RETS

PRACTICAL GUIDE BOOK SERIES

STEEL STRUCTURE FABRICATION FOR RAILWAYS

RAILWAY ENGINEERING TECHNICAL SOCIETY
PUNE - INDIA

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STEEL STRUCTURE FABRICATION FOR RAILWAYS

WRITTEN BY

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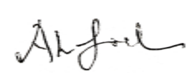
FOREWORD

The Indian Railway has very ambitious plans to construct New Lines, Doublings and Gauge Conversions in the next 5-year plan and the targets are almost 6-8 times more than average progress achieved in the past. Traditionally, the steel girder fabrication has been done in-house by the Railway Engineering workshops. Of late, however even with the present targets, the construction organizations, found it expedient to outsource steel fabrication of girders to private agencies due to i) enough workload on Railway workshops and ii) material procurement taking long time, starting only after placement of work orders on workshops by the indenters. The enhanced targets for Railway projects and Railway Boards policy to discourage RCC/PSC girders for longer spans above 24.3m will require lots of work of fabrication of steel girders to be outsourced to private contractors and fabricators. There have been some adverse reports also in regard to inferior quality of fabrication carried out by the contractors, mainly due to only partial understanding not only by contract agencies but also the Railway engineers and supervisors of the requirements of work and the end use of heavy dynamic forces resisted by Railway girders.

Shri N.L.Nadgouda, the compiler of the book, has spent his whole life in the railways either fabricating or erecting the girders on Central Railway, and also teaching at IRICEN/Pune, is certainly the most qualified person to offer tips on good practice, procedures and “do’s and don’ts” for proper quality standards for steel fabrication works. The book has been written in very simple language and avoiding complicated theory and terminology to make it understandable to all supervisors and field engineers alike. I am sure that all field engineers of Open Line and Construction, dealing with any sort of steel girders or steel structures will find it very useful and will be able to ensure quality work. The contractor’s supervisors also need certain basic training in requirements of Railway girders, many times and this book will be very helpful for them.

I on my own and on behalf of the RETS would like to thank Sh. V.B. Sood Prof. (Bridges) /IRICEN and many others from the society, who have worked tirelessly to bring the book to the readers in the present form. The purpose of the book is not to replace the text books and other detailed works on similar subject, but to assist the field engineers to have a better understanding of the intricacies in fabricating steel structures especially the Steel girders and ensure good quality and durable structures. The effort will be truly rewarded if the readers give their frank opinions and views and contribute to make the book further useful to all Railway Engineers for which any suggestions are welcome.



25-02-2011

A. K. GOEL

President, Railway Engineering Technical Society, and
Director, Indian Railway Institute of Civil Engineering
Pune-411001, INDIA

ACKNOWLEDGEMENT

I have worked for over 34 years in Central Railway, Engineering Workshop Manmad, RDSO and IRICEN. Even after my retirement in year 2000, I have been inundated with numerous requests for guiding regarding the subject. While I have been providing assistance to the people contacting me, I have felt that the knowledge about the subject is scanty and not readily available, despite some material being included my earlier book on “Maintenance of Steel Girders” published by IRICEN in 1998.

Mr A K Goel as Director IRICEN, on formation of Railway Engineering Technical Society (RETS) had pushed me for publishing this book. It is fortunate that his persistence has borne fruit and towards the fag end of his tenure, the book is finally ready.

The book could not have come at a better time. The Railway Board has banned use of concrete girders beyond 24.4 m spans and the railways have finally shifted completely to welded girders. The scope of steel girder fabrication has gone up tremendously of late and lots of work is being done by the private agencies. This book will guide the engineers and fabricators alike and help them avoid simple mistakes which often result in distress in girders during service.

Steel girder fabrication is a fascinating work. It is based on simple basic principles yet requires dedication on the part of fabricator. Good quality control and following proper procedure is a must to achieve fabrication to required tolerances. But where is the knowledge about the basic principles and foundation of steel girder fabrication? There ia dearth of sound knowledge about steel fabrication even with the fabricators of reputed private sector workshops. In my long tenure at IRICEN as faculty I have observed general lack of awareness of simple principles of girder fabrication, and hence this book was required to be written.

The book is based on codes/manuals and practices. The book draws heavily from my experience in the field which culminated in the most challenging work that I was associated with, namely, fabrication of 400’ welded girders for KRCL.

The book tries to combine all material in a simple flow so that the fabricators and engineers can read the book like a reference book and can have all the relevant information at a single location. This book was possible only due to the personal involvement of Sh A K Goel, Director IRICEN and President RETS. Sh V B Sood, Professor Bridges, IRICEN has worked hard on the book and made it presentable and also improved upon its language. Therefore I am thankful from bottom of my heart to Sh A K Goel and Sh V B Sood. Without their involvement, encouragement and, literally, physical pushing this book would not have been possible.

I am thankful to Sh V N Sohoni SE(Bridges), IRICEN and Sh S N Pophale, SE, IRICEN and who have worked hard and provided sketches for the book. Sh Pradeep B. Tawde, Technician, IRICEN who has improved the photographs in the book also deserves thanks for his efforts.

The book has been written carefully, yet there might still be some mistakes for which I apologize to the reader in advance. Any suggestions for improving the book and its content may be sent to RETS.

Feb 2011

N. L. Nadgouda
Retd. AP, IRICEN, Pune

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Chapter I

BASICS ABOUT RAILWAY STEEL GIRDERS

1.1 INTRODUCTION

Before the advent of Reinforced or Pre-stressed concrete in the Railways, mainly two types of bridges were constructed in Railways:-

a) Masonry Bridges:

These types of bridges were mainly Arch Bridges (culvert) of stone or brick masonry for span from 10 feet to 50 feet (3.05 m – 15.25 m) which had ballasted deck. For smaller spans, stone tops/pipes/rail clusters were also used.

b) Steel Girder Bridges:

This type of bridges had steel girder as superstructure. The piers and abutments were either stone/brick masonry or mild steel / cast iron piles. Girders were constructed for spans starting from 4 feet (1.22m). Generally the track was ballastless track and these were called open deck type because of opening between sleepers. However in few bridges, ballasted deck was also provided by using steel troughs (over stringers of open web girder or top flange of plate girders).

The masonry bridges are now obsolete and new such bridges are not being constructed any more, but the **steel bridges are still being adopted,** especially for longer spans. This book covers the fabrication of steel bridges for railways.

Following are some of the advantages of steel bridges that have contributed to their popularity over time:

- These can carry heavier loads over longer spans with **minimum dead weight**, leading to smaller foundations.
- **Greater efficiency** than concrete structures is achieved **in resisting seismic forces** due to the above reason.
- Due to shallow construction depth, steel bridges offer slender appearance, which makes them **aesthetically attractive**. The reduced depth also contributes to the reduced cost of embankments
- Steel has the advantage where **speed of construction** is vital, as many elements can be prefabricated and speedily erected at site.
- In urban environment with traffic congestion and limited working space, steel bridges can be constructed with **minimum disruption** to

the surrounding environment.

- The **life** of steel bridges **is longer** than that of concrete bridges.
- Steel has **good scrap value**.

All the above factors frequently lead to **low life cycle costs** in steel bridges even though initial cost of steel girders is higher than PSC girders.

1.2 CLASSIFICATION OF STEEL BRIDGES

Steel bridges are classified according to,

- The type of traffic carried
- The type of main structural system
- The position of the carriage way relative to the main structural system
- The type of support conditions

1.2.1 Classification based on type of traffic carried

- Highway or road bridges
- Railway or rail bridges
- Road - cum - rail bridges
- Pedestrian or Foot Over Bridges

1.2.2 Classification based on the main structural system

Many different types of structural systems are used in bridges depending upon the span, carriageway width and type of traffic. Normally one span constitutes two or more leaves (or girders). In railway steel girders, normally 2 leaves are used to form one span.

Girder may be either solid web girders, box girders or truss girders.

(i) **Solid web girders** could be of rolled steel I-section or the same can be built up with plates. The rolled I-Sections are available maximum 610mm deep and as such can be used only for short spans of up to 6.1m. A **plate girder** is made out of (mostly) flat steel sections and angles that are later welded or riveted into an I-beam shape. The components of a plate girder are shown in figure 1.1 below:

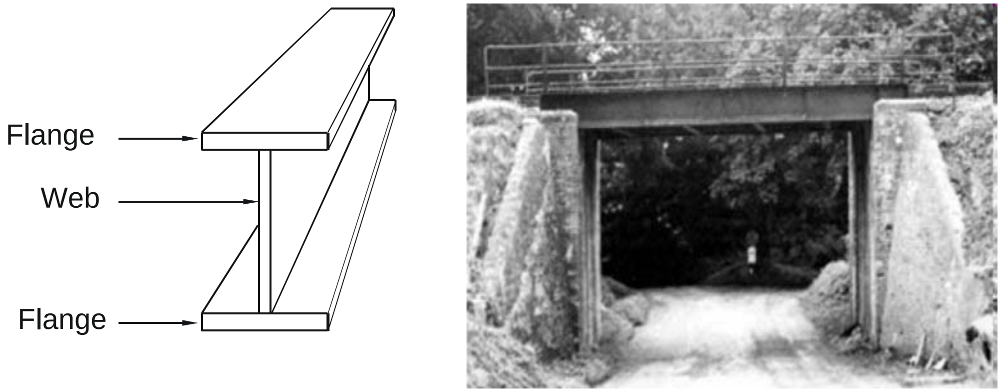


Fig 1.1: Plate girder

Plate girder spans are used for spans between 6 meters and approximately 30 meters. For getting the higher strength required, plate girders are fabricated with web (vertical member) taller than that of a rolled I-girder. The thickness of the top and bottom flanges of a plate girder does not have to be constant; the thickness can be changed to save on material costs. Stiffeners are occasionally welded between the compression flange and the web to increase the strength of the girder.

When the span increases beyond 30 m, the depth of plate girder increases and it becomes uneconomical to use the same. For longer continuous spans up to 250 m, BOX girders are used. Cross sections of a typical plate girder span is shown in Fig. 1.2 below.

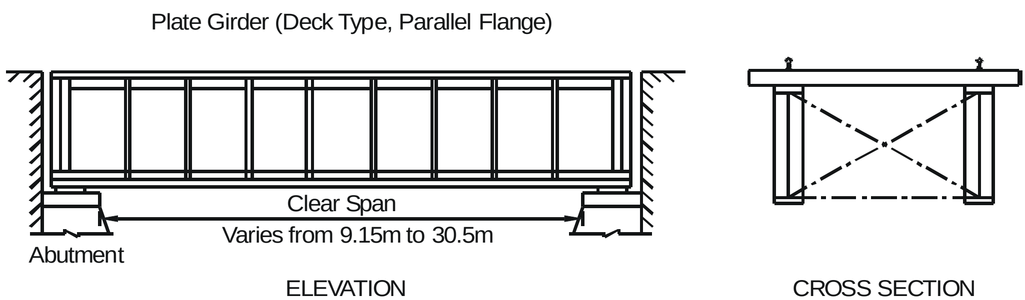


Fig 1.2: Plate Girder

If the depth of a plate girder at the end is less than that in the middle, it is called **Fish Bellied girder** (Fig 1.3). A girder which has uniform cross section through out is called **Parallel Flange Girder**. (Figs. 1.1 and 1.2)

Fig 1.3: Fish Bellied Girder

Steel girders can be fabricated in low depths also by increasing the thickness of the members. But if there is a requirement of reduced depth beyond what is normally possible, then girders having two built up **I**-Sections are sometimes fabricated. These are called duplicated girders, as shown in fig 1.4 below.

Fig 1.4: Duplicated Girder (Four girder leaves can be seen in the photograph as against usual two)

(ii) Box Type girder: The BOX type girders are constructed from plates to form enclosed BOX and can have single girder or a series of girders of the type shown in fig 1.5. The BOX formed is stiffened using suitable diaphragms. This type of girders have not been constructed on Indian railways so far but are very popular abroad with concrete deck for highways as well as railways.

