we worked out a quality control system whereby quality of each stud welding was judged based on whether or not each of the factors was within the respective range shown in **Table 1**. This system gained popularity because it enabled the users to judge the welding quality non-destructively and control the quality of all the welds.

2.1.3 Field applications of NS Stud Method

(1) Application to bridge pier footing concrete connection work

In the foundation work using steel pipe pilings, footing concrete (pile cap) has to be connected to the inner face of the pipe-piling wall. This was conventionally done at the site either by welding a steel plate to the pilings or inserting reinforcing bars through holes drilled into them. The NS Stud Method, in contrast, is an epoch-making technique capable of reducing the work period and enhancing the welding quality by stud-welding highly weldable deformed bars directly to the pipe pilings. **Fig.3** shows an outline of the pile cap connection work of a bridge pier footing.

A hundred or so of long deformed bar studs have to be welded to a piece of pipe piling in the pile cap connection work of a bridge pier footing. In order to improve stability, reliability and efficiency of the work, we developed an automatic multi-stud welder capable of automatically welding a required number of long deformed bar studs in the horizontal direction as well as moving the welding heads vertically. **Fig.4** is a schematic illustration of the pile cap connection work

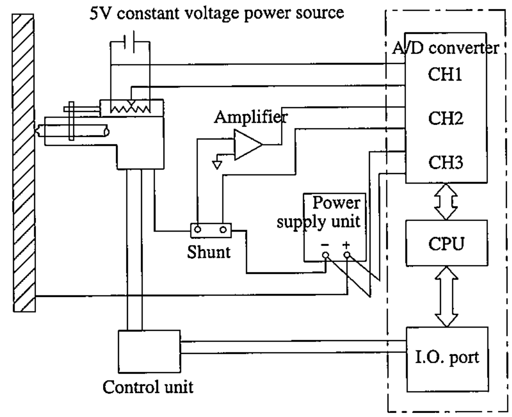


Fig.1 Block diagram of monitoring device

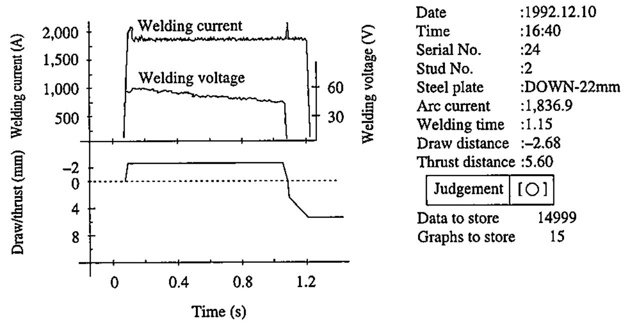


Fig.2 Monitoring screen

Table 1 Control ranges of monitored data

	19 mmϕ	22 mmϕ
Welding current	1,400-1,900 A	1,700-2,100 A
Arc time	0.9-1.3 s	0.9-1.3 s
Draw distance	1.5-3.5 mm	1.5-3.5 mm
Thurst distance	4.5-7.0 mm	4.5-7.0 mm
Short circuit	No	No

