Fabrication of 12.2 M Span Bridge Girders for Central Railway by Automatic Submerged Arc Welding Process

By N. K. SARKAR*

Introduction

More than 15000 bridges of different lengths span the rivers, over the Indian Railways. About 350 important bridges are over 305 M in length. The girders of all these bridges are of rivetted design though there are quite a few bridges viz. Rajendra Bridge at Mokamah, Jagjivan Ram Bridge near Sonepur, Second Godavary Bridge at Rajamundry, Third Krishna Bridge at Vijaywada, Brahmaputra Bridge at Gauhati etc. in which the flooring system has been provided with welded design. Langulia Bridge of 4 spans of about 46 M near Waltair is an example in India where open web girder truss members are of welded design (fabricated by one of the reputed Indian contractors) and site joints only are rivetted. In this bridge, imported steel was used. Many of the bridges are a century old—class or specification of steel used for these early bridges are not known.

The tempo of development in the field of bridge construction by welding in foreign countries has gained momentum with the advent of superior class of weldable steels, new welding processes, consumables, equipments and techniques. From the techno-economic studies, it has been observed that the welded plate girders are about 25% lighter than the equivalent rivetted ones. Besides, the rivetted girders require different size angles, packing pieces, drillings and splice plates besides a number of other inventories. It is hardly surprising therefore that Indian Railways too have gone for welded bridge girders. As a first step, the Railway Board have decided for 12.2 M span girders to be fabricated by welding.

Chemist & Metallurgist, Central Railway, Bombay.

*Paper presented at the 1982 National Welding Seminer held at Cochin adjudged the second best paper for the KCP Award on Fabrication.'

This paper deals with the material, welding consumables, welding procedures and technique followed for the fabrication of the first welded bridge girder on Central Railway. Though the maintenance and painting of welded girders are easy, their manufacturing calls for greater skill and higher quality control to ensure production to acceptable standards.

Materials

(a) Plates

The drawing stipulated the plate material to be steel conforming to IS ; 2062. Hence, steel plates to the required thicknesses i.e. 10 mm and 22 mm were procured. Samples of each thickness were tested and the typical results are given below :

(i) Chemical composition

Elements, %	*10 mm thick*	*22 mm thick*
Carbon	0.19	0.20
Silicon	0.15	0.15
Manganese	1.20	1.32
Sulphur	0.022	0.021
Phosphorus	0.020	0.020

(ii) **Mechanical properties**

U T S (kg/mm^2)	44	47
Yield Strength (kg/mm^2)	30	31
Elongation % (G.L.=5d)	26	25
Bend tests	— Satisfactory	—

(iii) **Fatigue Properties**

Fatigue properties were studied on IS : 2062 steel both in welded and unwelded condition on 22 mm thick plates. For comparison purposes, IS : 226 steel (both killed and semi killed variety) in welded as well as unwelded condition were also subjected to similar fatigue tests. The results are given below :

Material	*Condition*	*Endurance limit (kg/mm^2)*
IS: 2062	Only machined	±20.00
IS: 2062	Welded and machined	±20.00
IS: 226 (Killed)	Only machined	±20.38
IS: 226 (Killed)	Welded and machined	±20.38
IS: 226 (Semi killed)	Only machined	±18.60
IS: 226 (Semi killed)	Welded and machined	±18.60

It can be seen that the endurance limits for both IS : 2062 and IS : 226 (Killed variety) steels are almost indentical. But the semi killed variety of IS: 226 steel showed lower values.

(iv) **Weldability Tests**

Though the IS : 2062 stipulates a test to determine its weldability, the same test was not carried out, as in our opinion, this stipulation appears to be outdated and confusing. The latest concept of weldability of steel is primarily based on the tendency of the parent metal to Heat Affected Zone cracking. The susceptibility of this form of cracking increased with the total carbon plus alloy content of the steel although there is considerable variance in the influence of different alloying elements. The mass and temperature of the steel to be welded have an influence on the tendency of cracking. We have therefore, gone for the carbon equivalent of the steel using the ISI accepted formula i.e.