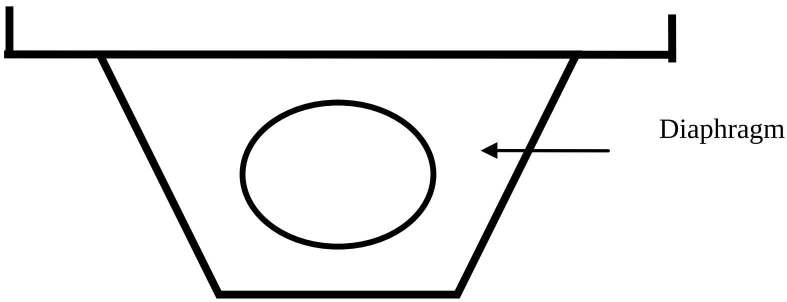


Fig 1.5: Box Girder (Typical X-SECTION)

(iii)Truss Girder bridges: The trusses are a different type of girder made up of a series of triangles which can take the load primarily through axial loads, with minimal bending loads. These are also known as **open web girders** as the web is not solid in this case. Fig. 1.6a & b shows some of shapes of trusses used in Rail/Road bridges, these are suitable for the span range of *30 m* to *375 m*. Cantilever bridges have been built with success with main spans of *300 m* to *550 m.*

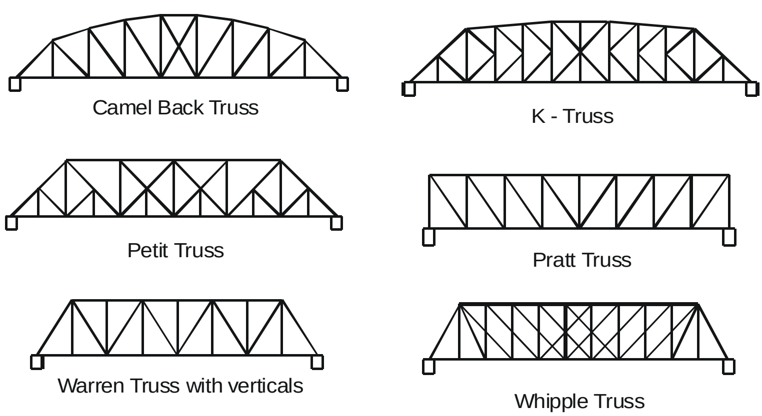


Fig 1.6a: Different Types of Trusses

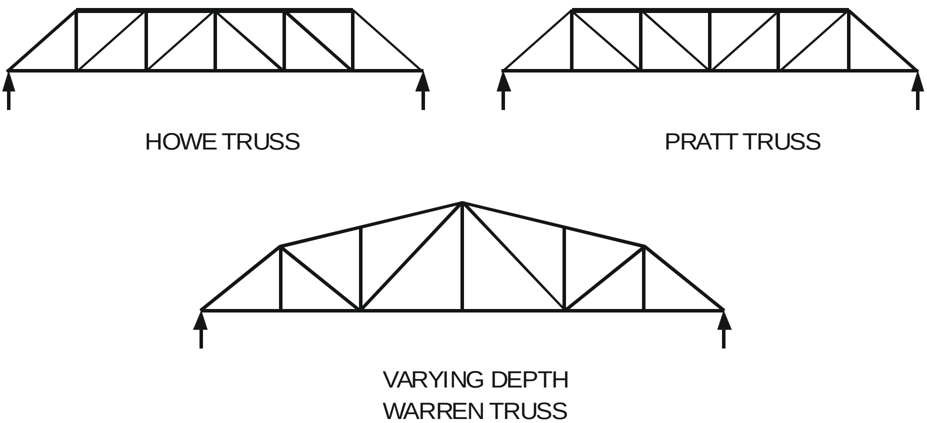


Fig 1.6b: Different Types of Trusses

The truss is a very efficient way of transfer of load and the weight of truss for a span/ load is less as compared to plate girder for the same span/ load. However, fabrication of trusses requires considerably more care and expenditure than that of plate girders. Weighing the increased cost of fabrication with saving in weight of girder, open web girders are found economical for spans larger than 30.5 m only. For span of 30.5 m, options of both, plate girder as well as open web girder, are available.

In this book, fabrication of plate girders and open web girders only has been discussed.

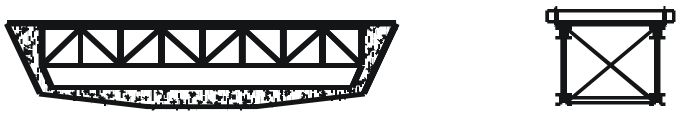
1.2.3 Classification based on the position of carriageway

Based on the site requirements, the load from the trains/ road vehicles can be put at different levels of girders. Accordingly, the bridges may be of the “deck type”, “through type” or “semi-through type” as described below:

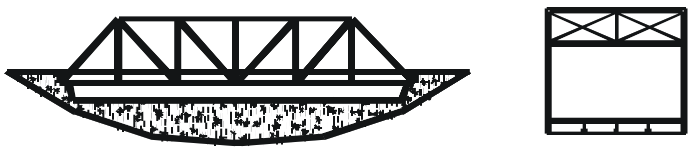
(i) Deck Type Bridge: The carriageway rests on the top of the main load carrying members of the girders. In the deck type truss girder bridge, the roadway or railway is placed at the top chord level as shown in Fig. 1.7(a). In the deck type plate girder bridge, the roadway or railway is placed on the top flanges as shown in figs 1.1 to 1.5. (Most of the plate girders and BOX type girders are of this type).

(ii) Through Type Bridge: The carriageway rests at the level of the bottom main load carrying member of the girders. In the through type truss girder bridge, the roadway or railway is placed at the bottom chord level as shown in Fig. 1.7(b). The bracing of the top flange or lateral support of the top chord under compression is also required. Through type plate girder bridges are normally not possible to be provided for track/ road loadings.

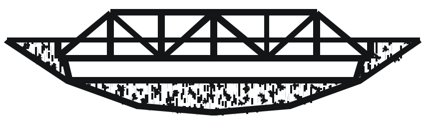
(iii) Semi through Type Bridge: The deck lies in between the top and the bottom main load carrying members of the girders (Fig. 1.7(c)). The bracing of the top flange or top chord under compression is not done to allow the taller vehicles to pass. A part of the load carrying system projects above the floor level as shown in Fig. 1.19. The lateral restraint in the system is obtained usually by the U- frame action of the verticals and cross girders acting together.



(a) Deck type truss (underslung)



(b)Through type truss



(c) Semi-through type truss

Fig. 1.7: Different Levels of Deck in Open web Girders

There are some plate girders also of Semi-through type which are used in locations where there might be restrictions in obtaining either vertical clearance or where the formation level is to be kept comparatively lower. A semi through plate girder span is shown in Fig. 1.8.

Fig 1.8: Semi-through Plate Girder

The fabrication principles for all types of girders are same and this book covers guidelines for fabrication of girders regardless of the position of deck.

1.2.4 Classification based on support conditions

Based on support conditions, different type of spans may be simply supported spans, continuous spans, suspended or cantilevered spans etc. **On Indian Railways however only simply supported spans are generally provided.** In simple supports either both ends of girder are allowed to rotate as well as move in longitudinal direction at the bearing or both ends free to rotate but only one end is allowed to move in longitudinal direction. Normally sliding bearings are provided on plate girders and metal bearing of sliding type (Bronze bearing) for composite spans/under slung spans and Rocker and roller bearing for through and semi-through open web girders are provided. Of late, for longer spans, POT-PTFE bearings are being adopted.

However, RDSO has issued standard drawings for 3-span continuous girders of 9.2 m and 60’ spans to MBG loading. Special design continuous steel girders are also being provided in Jubilee Bridge in Eastern Railway.

1.3 VARIOUS COMPONENTS OF GIRDERS/SPANS:

1.3.1 Plate Girders: The various components of a plate girder are shown in figs. 1.9 and 1.10.

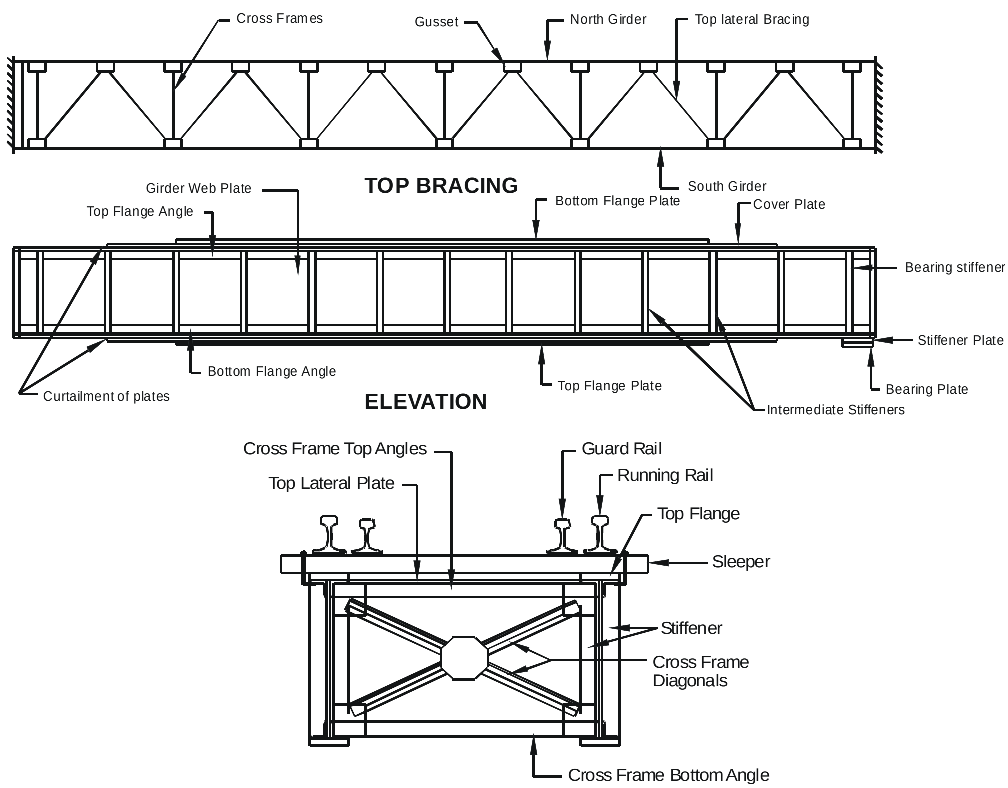


Fig 1.9: Side Elevation and cross section of a typical riveted plate girder

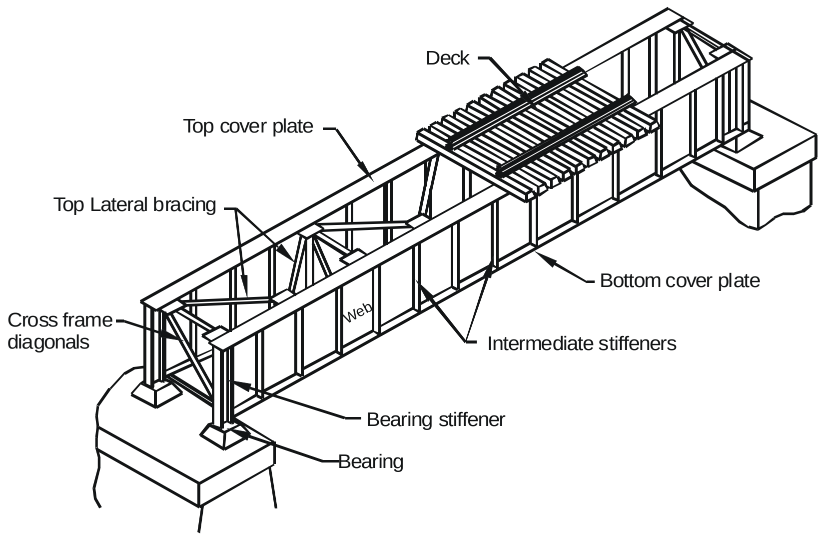
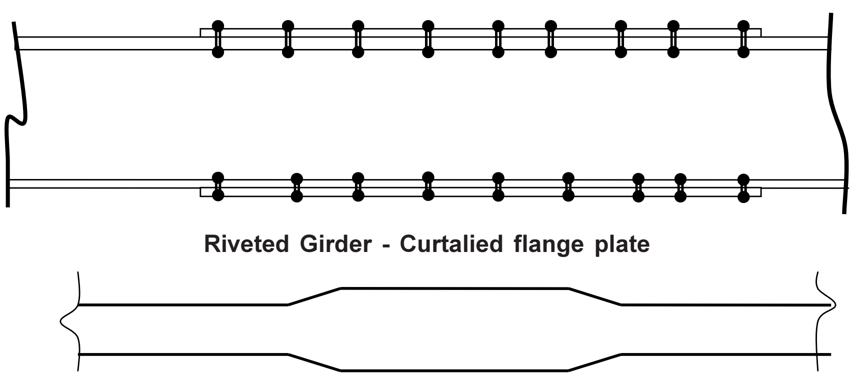


Fig. 1.10: Isometric view showing various parts of a welded plate girder

The web of a plate girder is normally a single plate whereas the top/ bottom flanges can consist of one or more members. In riveted construction, top/ bottom flange angles connect the web and flange plates whereas in welded girders, the connection is obtained by direct welding of plates. In a plate girder, the web takes most of the shear stresses and the flanges take the bending stresses. Since the bending moment is maximum at the center and reduces to zero at the supports for simply supported girders, the cross sectional area of the top/ bottom flanges can be reduced towards the supports. The top and bottom flanges may, therefore, not extend for full length of girder and can be curtailed. The curtailment can be in two manners as shown in fig 1.11.