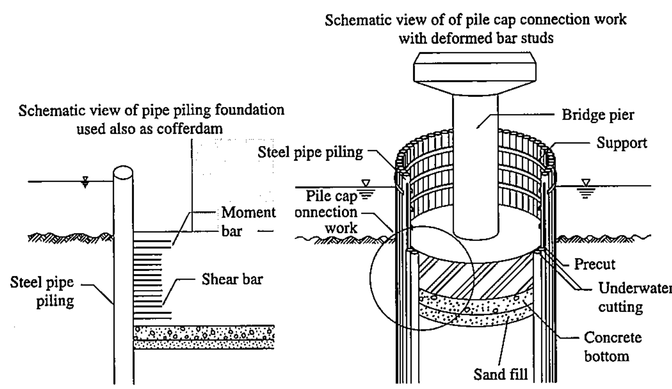
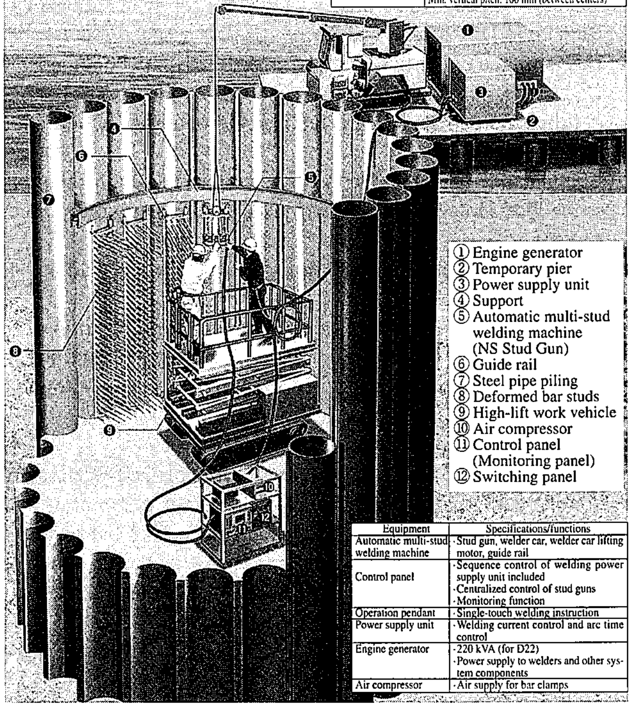


Fig.3 Outline of pile cap connection work of bridge pier footing

Item	Specifications
Pipe piling diameter	800 mm or larger, in principle
Number of stud guns	As required (usually 4)
Deformed bar studs	D19, D22
	Min. horizontal pitch: 100 mm (between centers) Min. vertical pitch: 100 mm (between centers)



Equipment	Specifications/functions
Automatic multi-stud welding machine	·Stud gun, welder car, welder car lifting motor, guide rail
Control panel	·Sequence control of welding power supply unit included ·Centralized control of stud guns ·Monitoring function
Operation pendant	·Single-touch welding instruction
Power supply unit	·Welding current control and arc time control
Engine generator	·220 kVA (for D22) ·Power supply to welders and other system components
Air compressor	·Air supply for bar clamps

Fig.4 Example of pile cap connection work of pipe piling foundation

of a foundation with pipe pilings using the developed equipment.

Today, a crew of four workers can weld 600 - 800 studs a day with a 4-stud welding machine under usual working conditions of the pile cap connection work.

(2) Another application

As stated above, the NS Stud Method can work either horizontally or vertically. Applications of the vertical movement include its use for the composite structure of sunken tunnel elements. The sunken tunnel element method is a method to construct an underwater tunnel whereby a tunnel element (immersed tube) is prefabricated at a fabrication yard such as a dry dock, sealed to float on the water, towed to the construction site and then sunken for installation at a predetermined position. The composite structured sunken tunnel element is a type of element wherein its steel plate outer skin, conventionally used only for making the element watertight, is effectively utilized also as a structural member by combining it with the concrete with headed studs and long deformed bars.

The welding of the studs for the sunken tunnel elements is done mainly in flat position. In order to weld 4,000 studs a day, a plurality of welding machines were used, to which were introduced a series of improvements such as enhanced operability for the welding in large quantities in good quality and the incorporation of as much human skill as possible into the machine system. **Photo 1** shows a work scene of the above-described equipment of the NS Stud Method applied to the fabrication of sunken tunnel elements for the Osaka Nanko immersed tube tunnel. The systematized work process of the method is highly evaluated due to its enhanced work efficiency and quality control capability, and more than 1.6 million studs have been welded by the method. As described above, the NS Stud Method has not only effectively responded to the demands for future automation and

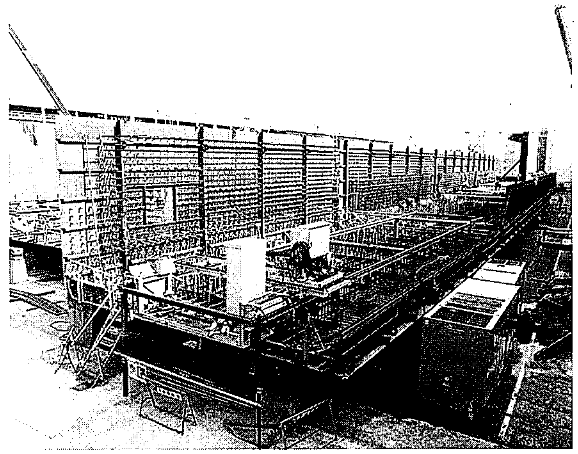


Photo 1 Work scene of sunken tunnel element

robotization of the field work of civil engineering but contributed to enhancement of structural reliability and reduction of construction period as well.