$CE = C\% + \frac{Mn\%}{6}$ and the values were as follows :

	10 mm thick	*22 mm thick*
CE (On the basis of the test results obtained on the sample plates)	0.39	0.42

This carbon equivalent needs no special precaution or procedure while welding the girder plates.

(v) **Micro examination**

Though not specified in the specification, this test had to be carried out to ensure that the steel is in normalised condition. One sample was cut from 22 mm thick plate, polished and etched with 3% Nital. The sample was examined under microscope at ×100 magnification and revealed fine grains of ferrite and pearlite evenly distributed throughout the matrix.

(b) **Consumables**

4.0 mm dia. Copper coated mild steel wire having the following chemistry and conforming to IS: 7280-74 grade AS-1 was used with agglomerated type flux. The all weld metal test results are also given below along with diluted metal :

(i) **Chemical composition**

Elements %	*Core wire*	*All weld deposit*	*Diluted Metal*
Carbon	0.08	0.09	0.18
Silicon	0.015	0.28	0.18
Manganese	0.48	1.04	1.40
Sulphur	0.020	0.022	Not deter-mined
Phosphorus	0.019	0.020	

(ii) **Mechanical properties**

	All weld metal	*Diluted Metal*
UTS (kg/mm^2)	51.0	46.5
Yield strength (kg/mm^2)	40.0	Fractured away from weld.
Elongation % (G.L.=5d)	28.0	—
Charpy Impact values (kgf. m) (at Room temp)	9.0	—
Bend test at 90°	—	Satisfactory

(*Note*— The fluxes were preheated to about 250°C for 2 hrs. prior to use)

Weld Design

For the first time the Railway Bridge Engineers have designed the welded girders keeping in view of the weldable quality steel, manual metal-arc welding process etc. existing facilities available on the Railways. The design is functional, asthetic and economical. But after scrutinising the drawing in details, it was felt that to ensure best possible fatigue properties, submerged arc welding process would be ideal as this is a controlled heat input welding process suitable for long continuous welds on thinner and thicker plates as well, and therefore we had gone for this process.

Fig. 1 shows the locations of the joints in the girder. 22 mm thick plates are required for the flanges having two butt joints each at the top and bottom flange plates. The web plate is 10 mm thick and has one butt joint only. Two I-sections required for one girder are to be made by fillet welding of the flange and web plates. Bracings will be rivetted. Neither partial penetration groove welds nor intermittent fillet welds were allowed. The joint preparations will be discussed later.

The plate sizes required are :

Top flange	325×3700×22—2 plates and 425×5900×22—1 plate.
Bottom flange	325×3475×22—2 plates and 425×6350×22—1 plate
Web plate	1340×2400×10—1 plate and 1240×10900×10—1 plate.

There is a transition in the width of the flange plates. A smooth transition was provided in the drawing by using a straight line out with a slope of 1 in 5. In this case, it was difficult to fix up the Run-on and Run-off plates and the joint also did not have equal width. After further literature survey, a curve was made on the wider plate having a radius of 2 feet, tangent to the narrower plate so that the welded joint had equal width. (Fig. 2) Since the weld is also finished smooth the butt welds are expected to have the same fatigue allowable as that of the plate.

The overall length of each I-section is 13.0 M but the actual span of the bridge is 12.2 M. The weight of rivetted plate girder of this span is 10.2 MT while the same for the welded design is approx. 7.76 MT, thereby a saving of about 2.44 MT i.e. approx., 25% of steel. The total weight of welded span includes weight of rivet heads and welds constituting 2%.