Riveted Girder - Curtalied flange plate

Welded Girder - Flange plate width changed

Fig 1.11: Curtailment in flange area from center to the ends

To stiffen the web and to prevent web buckling, intermediate stiffeners are to be provided. These stiffeners consist of angles on both sides of the web in case of riveted construction. If the stiffeners are welded, these may be simple plates. At the bearings location i.e. at the two ends of girders, the web has to be strengthened to transmit the concentrated vertical loads to bearings safely. Due to their action as a strut passing the reaction on the support, these are normally stronger than intermediate stiffeners. One differentiating feature of the intermediate stiffeners and bearing stiffeners is that the intermediate stiffeners need not extend from top flange to bottom flange or may be joggled or kneed, whereas the bearing stiffeners have to be snug fit between the top and bottom flange and cannot be joggled or kneed. (Fig 1.12)

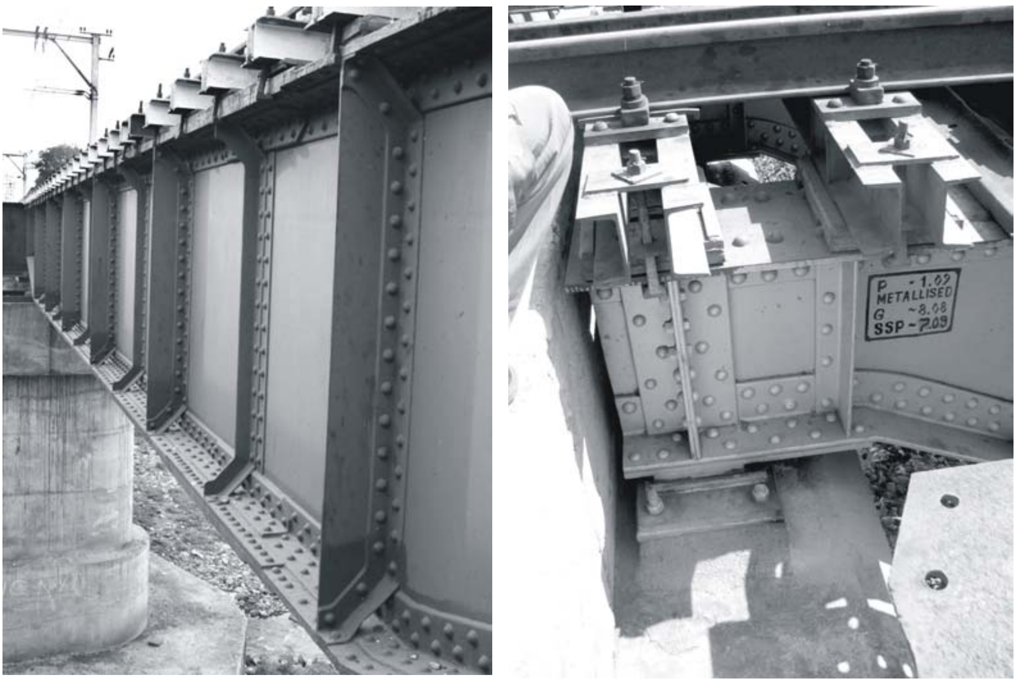


Fig 1.12: 'Kneed' Intermediate stiffeners and 'straight' bearing stiffeners

The flanges of the girders are to be stiffened for which top lateral bracing, bottom lateral bracing and cross frames are provided. The connection of the bracing with the girders are through plates cut in shape, called gussets. The girders, especially those longer than 12.2 m span cannot be fabricated in one piece as the plates and angles are supplied in approximately 12-13 m lengths only from transportation logistics point of view. Therefore, plate girder can have splices in web as well as flanges. (Fig. 1.13)

1.3.2 **Truss Girders**: Fig 1.14 shows the line sketch of side elevation of a typical Warren type truss girder. The main members of the girder are also identified therein, which are self explanatory. The first and the last diagonal are different in construction and function as compared to all other diagonals and these are called **End Racker**. To identify the parts of a girder, the nodes are numbered from one side to the other, starting from zero. The Bottom chord nodes are christened L (for Lower Chord) and the top chord nodes are christened U (for Upper chord). The nodes are, therefore, numbered as L_0, L_1, L_2 etc for the bottom (or lower) chord and as U_0, U_1, U_2 etc for the top (or upper) chord. The lower and upper chord nodes one above the other are given the same number. Consequently, there is no U_0 in the standard through type warren truss

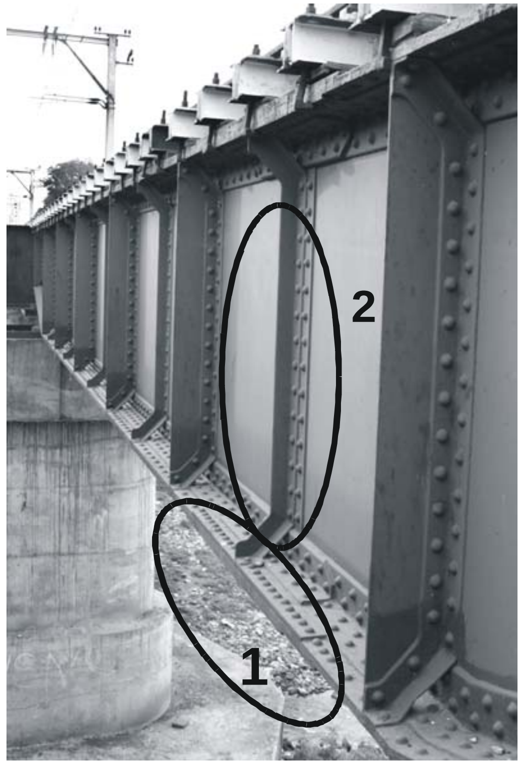


Fig 1.13: Flange splice (marked '1') and web splice (marked '2')

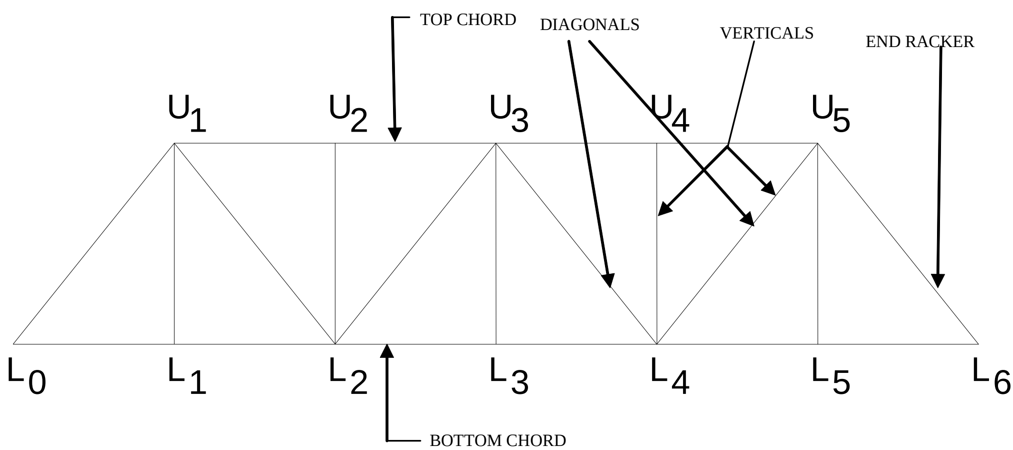


Fig 1.14: Numbering of nodes of an open web girder

shown in fig 1.14. The members are identified by their end nodes e.g. L_0-U_1, which means that it is the end racker. Similarly, L_4-U_4 is the fourth vertical and U_3-L_4 is one of the diagonals. The numbering of nodes for fabrication purpose can be done from any side as the girders normally are symmetrical about the center line. However, in girder laid in track, the numbering is done in the direction of increasing kilometers. Since there are two trusses in a girder, the right hand truss is identified as above, whereas for the left side truss, a prime is added to node numbers and these look like: L_0', L_1', L_2', U_0', U_1', U_2' and so on.

The sleepers of track in case of through type girders are resting on longitudinal girders called **stringers.** These stringers are supported by **cross girders.** The cross girders are provided at each of the node points so that the track load goes to the truss at the nodal points only (To satisfy one of the assumptions made in designing the design of open web girders). The fig 1.15 shows isometric view of a truss which shows the various components including the stringers, cross girders and the bracing in open web girders. (One girder is shown solid and the other dotted.)

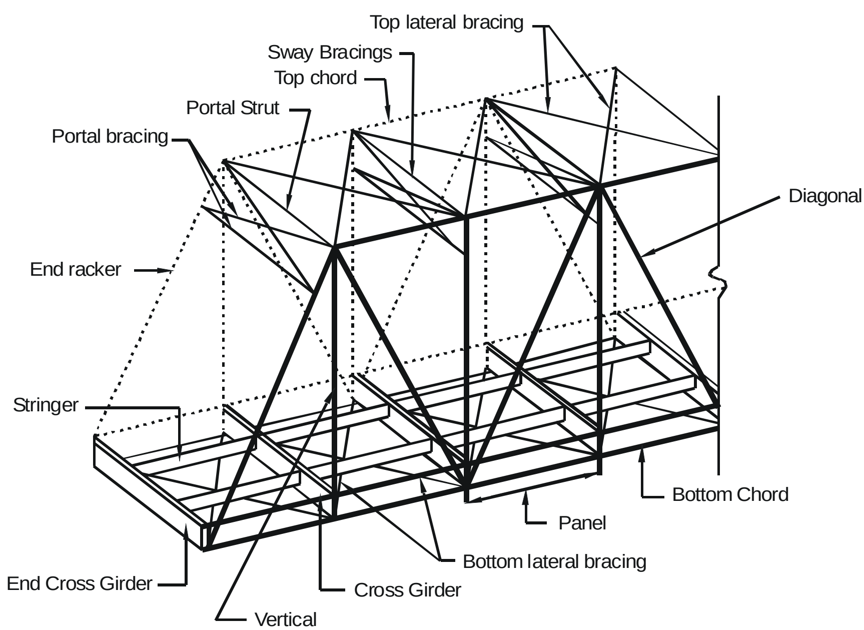


Fig 1.15: Isometric view of a truss showing various parts

The lateral bracing are more important in the truss type or open web girders as the members are slender and the lateral restraint is more important for these compared to solid web girders. In addition to the **top and bottom lateral bracing** which are provided in the main girder as well as stringer girders, open web girders require another set of bracing which connect the verticals. In the plane transverse to the track, the transverse loads such as from wind loads are to be taken by a frame with the verticals acting as the vertical legs and the top bracing acting as top strut. The joints of this portal near the top boom have to be stiffened else the lateral deflections will be excessive. For this, **sway bracing or knee bracing** are provided at the junction of each vertical with the top boom. All the lateral loads taken by the top lateral bracing system are transferred to the supports through the end racker and the portal formed by these is subject to more loads as compared to the portals formed by the verticals. Therefore, bracing provided at the junction of each end racker with the top boom is also heavier and is called **portal bracing**. The top/ bottom lateral bracing are shown in plan in fig 1.16 and 1.17 below. Fig 1.17 shows stringers, cross girders and stringer bracing also.

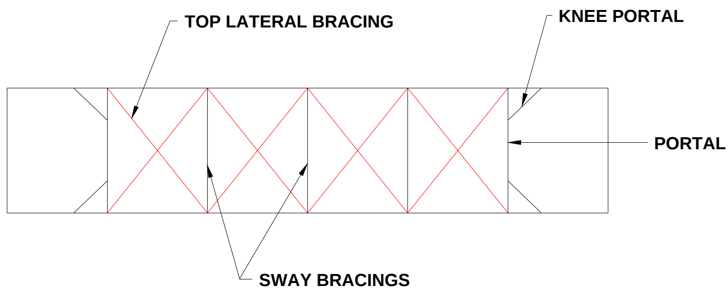


Fig 1.16: Top plan showing the top lateral bracing

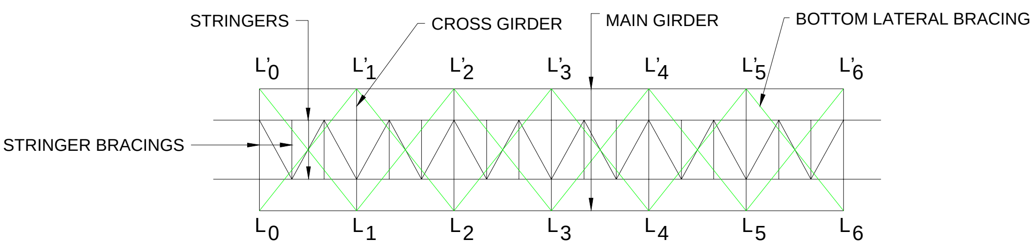


Fig 1.17: Bottom plan showing bottom lateral bracing, stringers, cross girders and stringer bracing

1.3.3 Semi Through Plate and Open Web Girders: The semi through type plate and open web girders are shown in fig 1.18 and 1.19 respectively. The semi though open web girders are extremely rare but semi through plate girders are provided where the rail-level to bed block distance available is very less and the clearances under the bridge are important.