2.2 NS-MAG Method

In the NS Stud Method it is essential to melt an end of a reinforcing bar instantaneously and thrust the bar into the molten metal pool while it is hot. The method is applicable only up to D22 at flat position. In response to further needs, we developed another process to weld larger diameter bars to steel pipe pilings or plates - NS-MAG Method.

2.2.1 Principles and process of NS-MAG Method

By the NS-MAG Method, it is possible to easily weld deformed bars, from D13 to D51 in size, by gas-shielded arc welding without requiring much skill, by maintaining a groove between the bar and the plate/piling with a windowed ferrule shown in **Fig.5** and by moving a thin solid wire in the groove thus formed as shown in the same figure. The end of the bar to be welded is cut in right angles. The process is applicable to the bars produced either by the blast furnace operators or the electric arc furnace operators. **Photo 2** is a metallographic macro-photograph of a test piece section of a D32 bar welded by the NS-MAG Method.

2.2.2 Field applications of NS-MAG Method

The NS-MAG Method has earned applications to widely varied projects such as the bridge pier reinforcement works of the Meishin

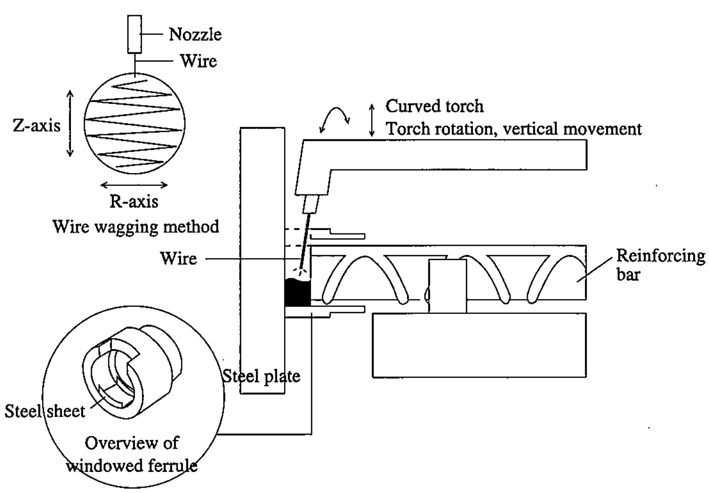


Fig.5 NS-MAG Method

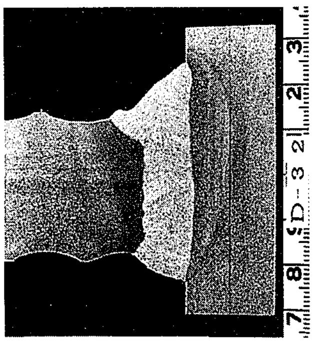


Photo 2 Sectional macro-photograph of weld by NS-MAG Method

Expressway (Kinki Region), the construction of the Minatomirai-Takashimacho Station (Yokohama) and other building construction works.

2.3 NS Robot 51

The NS Stud Method and the NS-MAG Method are for welding reinforcing bars to steel pipes or plates, but an overwhelmingly higher number of welds are done to weld bars to bars. Before the Hanshin-Awaji Earthquake in 1995, gas pressure welding accounted for 96% of the bar-to-bar connections up to D32, and gas pressure welding, mechanical joint and enclosed arc welding were employed in nearly equal shares for D35 and larger bars, but the percentage of gas pressure welding has tended to decrease since the Earthquake. Nippon Steel promoted robotization of welding work to make it independent of human skill, aiming at automatization of enclosed arc welding, and developed a three-axis control welding robot to connect reinforcing bars named "NS Robot 51." It has the following advantages:

(1) Bars up to D51 can be welded.
(2) Bar arranged either horizontally or vertically can be joined.
(3) D51 can be joined as quickly as in about 3 min.
(4) A fully automatic welding is realized by robotization, not requiring skilled welders.
(5) The machine is applicable to connecting of the reinforcing bars embedded in concrete, because no upsetting is involved in the process.
(6) Welding quality is controlled through monitoring of welding conditions.