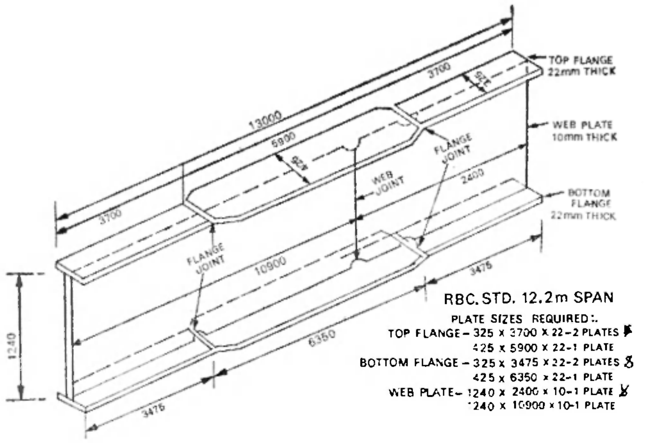


Fig. 1. Location of joints in I-Section of welded plate girder.

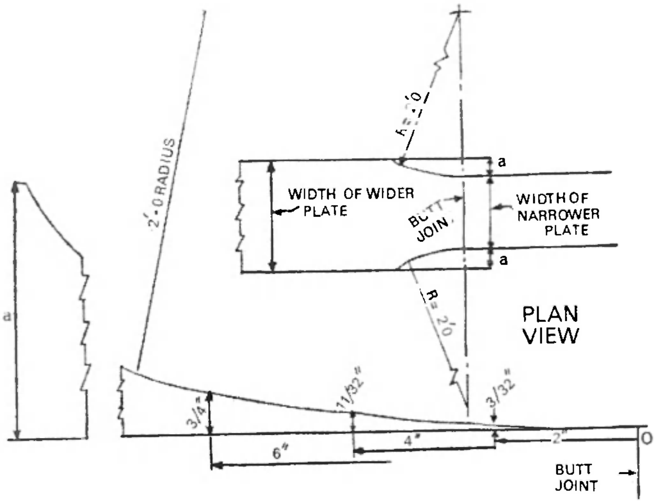


Fig. 2. Preparation for transition in width of plates.

Procedure Approval

Since no definite code or procedure has so far been laid down for welding of bridge girders, it was necessary to evolve such a procedure based upon series of trial exercises and the record of such trials. The behaviour of members as they got welded and the distortion caused by welding have been watched carefully on the trial assemblies and necessary corrective measures have been taken and incorporated in the procedure. As distortion is a part and parcel during fabrication by welding, the tolerances are generally wider. Nevertheless, this is not so in this case. RDSO, the designer as well as the Inspecting Authority demanded very close tolerances on dimensions. This necessitated judical application of welding sequences, balancing the shrinkage forces etc. for limiting the distortion within the accepted limits.

The following exercises were carried out for standardising the edge preparations and the welding parameters on different plates.

(a) **Web plates**

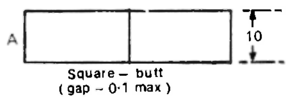
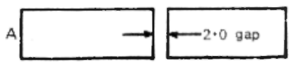
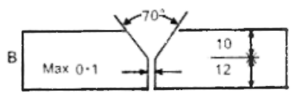
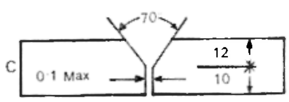
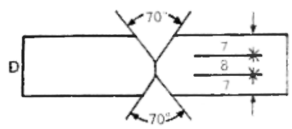
We had straightway gone for square-butt joint with two-run technique. The end faces were machined and matched properly with a maximum gap of 0.1 mm at isolated places. Three different welding parameters as shown in Table-1 were used. The second parameter was standardised as in this case proper interlocking of the beads were obtained. The bead was uniform and evenly rippled with its shape being flat to convex. The welding head was connected to the positive pole of the DC power source.