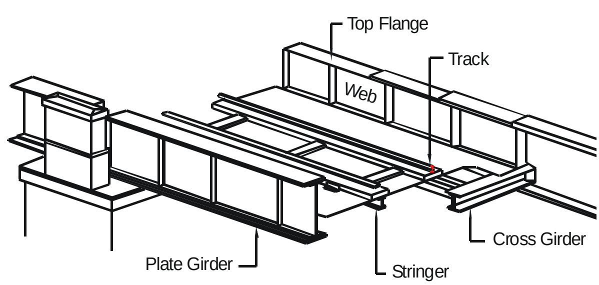


Fig 1.18: Isometric sketch of semi-through plate girder

Fig 1.19: Semi Through Open Web Girder

The construction of the semi through plate girders differs from the deck type plate girders in that these have stringers and cross girders similar to the open web girders described in 1.3.2 above. The semi through open web girders have the same components as the through type open web girders except that the top bracing, knee bracing and portal bracing are not there in these type of girders.

1.3.4 Underslung Girders: Deck type truss girders are of different types but the shape mostly used on Indian Railways has nearly zero depth at the ends near bearings. This shape is invert of a normal through type girder. This type of girders are known as Under Slung Girders.

The side elevation of a typical underslung girder is shown as fig 1.20 as follows:

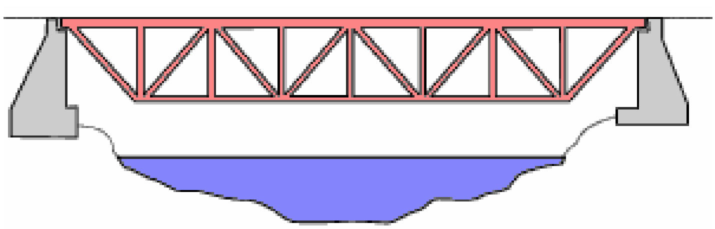


Fig 1.20: Sketch showing side elevation of underslung girder

The underslung girders have the same parts as through type girders except that in this case, the center to center spacing of girder leaves is lesser as compared to through type girders. The sleepers in this case rest directly on the top boom of the girder and the stringers are not required to be provided. Since the cross girders also are not subjected to the train loads directly, these are much lighter as compared with the cross girders in through type girders.

1.3.5 Composite Girders: Steel girders suffer from one major problem when used for the railways: **these have non ballasted deck.** Due to this, the stiffness of track is much higher on the girder as compared to the approaches. This creates the following problems:

a) The track fittings are subjected to higher dynamic loading on the girders and keep getting loose. Considerable efforts are required to be put in by p-way staff to ensure fittings are tight and ensure safety on track.

b) The fittings in track also suffer more wear and tear, requiring frequent renewals.

c) The approach track between the normal embankment and girder gives a huge shock during entry and exit of train from bridge due to difference in stiffness. This portion, therefore, requires frequent attention.

Therefore, in field, concrete girders were being preferred over the steel girders primarily due to the ballasted deck in the concrete girders. With composite girders, most of these concerns are addressed. **Moreover, due to concerns regarding the satisfactory inspection/ maintenance and the fear of sudden failure of concrete bridges, vide letter no 2005/CE-I/BR-II/8 Dated 28.05.09, Railway Board has specified that for all new bridges, spans more than 24.4 m shall be steel girders only. The letter, however, provides that composite deck can be provided over the steel girders.**

Of late, **the girders for road over bridges are also being preferred as composite, as against PSC being adopted earlier**. Therefore, the fabrication of composite girders is also an activity which will now be taken up increasingly by fabrication engineers. RDSO has already issued drawings for composite girder for track upto 30.5 m spans. The drawings for standard spans of Road Over Bridges are also under preparation.

The girders for composite construction are similar to deck type plate girders except that the top flange of the composite girders have welded shear connectors on top as shown in fig 1.21 below:

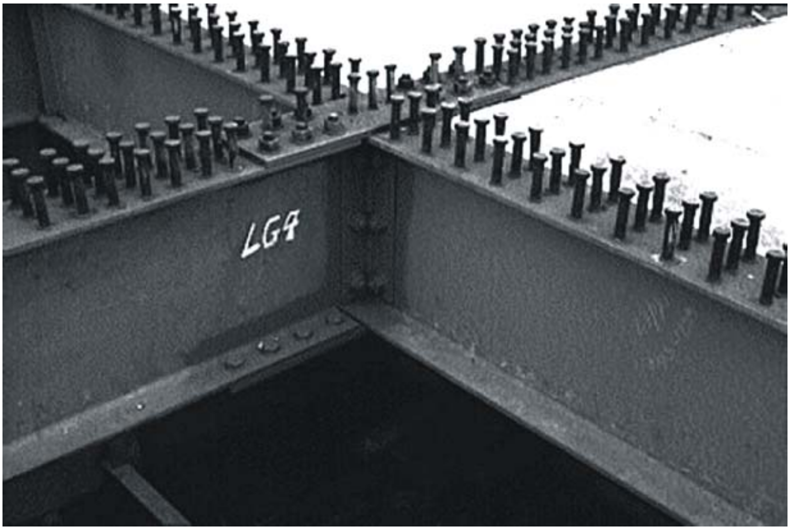


Fig 1.21: Shear connectors for composite girders

The composite construction in open web girders is still on design table and no such design has yet been approved. One of the methods of providing ballasted deck in the steel girders is to provide steel troughs of the type shown in fig 1.22 below. The troughs shown can be used to provide ballast to hold the ordinary track sleepers in position. The ballast is retained at sides using steel plates and the sleepers are provided in the trough of the decking to reduce height of construction as well as to get adequate cushion.

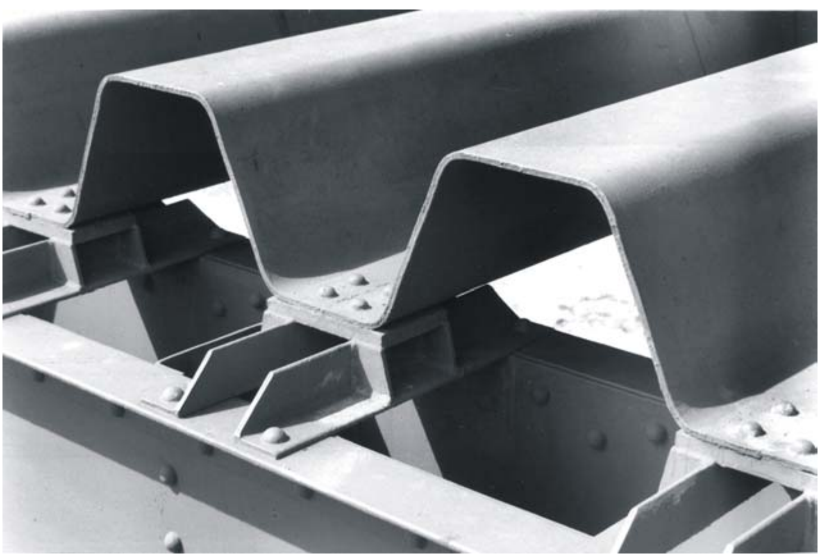


Fig 1.22: Troughs for holding track

1.4 History of Loading on Bridges on Indian Railways:

In the pre-independence era, most of the designs of bridges and fabrications were done in England as per the standards framed by the British. The first Indian Railway standards for B.G. were framed in 1926 known as Broad Gauge Main Line (BGML)-1926 standard. In these standards steam locomotives and wagons of that time were considered. Gradually steam traction gave place to Diesel traction and then to Electric traction. Simultaneously, axle loads increased and, after independence, RDSO-Lucknow has developed the standard design and prepared drawing for fabrication of steel girder for different loading standards:

1) BGML (Broad Gauge Main Line) loading –1926
2) RBG (Revised Broad Gauge) loading – 1975
3) MBG (Modified Broad Gauge) loading – 1987
4) HM (Heavy Mineral) loading -1995
5) 25 T axle loading - 2008
6) DFC (Dedicated Freight Corridor) Loading (32.5T axle load) - 2008

1.5 Standard Steel Girders for Track Bridges

1.5.1 PLATE GIRDERS

Only deck type riveted construction steel plate girders for span 9.15, 12.2, 18.3, 24.4 and 30.5 m were standardized. No semi-through & fish belly spans were standardized (Due to excessive fatigue load on the small span girders, drawings for span 6.10 m and below were later issued only as RCC / PSC slab, box culvert etc).

Prior to 1985, mostly standard plate girders were fabricated as riveted (in shop as well as field) as per RBG-1975 loading, steel girder to drawing No as below.

Span	G.A.D. Drg No.
9.15m (30’-0)	BA-11072
12.2m (40’-0)	BA-11073
18.3m (60’-0)	BA-11074
24.4m (80’.0)	BA-11075
30.5m (100’.0)	BA-11076

These drawings are not valid any more. Standard plate girders designed for 25T/32.5T loading with fabrication drawings having shop welding and field connection riveted are listed below:

Span	G.A.D. Drg No.	
	25T Loading	32.5T Loading
12.2m	RDSO B-16014	RDSO B-16017
18.3m	RDSO B-16015	RDSO B-16018
24.4m	RDSO B-16016	RDSO B-16019

1.5.2 OPEN WEB STEEL GIRDER (Standard)

Earlier truss type steel girders were fabricated with wrought iron, early steel and mild steel. A triangulated steel girders with pin connected at every panel points of truss is shown in Fig 1.23.

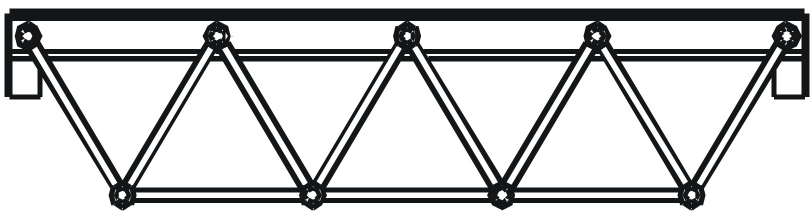


Fig 1.23: PIN CONNECTED TRIANGULATED TRUSS

Nowadays, pin jointed trusses are not preferred but riveted trusses are fabricated with gusset plates at joints. But the modern designs have followed these designs and as per clause 3.3.1 of SBC, to ensure that primary stresses in the design of triangulated structure truss are axial, stresses in members are computed based on assumptions that:

- All members are straight and free to rotate at the joints
- All joints lie at the inter section of the centroidal axes of member
- All loads including the weight of members are applied at the joints

With pin joint, the above assumptions were holding to considerable extent, but with riveted rigid connections, members are subjected not only to axial stress but also some bending and shear stresses. These bending stresses are called as **deformations stresses**. Special care is to be taken to ensure the proper performance of the open web girders in view of these design assumptions (or rather, their violations).

RDSO-LKO, during standardization, has prepared design and fabrication drawing with pre-stressed warren type truss (triangulated truss with vertical at each panel point) for riveted connection in shop as well as field. The drawings were issued for 30.5m under slung and 30.5m, 45.7m, 61.0m and 76.2m through type girders (Fig 1.24)

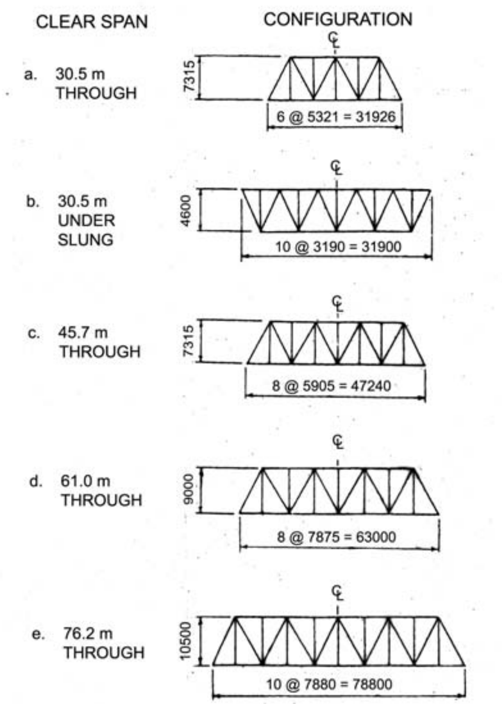


Fig 1.24: Configurations of Broad Gauge Standard Open Web Spans

The drawings riveted open web girders issued by RDSO are:

Span	Type	Fabrication Drg No.
30.5m	Through	BA-11341
30.5m	Underslung	BA-11401
45.7	Through	BA-11361
61.0	Through	BA-11321
76.2m	Through	BA-11151

RDSO-LKO has also designed and prepared fabrication drawings of open web girder (warren truss) with welded shop fabrication for forming members and field connection for assembly of span with riveted connection for 25T/32.5T loading as follows:

		Fabrication Drg No.	
Span	Type	25T Loading	32.5T Loading
30.5m	Through	BA-11678	BA-17061
45.7m	Through	BA-17001	BA-17081
61.0m	Through	BA-17021	-
76.2m	Through	BA-17041	-

The panel spacing for 25T/32.5T loading girders is the same as shown in fig. 1.24. The height of girders for 32.5T loading has been kept 10500mm due to higher operational requirements.