Fig.6 shows an example of the equipment configuration of the NS Robot 51, **Fig.7** an enlarged view of the equipment and **Fig.8** a computer screen for monitoring. Metallographic macro-photographs of the joint sections are shown in **Photo 3**.

2.3.1 Field applications of the NS Robot 51

The NS Robot 51 has been applied to the projects such as the reinforcing bar repair welding works of the bridge pier pilings damaged in the Hanshin-Awaji Earthquake, reinforcing bar joints for sunken tunnel elements, reinforcing bar arrangement for foundation of new bridge piers, and so on. **Photo 4** shows a field application of the NS Robot 51 to the Hanshin Expressway System.

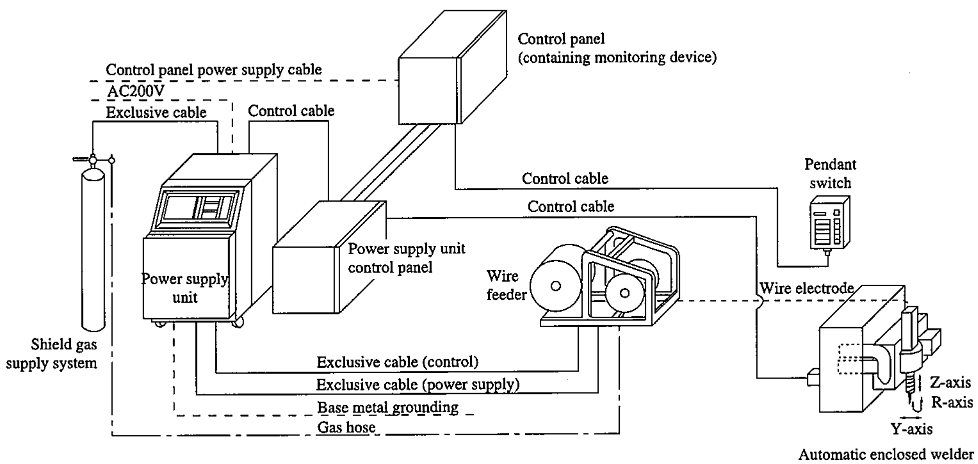


Fig.6 Equipment configuration example of automatic enclosed welder

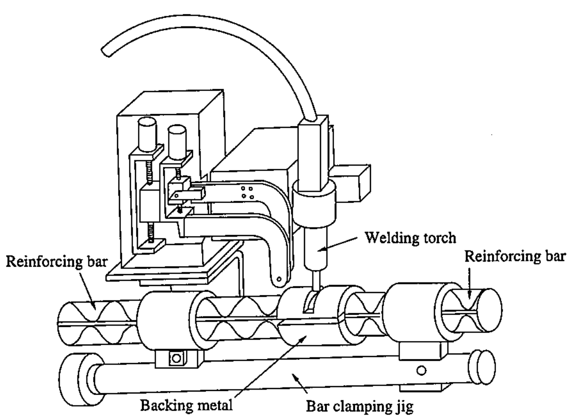


Fig.7 Example of welding jig for automatic enclosed welder

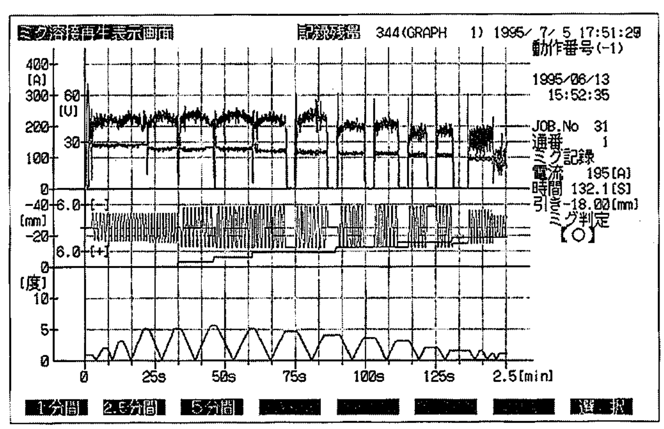


Fig.8 Example of monitoring screen of NS Robot 51

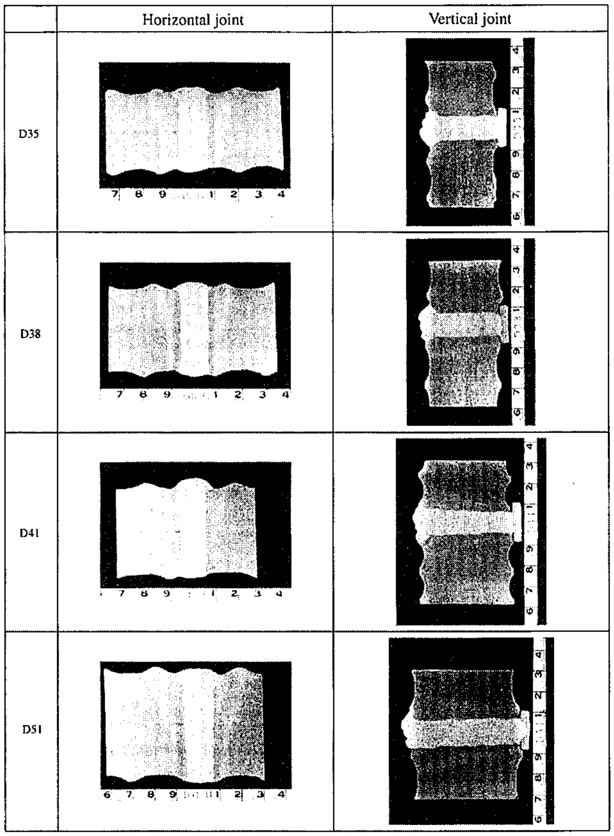


Photo 3 Sectional macro-photographs (D35-D51)

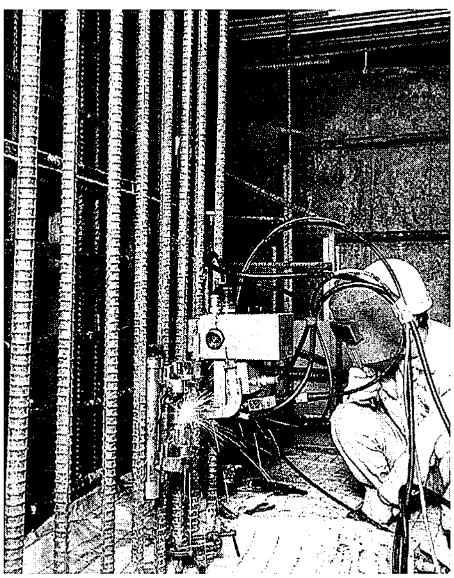


Photo 4 Field application of NS Robot 51

3. Welding of Steel Plates

3.1 Plate Welding Work by the NS Robot 51 for Bridge Pier Reinforcement against Earthquake

A great number of bridge pier reinforcing works were carried out after the Hanshin-Awaji Earthquake, wherein the bridge piers were wrapped with steel plates for enhancing their resistibility against earthquake. Nippon Steel actively undertook this type of works, where an automatic steel plate welding system using the NS Robot 51 was widely applied.

3.1.1 Characteristics of automatic plate welding machine

(1) The NS Robot 51 is mounted on a welder car to weld steel plates automatically.

(2) Three axes are automatically controlled, namely the directions of the travelling, groove width and groove depth.

(3) Welding in both horizontal and vertical positions is possible.

(4) In order to cope with fluctuation of groove shape, the welding is proceeded through copying of the groove line by teaching and automatic control of welding speed and wire wagging amplitude in accordance with the cross section area of the groove.