(b) **Flange plates**

We had tried first with square-butt with 2.0 mm gap all through using two-run technique. The weld beads were not interlocked—there was lack of fusion at the root as we could not go beyond 800 Amp. with 4 mm diameter wire. We had therefore, preferred 5.0 mm dia. wire with following parameters using DC(+) :

Pass	*Volts*	*Amps*	*Carriage speed (m/min)*	*Wire feed (m/min)*
1	32	900	0.5	1.9
2	32	950	0.5	2.0

Table 1 Experimental Edge Preparations & Welding Parameters

Edge preparation		*Passes*	*Volt*	*Amp.*	*Carriage speed (m/min)*	*Wire feed speed (m/min)*
(a) Web plates—10 mm thick	A.a.1	1	30	500	0.3	1.15
		2	32	550	0.3	1.20
	A.a.2	1	32	550	0.4	1.25
		3	32	600	0.4	1.25
	A.a.3	1	34	550	0.4	1.10
		2	34	600	0.4	1.10
(b) Flange plates—22 mm thick						
	A.b.1	1	32	800	0.3	1.20
		2	32	800	0.25	1.20
	B.b.2	1	32	600	0.3	1.75
		2	32	650	0.3	1.75
	C.b.3	1	32	650	0.3	1.75
		2	32	700	0.3	1.75
	D.b.4	1	32	650	0.5	1.50
		2	32	700	0.5	1.50

Notes: 1. In all cases 4.0mm dia. wires were used with the welding head connected with positive pole of the D.C. Power scorce.

2. For Web plates, A.a.2 edge preparation and welding parameters and for Flange plates, D.b.4 edge preparation & welding parametres standardized for butt joints.

Observations

Though the interlocking was satisfactory, careful attention had to be given to the path of the welding head so that it travels strictly along the line of the joint. The reinforcement was excessive necessitating more time for flushing-off. Any misalignment or slight deviation in procedure leads to unsatisfactory welding.

We therefore, tried different edge preparations and parameters as given in Table 1. The preparation and parameters given at Db.4 in Table I, were standardised after conducting a series of tests.

Fillet welds

The design desired 8 mm fillet. Since this was the first job of this nature, we had no jigs and fixtures. We therefore tried to carry out the welding in the horizontal fillet position after providing a gadget to the welding head. But inspite of various parameters used, it was not possible for us to obtain the desired 8 mm fillet size with equal leg length. Besides, the weld was found to be porous.

We therefore, went for welding in the flat position by keeping the job inclined to about 45° to 50° to the horizontal level with the following parameters using 4 mm dia. filler wires.

With Arc Volts—30, Amp—550, Carriage speed—0.3 m/min. and Wire feed speed—1.25 m/min. we got 8 mm fillet size. This parameter was standardised to ensure that the bead width be at least 25% greater than the bead depth to avoid cracking (narrower beads have a tendency to cracking).

Discussions

It was significant to observe during the experiments that the electrode stick out of the wire was a very important factor for obtaining optimum bead size together with weld metal deposition rate. After a series of experiments, we standardised the stick out to about 25 mm.

Voltage primarily controls the bead shape. When other variables were held constant, increase in voltage resulted in a flatter/wider bead. Slightly lower voltage improved the penetration. An excessively low voltage produced a narrow and excessive convex bead.

Higher carriage travel speed improved the weld size. The penetration was satisfactory and the surface was defect free. Improper carriage speeds resulted in porosities and undercuts associated with occasional burn-through. Wire feed speed was adjusted with the carriage speed to obtain satisfactory bead shape and size, proper interlocking in the multipass welding. When other variables were kept constant, change in wire feed speed altered the amperage. Excessively low wire feed speed produced unstable arc while excessively high speed produced an erratic arc coupled with undercut.

Approval of the Welders

Though during the procedure approval, the welders engaged in welding were also getting enough experience and simultaneously tested, the inspection authorities insisted on separate welders' approval in the procedure and technique to be used finally. Hence, two welders were tested and certified on butt-welds of 10 mm and 22 mm plates and fillet weld on 10 & 22 mm plates. Welding parameters standardised earlier were used by the welders in all the cases.