1.6 Special Open Web Steel Girders for longer spans:

In Indian Railway there are many open web girders between 91.4m and 122.2m span and some of these bridges are Rail-cum-Road bridges also. Fig 1.25 shows the typical girder arrangements for long span girder bridges provided on Indian Railways.

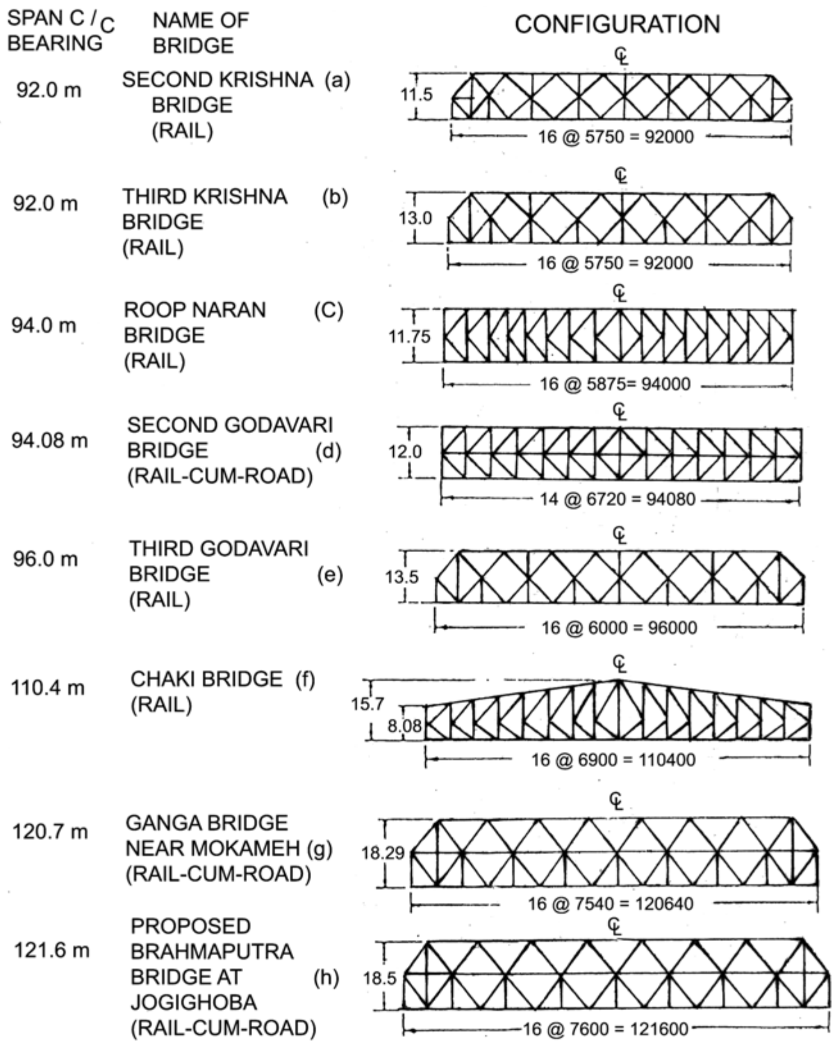


Fig. 1.25 SPECIAL THROUGH GIRDERS OF LONGER SPAN

The longest steel girder span adopted till date on Indian Railways is 153.4 m provided in bridge no. 20 (Jhajjar Khad) on Udhampur-Katra section of Northern Railway. The side elevation of this bridge is shown in Fig. 1.26 below.

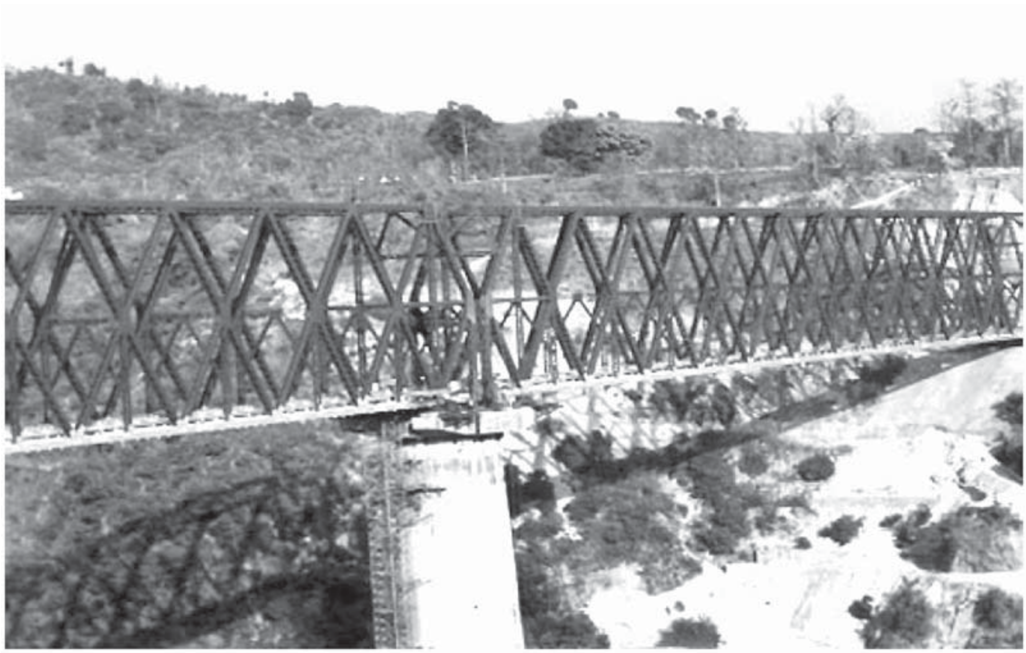


Fig. 1.26: 153.4m span in bridge no. 20

1.7 Fabrication of girders for KRCL: Three spans of steel girders of 122.2m (two middle spans at Zuary river and one middle span of Mondovi Creek Bridge) with welded open web steel girder were fabricated with variable heights for Konkan Railways. Fig 1.27 shows the arrangement used for the bridges for KRCL.

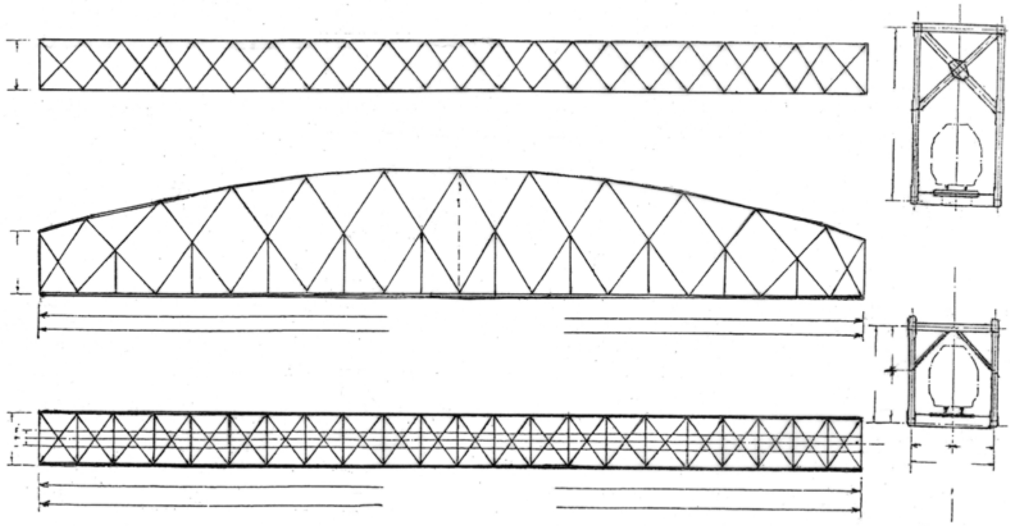


Fig 1.27: SCHEMATIC SKETCH OF KRCL- STEEL GIRDER

1.8 Important steel girder projects currently going on:

Some important projects with steel girder fabrication taken up by the Indian Railways at the moment include:

a. **Ganga Bridge** near Patna having 36x123 m+ 2x64 m (rail cum road bridge)

b. **Ganga Bridge** near Munger having 29x125 m (rail cum road bridge)

c. **Jubilee Bridge** near Kolkatta on Hugly river in Eastern Railway having three span continuous (132.65 m + 150 m + 132.65m) Warren type truss for double track with variable heights.(Fig 1.28)

Fig 1.28: Schematic view of Jubilee Bridge

d. **Bogibeel bridge** on river Brahmaputra near Dibrugarh in Assam, having 1x32.5m+34x125m+ 1x32.5m spans for the rail cum road bridge where welded gussets are being planned for the first time in India. (Fig 1.29)

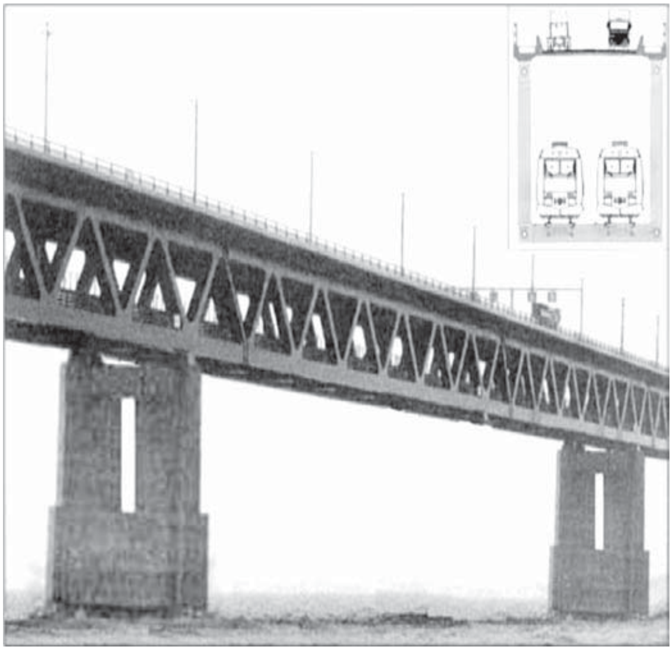


Fig 1.29: Schematic view of Bogibeel Bridge

e. Chenab Bridge in Katra – Quazikund section of Northern Railway where 467 m long steel arch bridge has been planned. (Fig 1.30)

Fig 1.30: Schematic view of main arch span of Chenab Bridge

Looking at the projects underway, and the recent policy changes, the future of the steel bridge fabrication in India and hence the relevance of this book looks pretty bright.

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Chapter II

UNDERSTANDING WELDING PROCESSES

2.1 General: In the past, there were apprehensions about using the welds for dynamically loaded structures such as railway girders whereas for non-dynamically loaded structures, welding has been in wide use for quite some time. Historically, in railways only steel girders for track bridges were fabricated as riveted structures and remaining steel structures like FOBs, IRS platform cover sheds and workshop sheds etc were fabricated by welding. Keeping pace with other industries, railways first started fabrication of welded plate girders of span 9.15m, 12.2m, 18.3m and 24.4m as fabrication is simply to form 'I' section. With the experience gained during fabrication of 3 x 122.2m spans for Konkan Railway, which were first open web girders fabricated by welding in Civil Engineering Workshop, Central Railway Manmad, from year 2000 onwards, RDSO/LKO has designed and prepared fabrication drawings of open web girders of spans 30.5m, 45.7m, 61.0m and 76.2m. Now railways are shifting completely over to welded girders and for 25 T loading 2008 and DFC loading, no drawing of riveted construction has been issued. As per clause 616(5) of IRBM, "Adoption of riveted fabrication plate/composite girder should not be done without prior approval of Board". However, due to apprehensions about the field welding quality, welding is approved for shop fabrication only, and all jointing during assembly of span in field is required to be done by riveting.

2.2 Introduction to Welding: The welding is a process by which the steel parts are joined together so as to act as a single unit under load. There are various methods of welding, but the electric arc welding is the only type of generic process used in fabrication of railway girders. This welding process includes introduction of external molten steel from an electrode tip which melts due to intense heat from arc formed between the tip and steel members at the joint location[1]. Some portion of the steel members at the joint also melt due to the heat generated by the arc. When the molten metal 'pool' cools, the steel members get fused and are said to have been 'welded'. Fig 2.1 shows the generic arc welding process. The weld metal deposited is known as **bead** and the depth of parent metal affected is called **penetration**.