3.1.2 Field applications

Fig.9 is schematic illustrations of the welding operations, and **Fig.10** shows the configuration of a field welding system. The guide rail is fixed roughly in parallel to the groove line with magnets and

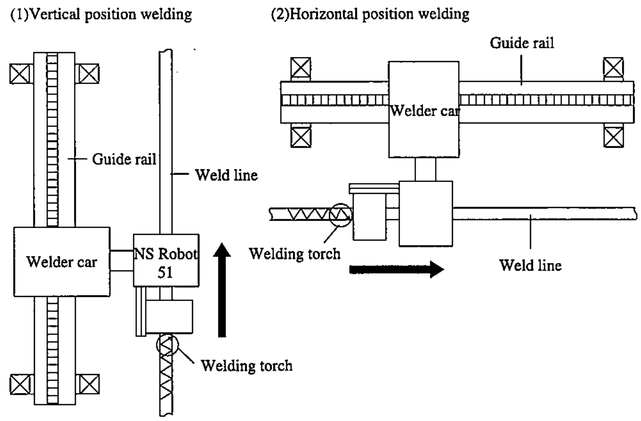


Fig.9 Schematic view of welding operations

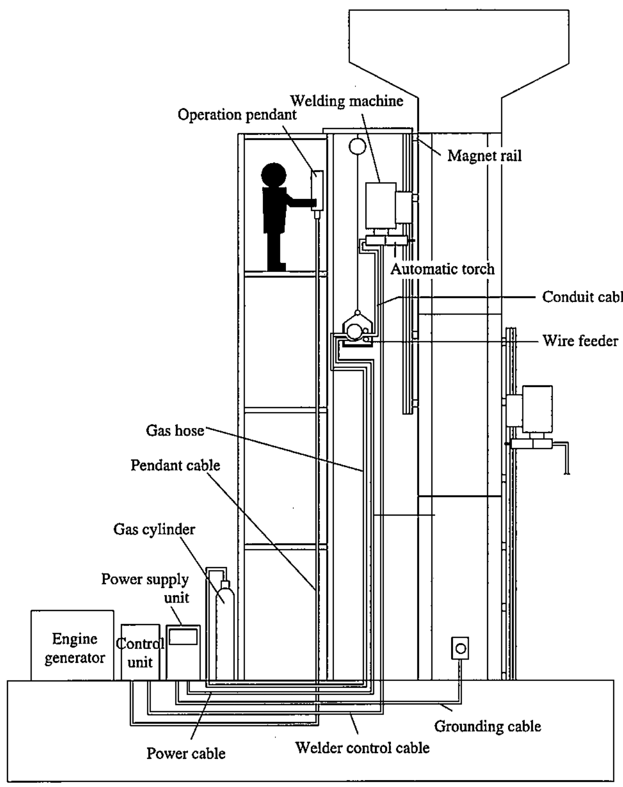


Fig.10 Configuration of field welding system

the welder car is mounted on the rail. An operator teaches the shape of groove during a non-welding travel before the actual welding, instructing 3 to 4 points of groove inflection and groove width change per meter. Then, the NS Robot 51 proceeds with automatic multi-layer welding controlling the welding speed and torch oscillation amplitude in compliance with the groove width. Typical groove shapes and weld layer arrangements are shown in **Fig.11** and an actual field operation scene and the appearance of a weld bead in **Photos 5 and 6**, respectively.