The butt welded test plates were subjected to radiographic tests followed by transverse tensile and bend tests. The fillet welds were tested for visual examination, fillet size and penetration tests.

Assembly and Welding of the 'I' Sections

While cutting, the plates were kept about 5 mm longer in length than stipulated in the drawing. The width of the web and flange plates were kept about 1 mm and 3 mm more respectively. In case of centre piece of the flange plates, the length was kept about 2 mm more in length. The web plates were assembled first. The abutting faces were machined square. One solid platform at a height of about 1.22 M. from ground level was made with 25 mm steel plates duly aligned with pillars etc. The web plates in desired lengths were placed over this plate with the help of channels. The surrounding areas of the edges were cleaned to remove traces of paints, rust, dirt etc. by hard brushing. The plates were visually checked for its straightness and any superficial damage marks caused during handling.

The abutting faces were aligned properly with maximum gap of about 0.1 mm at isolated places. 4 Nos. of 300 × 150 × 10 mm plates were also assembled along with the web plates to be used as 'Run-on' & 'Run-off' plates. The plates were clamped properly and tack welded. The nozzle of the welding head was aligned over the joint line and moved to-and-fro so that the welding is done exactly along the line of joint. Using the standardised parameter an arc was struck on one edge of the run-on plate over steel wool, which was found to be advantageous during our experiments. After the completion of one run on one side, the assembly was reversed taking special precautions so that neither the run-off & run-on plates nor the web plate are damaged.

During reversing, one long channel of 350 mm size was placed over this plate and anchored properly at the centre as well as at both the ends using two overhead cranes. The plate and channel were lifted and tilted, handling carefully. Again another channel was used for bringing this plate to its original place. While bringing this plate, the earlier channel was removed. After reversing, the other side was welded with the approved welding parameters.

After the completion of welding, the run-on and run-off plates were gas-cut and the cut edges were ground, polished smooth and subjected to macro-etching using 10% Nitric acid. The interlocking was satisfactory. The butt joints were also subjected to radiographic tests and found to be conforming to the Black colour of IIW standard radiographs. On dimensional checking, no distortion was observed.

The templates of 22 mm flange plates were marked on the completed web assembly. The flange plates were placed over channels on the top of the web plate. The edge preparations as standardised earlier were made on the flange plates. After cleaning, the abutting faces were aligned properly with a maximum gap of 0.1 mm at isolated places. The run-on and run-off plates were also used. Welding was carried out with the standardised parameters. After welding from one V-side, the plates were reversed carefully and the other V-side was welded.

The run-on and run-off plates were tested for ensuring the interlocking while the butt joints of the flange plates were subjected to radiographic tests and found to be conforming to the Black classification of IIW standard radiographs.

The alignment of the I-section was very difficult as neither we had any jigs and fixtures nor any manipulator. Therefore some make shift arrangements as shown in Fig. 3 was made to ensure that the flange plates match squarely to the web plate so that the tack welding can be done correctly.

The web plate was placed on the channels as described earlier. The flange plates were kept vertical with the help of angles and long adjustible bolts and screws.

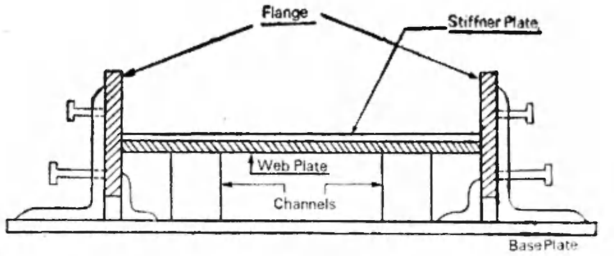


Fig. 3. Alignment for I-Section.