The welding method can be explained by a simple analogy of joining two ice blocks. When two Ice blocks are heated up locally, interface gets converted to water and when cooled back to freezing temperature, the water

[1] An arc is the state where the electric current flows through a gap between electrodes when the air in between gets converted to plasma.

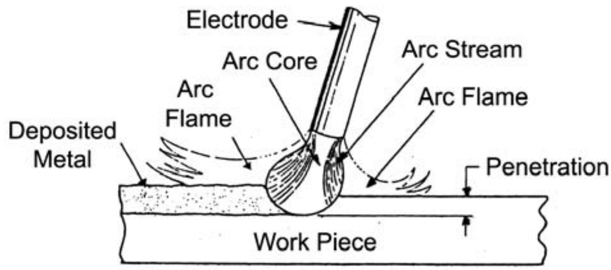


Fig 2.1 ARC WELDING

freezes, causing the two blocks to join i.e. these become one piece of ice block. In the same way, joining edges being heated by electric arc get converted to liquid state and when allowed to cool back to room temperature, the two edges solidify to join together.

When steel converts from solid to liquid state, it will be in hot condition and if it is allowed to come in contact with atmosphere, oxygen present will oxidize metal and hydrogen may also get included. In order to avoid such occurrence, flux is used which provides a cover to the hot molten metal like a blanket till the steel reaches lower temperatures.

If we look at a weld in plan as shown in fig 2.2, we see that molten metal pool forms a bead which gets deposited at the interface of members. The welding process has to be controlled to get the uniformity of the bead and also to ensure its continuity. Improper welding process can also result in overheating which can damage the members. This is particularly important for the welds in railway girders as the welds are subjected to dynamic loads and any flaws are likely to increase the stress concentrations and reduce the ‘fatigue life’; of the welded components. (See Annexure I for concept of ‘fatigue’)

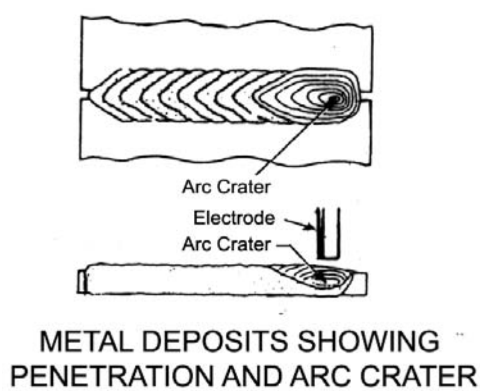


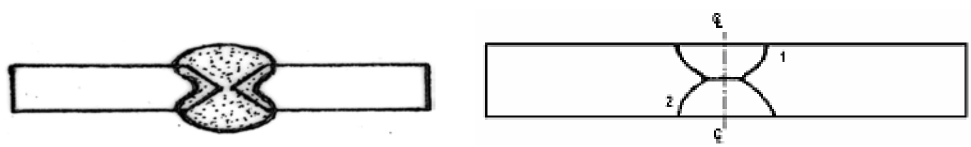
Fig. 2.2 : Plan and cross section of a welding

There are different methods within the generic ‘electric arc welding’ which accomplish the ‘welding’ in different ways. These methods have been discussed later in this chapter.

2.3 Types of Welded joints used for fabrication of Steel Girder for Track Bridge: Various types of welded joints are possible but mostly two types of weld joints are used in railway steel girder fabrication viz, (i) Butt welds (ii) Fillet welds.

2.3.1 BUTT WELDS: When it is required to increase the length of member, two sections are welded side by side and butt(or groove) weld joint is resorted to. There are several types of butt welds used for fabrication such as V-groove weld, Double V-Groove weld, Square butt weld, single bevel V-butt weld, double bevel V-butt weld etc. These are adopted according to the location specific requirements.

When butt welds are used, these are subjected to axial loads, transverse to the weld and any defect is likely to affect the stress distribution. Due to fatigue considerations for repetitive train loads, these welds are considered critical. For Indian Railway Bridges, **Clause 13.3** of WBC stipulates that permissible stress of butt joint shall not be less than the permissible stress of parent metal. Therefore, it is essential that good quality butt weld shall extend the entire thickness of parts to be joined and shall have ‘full penetration’. Therefore, for railway girders, double V groove butt welds or square butt welds are generally used (shown in fig 2.3). As per clause 32.1 of WBC, these welds are required to be tested by radiography.



(a) **(b)**

Fig 2.3 Butt Welds (a) double V groove (b) Square Butt Weld

Fig 2.4 shows a single bevel butt weld and various parts of the weld are also indicated therein.

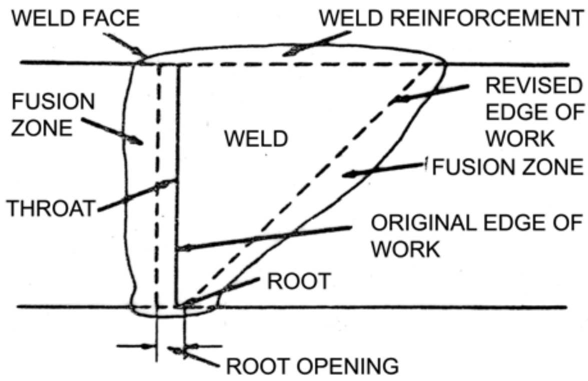


Fig 2.4: Parts of a Single Bevel Butt weld

Parts of a Butt weld:

Weld face: The visible part of weld from top is called the weld face.

Root: The location where the steel parts being welded are the closest. This is at the base between members joined together by bevel butt weld shown in fig 2.4. (In case of double V weld the root is in the middle and in case of square butt weld, there is no root)

Fusion Zone: In any welding, the weld material shall fuse with the parent metal and the area which is a combination of the parent metal and the weld material is called fusion zone.

Weld Reinforcement: In butt welds, the throat dimension is kept slightly greater than thickness of base metal which is called weld reinforcement. For better fatigue strength of the joint and to avoid stress concentration, this reinforcement is required to be ground flush by grinding.

Edges of Work: The original edges of work of the steel sections to be welded are shown in the figure above as dotted lines. The regional square edge of the steel plate is beveled to get the revised edge of work before welding is done.

Ensuring that the butt weld has strength equal to the parent metal requires very close quality control and checks and it is better that these welds are avoided. The steel plates from rolling mills in India are available in lengths upto 12.5m from transportation logistics point of view. Therefore, in order to avoid unnecessary splicing as well as butt welds, all fabricators should place order on rolling mills stating that no steel sections for track bridge steel girders shall be less than 12.5m in length. However, for girders beyond 12.5 m lengths, joints are unavoidable. For these, field welding is not permitted and the riveted joints have been provided in RDSO fabrication drawings. The details of splices in 25T loading drawings issued by RDSO are as follows:

- In 12.2m span, the overall length is 13.3m and if plates to this length are not available, butt welded joint has to be provided.
- In 18.3m span plate girder, overall length is 19.67m hence one central joint is provided.
- In 24.4m & 30.5m plate girder, two splice riveted joints have been provided.
- In 30.5m and 45.7m open web girder through spans, two panel lengths (i.e. L_O-L_1-L_2) are less than 12.5m, and hence two panel lengths are fabricated as one member.
- In 61m & 76.2m open web girder through spans, two panel lengths become more than 12.5m, hence each panel length (i.e. U_4-U_5, L_2-L_3 etc) is fabricated as one member.

2.3.2 FILLET WELD:

A fillet weld is the most common type of weld. Used to make lap, corner and “T” joints, the fillet weld is the most basic of welds. In this case, the weld bead fills the edge at junction of two pieces of steel, hence the name fillet weld. The fillet weld is used to join two pieces of steel, mostly at 90^0 angle. The fillet welds can be made for angles 60^0 to 120^0 (Clause 6.4 of WBC), but 90^0 welds are the most common. A fillet weld is produced by running a weld bead at a 45-degree angle to a corner, as shown in fig 2.5. It resembles a triangle when viewed from the side or in cross section view. Fillet welds are mostly subjected to shear load and very less axial loads. Hence these welds are lot less susceptible to fatigue failure even if there are small internal flaws. The Steel structure fabrication is preferably carried out with fillet welds as the required quality of welds for satisfactory service can be easily achieved. Automatic welding machines are available to produce sound uniform cross section of weld with required penetration depth and length of fillet weld.

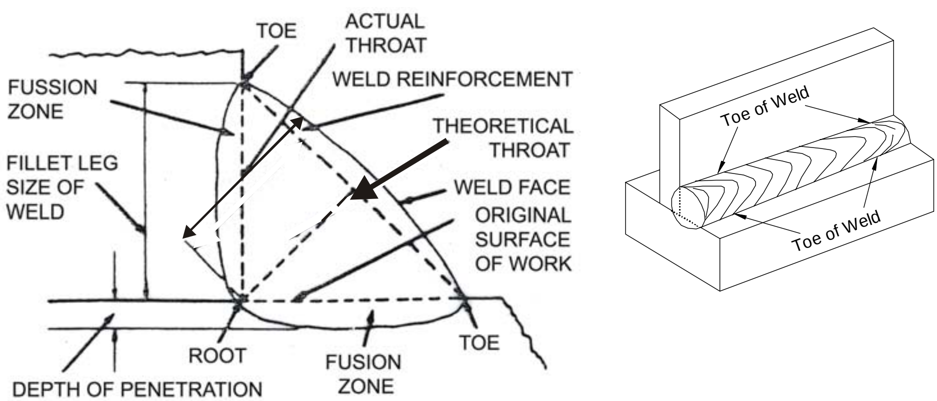


Fig 2.5 Cross Section of a fillet weld

- Parts of a fillet weld:

Toe: The point where the weld touches the parent steel

Weld Reinforcement: The extra weld material over the theoretical triangular profile of a fillet weld.

Leg: the dimension of weld as measured along the side of steel parts being welded

Root: The location where the steel parts being welded are the closest

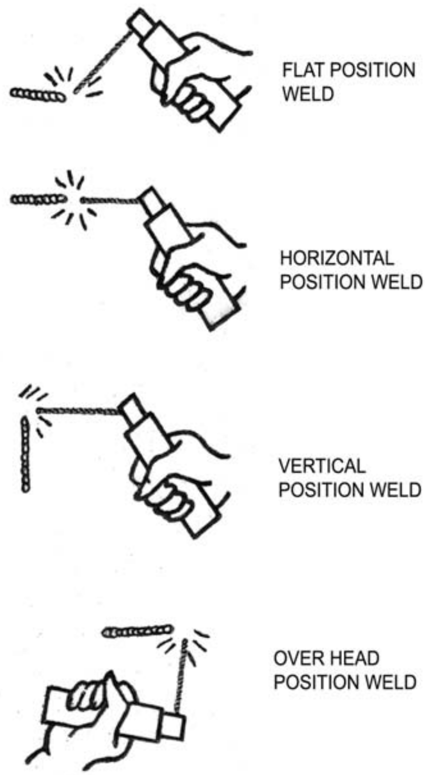
Weld face: The surface of weld away from its root.

Throat: The dimension of weld which gives the effective area for structural action of the weld. The throat size is expressed as a proportion of the leg length.

Edges of Work: The original edges of work of the steel sections to be welded (shown in the fig. 2.5 as dotted lines).

2.4 Positions of Welding: Depending on the member details, location and orientation, various positions for welding shown in Fig 2.6 are:

1) Down hand (flat) 2) Horizontal[2]
3) Vertical (up/down) 4) Overhead.



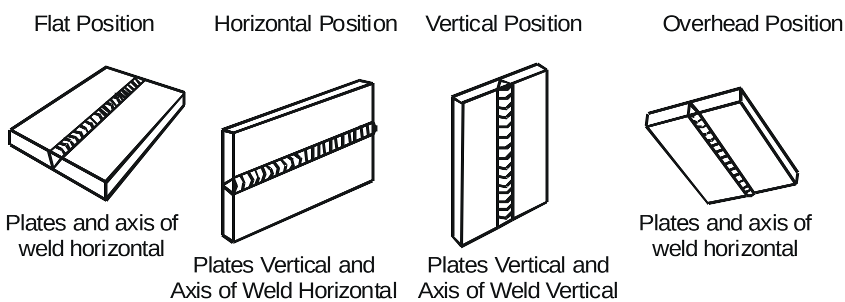


Fig 2.6 POSITIONS OF WELDING

[2] In flat position of welding, the hand is above the weld whereas in horizontal position the hand is level with the weld.

As is very obvious, the flat position is the best position for welding as the molten metal is stable and does not tend to flow and it is easier to move the electrode. The welding becomes more difficult as the position changes from flat position to horizontal, to vertical and then to overhead position. The vertical and overhead welds are very difficult as the molten metal tends to flow too much and comes off the surface of steel being welded. The welding electrodes, methodology and skills etc. required to make weld change as the position of welding changes. **Welders are qualified for specific positions and a welder qualified for easier position, say flat position, cannot make a weld in more difficult position, say vertical position.** However, a welder qualified for more difficult position can weld all positions easier than that i.e. a welder qualified for overhead position can weld in all positions.