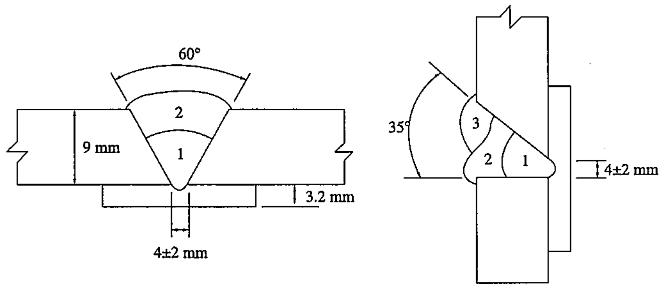


Fig.11 Typical weld layer arrangement

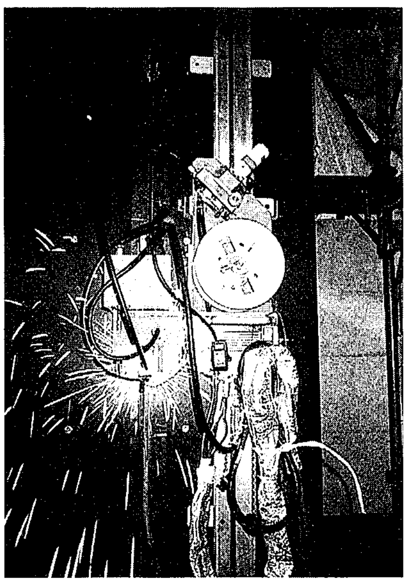


Photo 5 Field operation scene of automatic plate welding machine

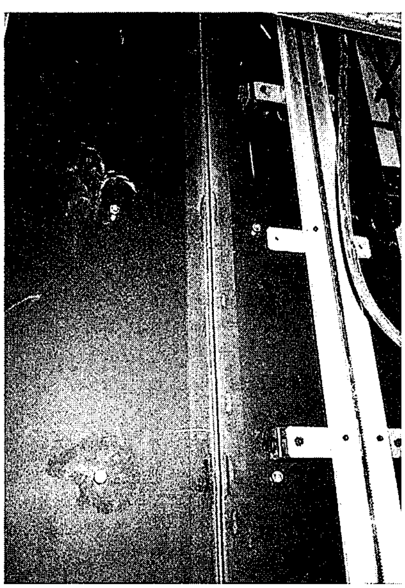


Photo 6 Weld bead appearance

4. Automatic Welding of Rails

Welding of rails is done by methods such as flash-butt welding, gas pressure welding, thermit welding, enclosed welding, and so forth. Each of these methods is employed according to its respective characteristics. As a substitute for enclosed welding and thermit welding, Nippon Steel has newly developed an automatic rail welding method (ARW) based mainly on electroslag welding. The new method is a combination of gas shielded metal arc welding for the base and electroslag welding from the web to the head.

4.1 Welding Conditions of ARW

The base of the rail is welded by CO_2 gas shielded arc welding with a ceramic backing plate. The CO_2 gas is fed through a gap between the welding torch and a glass tube mounted around it as well as from wind shield covers on the sides. When the welding of the base is completed, flux is fed in place of the CO_2 gas and the operation switches to electroslag welding. Both the welding methods use a same 1.6-mm diameter high carbon solid welding wire, the chemical composition of which is shown in **Table 2**. Normal welding time is approximately 15 min. After the welding, the joint is heated with a burner (for gas pressure welding) to 1,000°C for normalizing, and then extra fills are removed with a grinder. Welding conditions and torch movements are shown in **Fig.12**.

4.2 Configuration of ARW

Fig.13 shows the configuration of the ARW. The welder system consists of an automatic melting/welding machine proper, copper gussets, a wire feeder, a control unit, a power supply unit, a water cooler, and so on. The torch is a 10-mm diameter water-cooled narrow groove torch and the groove width is 16 ± 2 mm. The welding wire is wagged by slightly bending and then rotating it. Mechanisms of the wire rotating/wagging device, the welding head and the flux feeder are shown in **Figs.14, 15 and 16**, respectively.

Table 2 Chemical composition of weld wire (mass %)