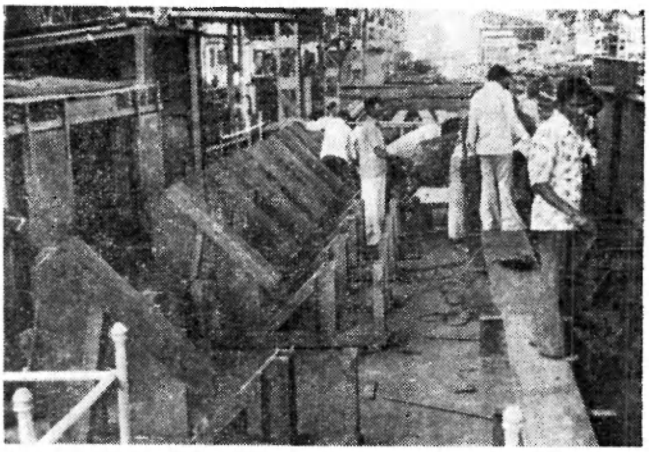


Fig. 4. Photograph showing the fixture fabricated for positioning the I-Section for fillet welding in flat position.

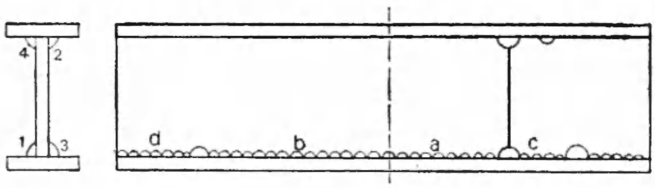


Fig. 5. Sequence of welding.

Stiffner angles had been provided for keeping the web plate straight (otherwise there was heavy wobbling of the web plate during handling). After aligning the I-section, suitable tack welding was done. Since the fillet welding had to be carried out in flat position, another fixture was made as shown in Fig. 4. The 'I'-section was placed in this fixture at an angle of about 50° to the horizontal level. The success of the entire fabrication depended on the fillet welding only as lot of distortion was likely to take place as was evident in our trial jobs. We had therefore to plan the sequence of welding as shown in Fig. 5. For the first pass of the fillet welding at position No. 1, the segments were devided into a, b, c & d. Welding was carried in the outward direction from the centre line using the following parameter with 4.0 mm dia. filler wire and DC positive polarity :

Arc Voltage—30V
Amperage—550 amps
Welding speed—0.4 m/min.
Wire feedspead—1.25 m/min.

Run-on & Run-off plates were used. The penetration was found to be 3 mm beyond the root on either side of the web plate. The fillet size was 8.5 approx. The shape of the bead was flat to concave. Similarly the other fillet welding was also carried out in the sequences as shown in Fig. 5.

Then the I-sections were removed from the fixture and laid on the floor level (Fig. 6). Requisite number of stiffner plates were tack welded one side first. Standard planned sequence was followed during welding. The following parameters were used to attain a minimum 6.0 mm fillet size :

Arc Volt—29	Welding speed—0.4 m/min.
Welding Amp—450	Wire feed speed—1.1 m/min.

After completion of welding on one side, the 'I'-sections were reversed and stiffner plates were welded in the same sequences and using same parameters as was done for the first side but the direction was only reversed i.e. welding was started from opposite direction on either side of the web plates. Welding was carried out in horizontal-vertical position, keeping the welding head at an angle of about 40° to the horizon. Continuous fillets were welded on both sides turning round the edges. Fig. 7 shows a complete fabricated I-section.

In order to limit the distortion to the minimum, it was felt necessary to keep the plates under some restraints by means of bolts, clamps etc.

Final assembly of the Girder

Both the 'I'-sections were assembled side by side and the bracings were positioned and rivetted.