2.5 Likely Flaws during welding process:

Flaws in welded fabrication vary in size from very small undetectable ones like nonmetallic inclusions to large flaws depending upon:

- Quality of steel and weld material used for fabrication.
- Welding process and procedure, position of welding during fabrication.
- External flaws on surface like corrosion pits and segregation marks before fabrication.
- Cleanliness of adjoining surface of weldment and moisture free condition during welding.
- Welder's qualifications

During welding, flaws which may be introduced in weldment include

- Incomplete fusion
- Slag inclusion
- Porosities (on account of moisture presence)
- Blow holes
- Under cuts
- Start and stop defects including craters
- Arc strikes, including stray arc
- Tack weld defects
- Hot and cold cracks

One should realize that repairing weld flaws does not always eliminate defects because repair weld may also be flawed. It is essential to use welding procedure with approved parameters to minimize defects during fabrication of steel girders.

2.6 Care required during fabrication for welding: Fabrication of members to be welded requires care in the following aspects:

- Oxy-acetylene gas cut edges may contain drag marks and notches.
- Preparation of joint face which will be part of weldment shall be prepared as per provision of IS-9595. But if long cut edge (9 to 10 meter) is to become fusion face, it cannot be prepared by grinding. Therefore, it is essential to prepare by edge planning machine which will remove 1 to 2mm brittle metal and produce uniform contact throughout length of member thus, avoiding stress concentrations due to variable gap included in weld.
- While chipping and straightening, care shall be taken to avoid notch formation
- Brittleness by grinding called hard spot shall be avoided
- Sharp corners at cut edges to be avoided.
- Punching of holes (it is totally prohibited in the truss member of open web girder as per clause 18.2 of IRS-B1).

2.6.1 Choosing Steel for welding: IRS B1 clause 8.1 stipulates that IS-2062 Grade A (equivalent to old IS-226) as rolled Semi killed or Killed[3] shall be used for foot over bridge and other structure subject to non critical loading. For structures subjected to dynamic loading, such as for railway loading, IRS B1 specifies that steel conforming to IS: 2062 grade B, fully killed and normalized[4]/ control cooled[5] shall be used. If the temperature of the structure in use is not going to go below 0^0 C. If lower temperatures (-20^0 C to -40^0 C) are expected, the steel conforming to IS: 2062 grade C fully killed and normalized/ control cooled shall be used as per clause 8.3 of IRS B1. (Plates less than 12 mm thickness need not be normalized/ control cooled). Mill test certificates shall be taken for steel being used, and testing may be done if the test certificates are not available or there is some doubt about the properties of steel. The chemical and mechanical properties of

[3] **Killing:** Process of reducing the dissolved oxygen to a minimum which is achieved by addition of silicon, aluminium etc. during the manufacture of steel to prevent reaction between carbon and oxygen when the steel is in molten state. The silicon percentage added is between 0.1 to 0.4. The MTC (manufacturer's test certificate) mentions remarks such as Al killed, Al-Si killed etc to indicate the killing process used.

[4] **Normalising:** The process of heat treatment for improving the mechanical properties of steel which leads to grain refinement and uniformity in structure of steel. The MTC should clearly specify whether steel is normalised or not.

[5] The IS:2062 does not use the term "control cooled". There is some ambiguity due to the above IRS B1 clauses. If the steel is "control cooled", it no longer is as per IS:2062

steel conforming to IS: 2062 are given in tables below:

IS:2062 - Specification of Steel for General Structural Purposes						
CHEMICAL COMPOSITION						
Grade	C% Max.	Mn% Max.	S% Max.	P% Max.	Si% Max.	C.E.% Max.
A	0.23	1.50	0.050	0.050	0.40	0.42
B	0.22	1.50	0.045	0.045	0.40	0.41
C	0.20	1.50	0.040	0.040	0.40	0.39

MECHANICAL PROPORTIES						
Grade	UTS(MPa)Min.	Y.S.(MPa)Min.			El.%Min.	Bend Test
A	410	250	240	230	23	3T
B	410	250	240	30	23	2T & 3T *
C	410	250	240	230	23	2T
* 2T - <=25mm * 3T - > 25mm						

Rolled steel taken up for welding shall be free from surface defects like lamination, corrosion / pitting as well as inherent flaws like piping, slag inclusion, porosity etc. Steel section used for fabrication shall be straightened to ensure proper contact of surface for weld joint.

When there is no choice in steel, say while carrying out repairs or when we have to weld two dis-similar steels, weldability of steel has to be checked and compared. The term **weldable steel** is used to denote if a steel has the capacity to be welded such as to ensure satisfactory performance in the intended service life (i.e. steel with good weldability can be welded readily for fabrication as well as for repairs. Steel used in older times may or may not be weldable). Steel of old structure shall be got tested to confirm weldability by specimen test as well as by determining Carbon Equivalent (CE).

$$CE = C\% + \frac{Mn\%}{6} + \frac{Cr\% + Mo\% + V\%}{5`} + \frac{Cu\% + Ni\%}{15}$$

Steel is considered weldable if CE is less than 0.42%. If carbon is less than 0.12%, CE for weldability can be upto 0.45%.

2.7 Different Welding Processes: The fabrication work or the inspection of fabrication work (carried out by private firms) has to be carried out by officials of Engineering departments of Zonal Railway. Therefore, it is essential to have understanding of basics of welding process used in fabrication of steel girder. Welding technology is a vast field and numerous processes are used in other industries for joining similar or different metals. However, the following 3-types of electric arc welding methods are used in Indian Railways.

- Manual Metal Arc Welding (MMAW) or Shielded Metal Arc Welding
- Submerged Arc Welding (SAW)
- CO_2 Welding or Metal Active Gas Welding (MAGW)

2.7.1 Manual Metal Arc Welding (MMAW):

A process wherein coalescence is produced by an electric arc set up between a flux coated electrode held by a welder (workman) and steel members to make a weld is called manual metal arc welding (MMAW). In MMAW process, flux covers the mild steel electrode all around, hence electrode is called flux coated. Electrode, which is of mild steel melts under heat when the arc starts and supplies the additional filler metal necessary to form the bead. The flux covering is combustible and decomposes due to arc heat thereby providing inert atmosphere to the molten metal by consuming all oxygen around it. The flux also performs additional functions like arc stability, alloying the weld bead etc. as designed.

Since the electrode is held manually by a welder the process is called manual welding. Direct viewing of the arc is injurious to the eyes and hence a shield is held by the welder to protect his eyes when the arc is on. The fig 2.7 shows a welder carrying out the MMAW with adequate protection to eyes as well as with protective clothing to protect against sparks etc.

Fig 2.7: Manual Metal Arc welding Equipment and Welder

The electric current for a MMAW is supplied through a portable or semi-portable welding transformer. The transformer gives a high ampere, low voltage current which is employed to form the arc. The MMAW can be done using AC current or DC current. The difference between the two is given in Annexure II.

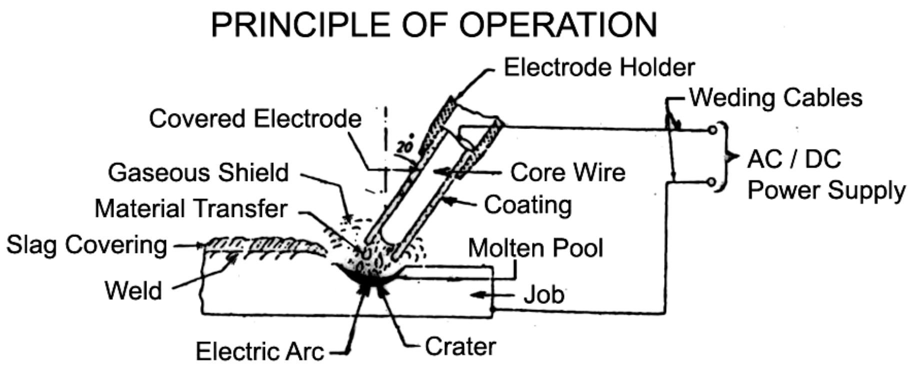


Fig 2.8 MMAW PROCESS

To control the welding parameters, the arc temperature (arc heat) can be increased or decreased by employing higher or lower currents (Setting the transformer to required current and voltage). High current with a smaller arc length produces a very intense heat. The heat generated at arc melts the tip of electrode and a portion of job. Metal droplets are transferred from electrode to the job through the arc and deposited along the joint to be welded. The flux coating burns and produces a gaseous shield to prevent atmospheric contamination of molten weld metal. The bye product of the flux consumption is called slag, which being light weight, floats to the surface of molten weld pool. Fig 2.8 shows MMAW process schematically. To achieve uniform penetration throughout, constant arc length (distance between work piece and tip of electrode) is very important aspect. The electrode shall progress along the joint at constant speed and hand shall be lowered at the same time (because tip of electrode keeps on melting and electrode keeps getting shorter) to maintain a constant arc length. All this has to be controlled by the welder and therefore quality depends totally on experience/skill of welder in MMAW. After welding, the slag forms a brittle layer on the bead which has to be removed by light hammering.

- **Advantage of MMAW:**

a) It is simplest and easiest of all arc welding processes.

b) The equipment is portable and can be taken to any field location and the cost of equipment is also low.

c) Equipment required for this process is quite simple and portable to take any where when AC supply is available. DC generator can be used where no AC supply is available.

d) Welding can be performed to any position by this method hence repairs of structures in the field is possible.

- **Limitations of MMAW:**

a) In this process, all the functions of maintaining arc length and manipulation of the electrode to produce continuous weld are in the hands of welder. Hence sound homogeneous and defect free weld is dependent to a large extent on welder's experience and skill. This is a major limitation of MMAW.

b) The welding parameters while starting/ stopping welds are not stable and affect the weld properties, hence a crater (depression) will be formed at start and at end of welding process (Fig. 2.9). The crater portions have improper root penetration and flaws. Therefore, the process forms two craters which are weak points in a weld.

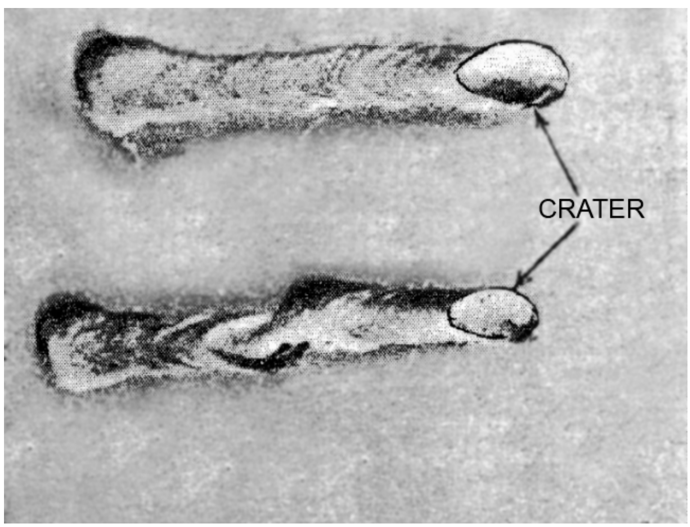


Fig. 2.9 Craters In Welds

c) Crater also forms if the welder accidentally removes the electrode too far away from the surface and arc stops. Similarly if the work is stopped for any reason, craters form. **One of the main reasons for which the work has to be stopped is when one electrode is consumed up and new one has to be employed.** To suit the manual welding process, the electrode length has been kept as 300mm to 450mm (50mm one end uncoated with flux to grip the electrode in holder for proper flow of current while welding). Therefore, one electrode can deposit only 150mm to 200mm length weld depending upon size of weld. For finishing, the crater has to be removed by grinding or gouging the end of weld bead and cleaned properly for removing slag by wire brush before restarting weld in continuity (Fig.2.9). If we have to repair the craters at such close intervals, it becomes a very tedious process for long lengths of welding and some times, even after treatment, flaws may remain in weld. If we weld members of steel girder components of 10-11 m length by this process, there will be a large number of weak locations and uniform sound weld will be almost impossible to produce.