C	Si	Mn	P	S
0.70	0.24	0.87	0.019	0.011

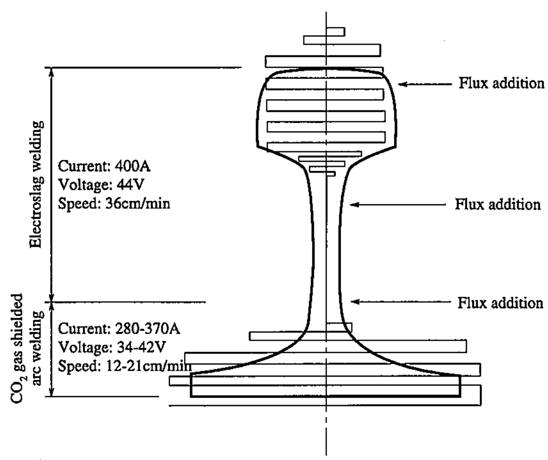


Fig.12 Welding conditions and torch movements

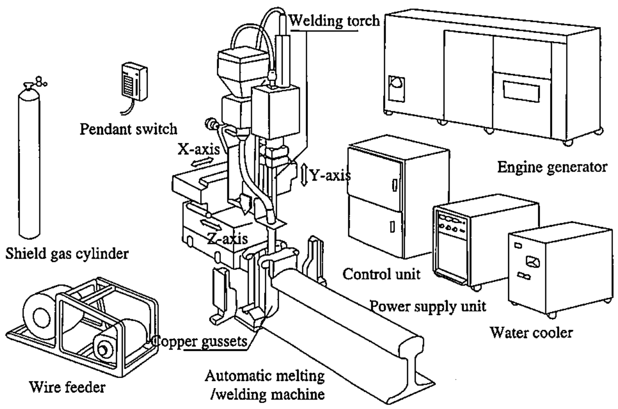


Fig.13 Configuration of automatic melting/welding machine

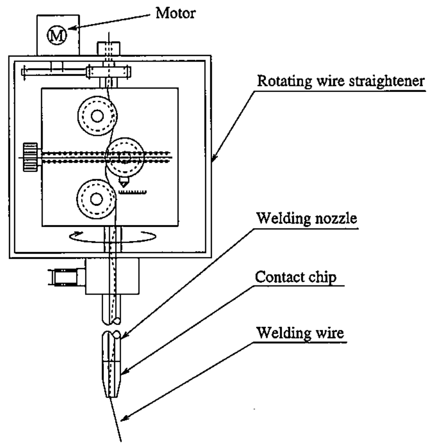


Fig.14 Rotating wire straightening mechanism

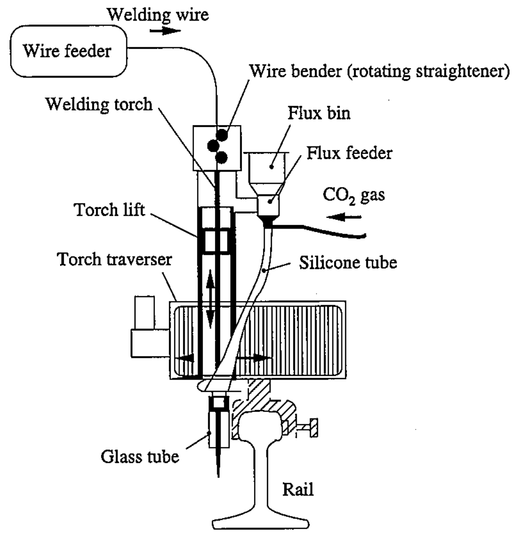


Fig.15 Welding head

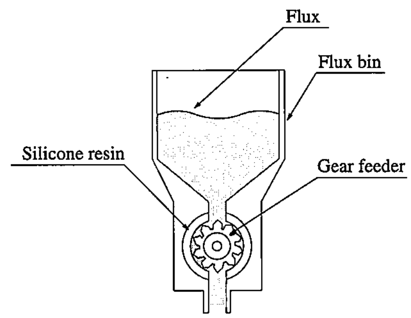


Fig.16 Flux feeder

4.3 Field applications of ARW

The ARW was first applied to welding works in the premises of Nippon Steel's Kimitsu Works and Yawata Works and tested at JR East Japan's Chuo Line and Tokaido Line. Then it was commercially used for the extension work of Yamagata Shinkansen (bullet train line) in fiscal 1999. **Photo 7** shows the use of the ARW at Yawata Works.

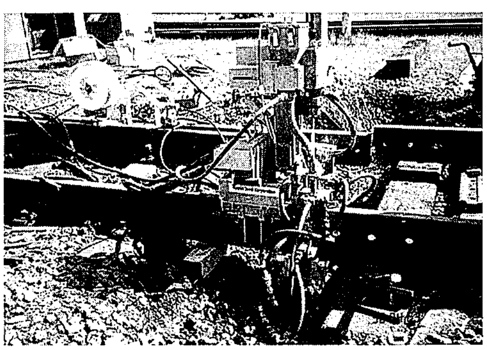


Photo 7 Use of ARW at Yawata Works

5. Conclusion

In this report were presented some of the welding-related activities of Nippon Steel's Civil Engineering & Marine Construction Division in the field of civil construction. A few of them, such as the NS Stud Method, have been commercially applied as one of the main stays of our business, but most of them are yet to be improved and refined to be widely accepted. It is understood that these technologies have to be improved to meet the requirements of the actual field work through analysis of the real situation at each of the work sites in order to foster them into new main stays of our business activities.