Inspection, quality control & tests

Inspection by the quality control department was carried out at every stage i.e. before, during and after welding. Chemical composition and mechanical properties of the parent metal, filler wire as well as wire-flux combination were also assessed prior to starting the work. Approval for the procedure for welding together with the certification of welders' skill were also taken

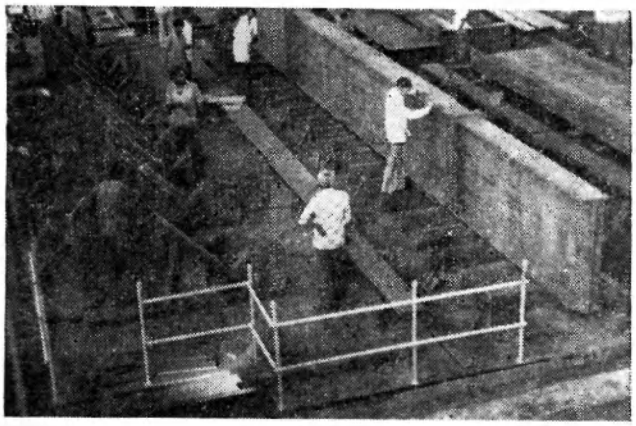


Fig. 6. Photograph showing the removal of the I-Section after fillet welding from the fixture.

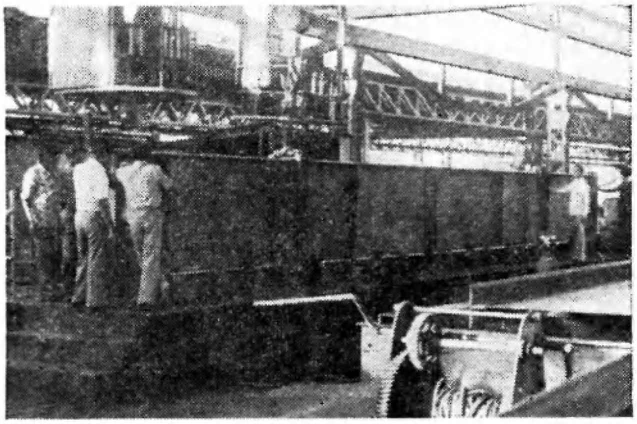


Fig. 7. Photograph showing one complete I-Section.

from the competent authorities. All the butt welds were subjected to radiographic examination and were found to conform to black colour of IIW Standard Radiographs. Macro-examinations carried out on the run-on & run-off plates at each stage to ensure the interlocking of the weld beads.

The fillet welds were visually examined and found to be satisfactory. Macro-examination of the run-on and run-off plates revealed the fillet size and penetration. The total distortion on the assembly observed was about 2 mm which was within the permissible limit.

Recommendations

During the course of fabrication, it was observed that one of the butt joints of the flange plates could be dispensed with for the future girders as the excess welding is not only costly but it is prone to produce weld defects and distortion.

In order to have better fatigue properties, a radius of 2 feet should be provided in the wider plate in case of transition in width of the plates as was done in this case.

Proper manipulators as well as jigs and fixtures are prerequisites for such type of fabrication.

The supervisors and the welders should be properly trained in welding technology, which will be helpful to understand the intricacies of the welding techniques.

As the edge preparations and assembly are vital for obtaining defect free welding, more attention should be given on these aspects.

Preheating of the agglomerated fluxes are to be done at 250° C for 2 hours prior to use for obtaining improved ductility.

References

(1) AWS Hand Book, Section Five.
(2) IS : 9595—80
(3) IS : 1024—79
(4) IS : 2062—74
(5) Welded Bridge Code—1972 issued by RDSO, Lucknow.

The author expresses his thanks to the Chief Workshop Engineer and Chief Bridge Engineer of Central Railway for their kind permission for publishing this paper. The author also wishes to place on record the valuable assistance and co-operation received from Shri V. P. Sambrani, Dy. Chief Engineer (Workshop) Manmad and his staff for carrying out the above fabrication.

In the NEXT ISSUE

JANUARY 1985

Technical articles on

—the recent developments in MIG/MAG equipments

—resistance spot welding of mild steel sheets

Product News—to inform the readers the new products introduced to the market by our Industrial Corporate members.

Branch News and other features.