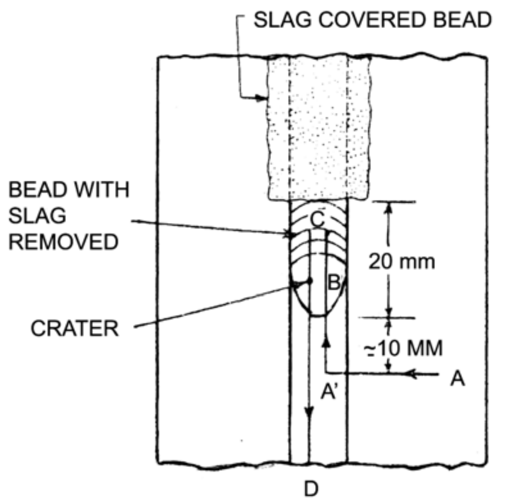


Fig. 2.9 Repairs to Crater

- **Electrodes for Manual Metal Arc Welding (IRS-M-28 (2002)) specification**

Electrodes in other industries are covered by AWS (American welding society) specification or IS-814 (Part 1 & II), but for structural fabrication for Railway loading, these specifications have to be read together with IRS specification M-28. Provisions of IRS-M-28 related to steel structural welding are given below:

Electrodes for Manual Metal Arc welding (MMAW) for fabrication of steel structure on Indian Railways		
Parent Material	**Use**	**Class of Electrode**
Low Tensile Steel	Static loading	A1
Low Tensile Steel	Mod. Dynamic	A2
Low Tensile Steel	High Dynamic / Low Temperature	A3, A4
Medium Tensile steel	All Standard application	B1, B2
Medium Tensile steel	Low Temperature application, below 20^0 C	B3, B4
High Tensile steel	All applications	C1, C2
Corten Steel to IRS M – 41 & IRS M –42	All applications	D

The correlation of electrodes as per IRS specifications with the IS/AWS specifications is as follows:

S No.	IRS	Purpose of Use	IS / AWS specification	IS / AWS Code
1	A1	Fabrication of component meant for static loading of steel IS – 2062 Grade 'A' i.e IRS Cover and FOB.	IS 814 – 91	ER 4112 (Medium Coated)
2	A2	Fabrication of component for moderate dynamic loading to Steel IS – 2062 Grade 'B' i.e Road Over Bridge & Track Bridge. Weld deposit shall be of radiographic quality.	IS 814 – 91	ER 4112 X (Medium Coated)
3	A3	Fabrication of component for high dynamic loading to steel IS – 2062 Grade 'C' for low temperature radiographic quality.	IS 814 – 91	EB 5326 H2 X
4	A4	Same as A3 with high deposited efficiency.	IS 814 – 91	EB 5326 H2 J X
5	B1	Fabrication of component for steel IS 8500 – 91 Grade 440 B deposit radiographic quality	IS 814 – 91	EB 5326 H3 X
6	B2	Same as B1 with high deposit	IS 814 - 91	EB 5326 H3 J X
7	C1	Fabrication of component for steel IS 8500 – 91 Grade 540 B.	IS 1395	E63BD 126 Heavy Coated.
8	C2	Same as C1 with high deposit.	IS 1395	E63BD 126 J

- **Use of MMAW welding in Railway Girder Fabrication:** In view of above advantages and limitations, in railway loading members, **MMAW is used for tack welding for assembly of individual components**. For main girder, as per clause 21.4 of WBC, **the MMAW may be used only in unavoidable circumstances for very short runs of minor importance or where access of the locations of weld does not permit automatic or semi-automatic welding.**[6]
- Guidelines for good welding fabrications by MMAW are given in **ANNEXURE-II**

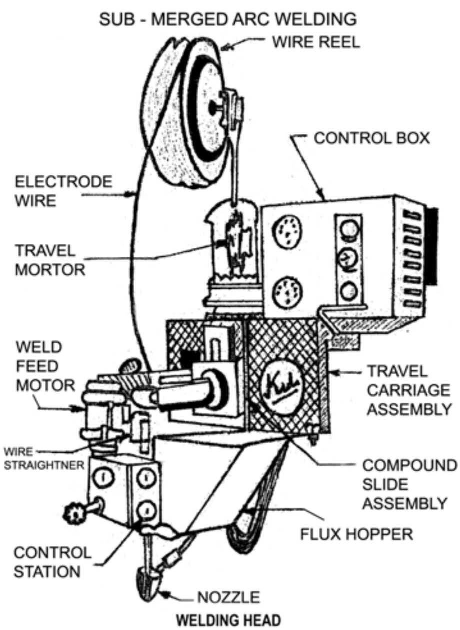
2.7.2 Submerged Arc Welding (SAW):

In this arc welding process, coalescence is produced by heating with an electric arc set between a bare metal electrode (not coated with flux) and job (steel member). In this process, the flux in granular form (like sand) is poured in front of electrode and arc formed is submerged in the flux hence the process is called **submerged arc welding**. The arc at tip of electrode and molten pool are not visible and it is completely hidden (submerged) under blanket of granular material (flux). The flux oxidises when arc forms and provides shield similar to the one provided by the coated flux in MMAW.

[6] The problems due to the crater formations do not affect the static load carrying capacity/ performance of structure under static loads, so MMAW can ba satisfactorily used for all structures subject to static loading.

Bare electrode to be used is in wire form, to a length of 30m. It is coated with copper to prevent rusting of steel electrode as well as to ensure good contact for electric current conductivity. The long length of electrode facilitates continuous weld to longer lengths(up to 20 to 25m length) without any interruption, which is a major improvement over MMAW. Machine for SAW is shown in Fig 2.10 below.

The equipment has automatic travel arrangement for the welding equipment to move as the welding progresses. The welding electrode wire is mounted on a reel and is fed as per parameters fed into the machine by the welder. The feeding of wire is also controlled automatically by the machine. It can be seen that this is an automatic process and the quality of welding does not depend on the skills of welder as much as in case of MMAW. **This is an automatic process and the welder in SAW becomes skilled operator instead of skilled artisan.**



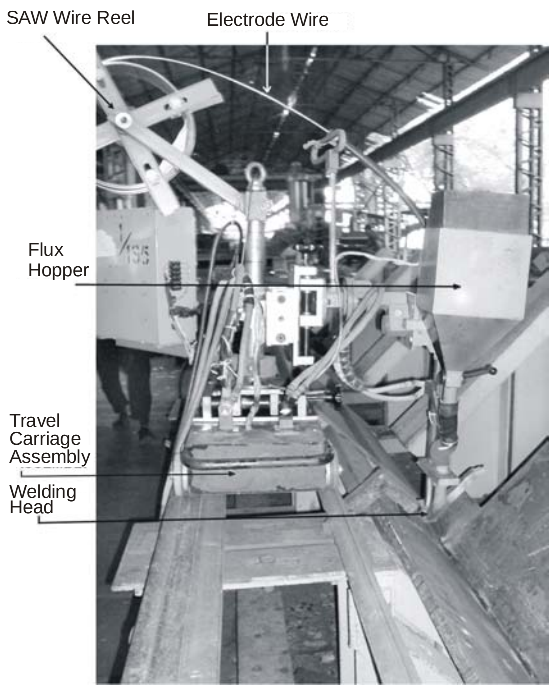


Fig 2.10: SAW MACHINE: Schematic and Actual

- **SAW Process:** The process for SAW is shown in fig 2.11 schematically. Flux is filled in a hopper and when trigger is pulled, flux starts depositing on the joint to be welded. Arc is set up by making the wire touch the job and then pulling it back; or by placing steel wool between electrode and job before switching on the welding current (The arc is set up under cover of flux in either case). For good quality weld, the distance between the job and the electrode (arc length) shall be constant. Equipment is provided with electronic sensor to keep the arc length constant i.e. if due to certain reason arc length decreases, self adjustment of arc voltage and current will cause burn off rate to increase and vice versa to ensure constant arc length. Welding current can be rated up to 1500 Amps hence this process can produce 8mm fillet with required penetration in one pass. Electrode wires are available in 1.6, 2, 2.4, 3.2, 4, 4.8 and 6.4mm dia. and 30m length.

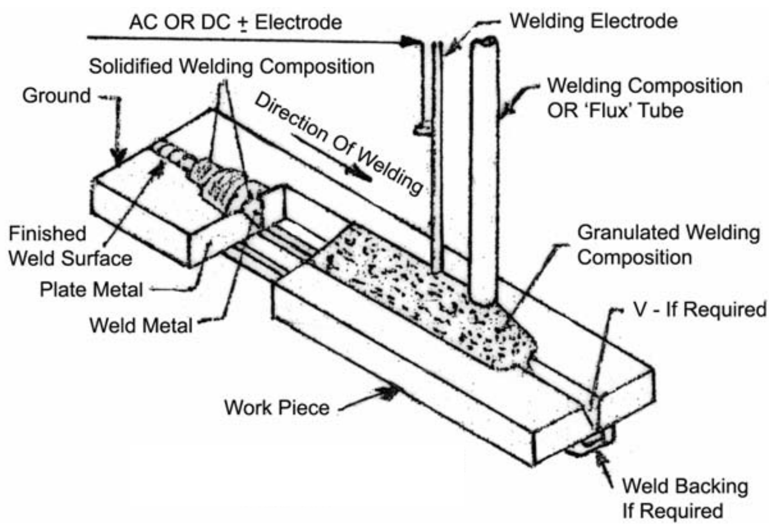


Fig 2.11: Submerged arc welding process

The flux is granulated material which oxidizes under heat. A mixture of fine and coarse particles is recommended for thicker plates. Flux should be dry and for this, it shall be baked for 1 hour at 200°C temperature in oven before use. If this is not done, moisture present in the flux will cause inclusion of hydrogen in weld pool (Molten metal) causing cold cracks in weld bead or in Heat Affected Zone (HAZ). All the flux is not consumed in the welding process and approximately 33% is available for reuse.

- **Electrodes for SAW process (IRS – M – 39)**

The electrode wire and flux combination for SAW process for steel girder of Track Bridge shall be confirming to IRS M-39, which are given below:

CLASSIFICATION OF DIFFERENT WIRE-FLUX COMBINATIONS AND THEIR PURPOSE OF USE

SN	Class of wire & flux combi-nation	Purpose of use	Equivalent Class of IRS M28-2001	Grade of wire	*Flux*	
					Type	*Grade*
1	I	For two run and multi run submerged arc welding of steels to IS:2062-91, IS:1875-91 Class I & IA and other equivalent steels. The weld shall be of radiographic quality.	A3	W-1	Agglome-rated / / fused	*F-1*
2	II	For two run and multi run submerged arc welding of steels to IS:8500-91 grade 440B and 490B and 490B, IS: 2002-91 grade I&II, IS:1875-91 Class II&IIA or other equivalent steels. The weld shall be radiographic quality.	B2	W-2	-do-	*F-2*
3	III	For two run and multirun submerged arc welding of steels to ASTM 516 Gr.70 or equivalent where low tempe-rature (at-46°C) impact properties are required. The weld shall be of radiographic quality.	B3	W-3	-do-	*F-3*
4	IV	For two run and multirun submerged arc welding of steels to IS:8500-91 grade 540B, 570B and 590B, IS:2002-91 Grade-III, IS:1875-91 class IIIA or other equivalent steels. The weld shall be of radiographic quality.	C3	W-4	-do-	*F-4*
5	V	For two run and multi-run submerged arc welding of weather resistant steels to IS:M41 and IRS:M42 with same steel and with other grades of steel with same or low strength to IS:2002-91, IS:2002-91, IS: 1875-91 & IS:8500-91. The weld shall be of radiographic quality.	D	W-5	-do-	F-5

- **Advantages of SAW:**

a) The process helps produce welds with uniform beads, good ductility and good impact strength which are free from defects like spatter, undercut and overlap etc without depending on skills of the welder.

b) The weld produced in this process has continuous weld bead which reduces stress concentration at start / stop locations and this in turn helps improve fatigue performance of the structure in service.

c) In this process, since the entire process is controlled automatically, high current flow is possible and consequently, great intensity heat can be generated. This method can, therefore, be used to weld thicker sections with deeper penetration.

d) Speed of welding in this process is high and making upto 8mm size fillet weld in single pass helps minimize distortion of members.

- **Disadvantage of SAW:** As SAW requires the arc to be submerged in the flux pool, it can be used only in flat (down hand) or horizontal positions. Therefore the job has to be held in position with the help of manipulator or Jig & fixture in workshop during fabrication such that appropriate access for welding is available, otherwise this method cannot be used.[7]

- **Use of SAW welding in Railway Girder Fabrication**: Due to its good quality, IRS B1 clause 26.2 stipulates that all welding works in workshop for fabrication of steel girder for railway track bridges shall be done by SAW only. **The SAW welding is used in manufacture of girders for railway loading for making all the main welds, by fillet welding as well as butt welding.** The steel members are manipulated to get the Flat/ horizontal welding positions. Only in case it is not possible to do some welds due to position constraints or space constraints are there, other methods of welding are employed.

2.7.3 CO_2 welding or Metal Active Gas (MAG) process: CO_2 welding is an arc welding process wherein coalescence is produced by an electric arc established between electrode and steel member, the role of flux being performed by CO_2 gas sprayed on to the arc covering the molten metal instead of granular flux as in case of SAW or coated flux as in case of MMAW. This welding is also known as Metal Active Gas (MAG) process[8] as during welding, CO_2 becomes an active gas.

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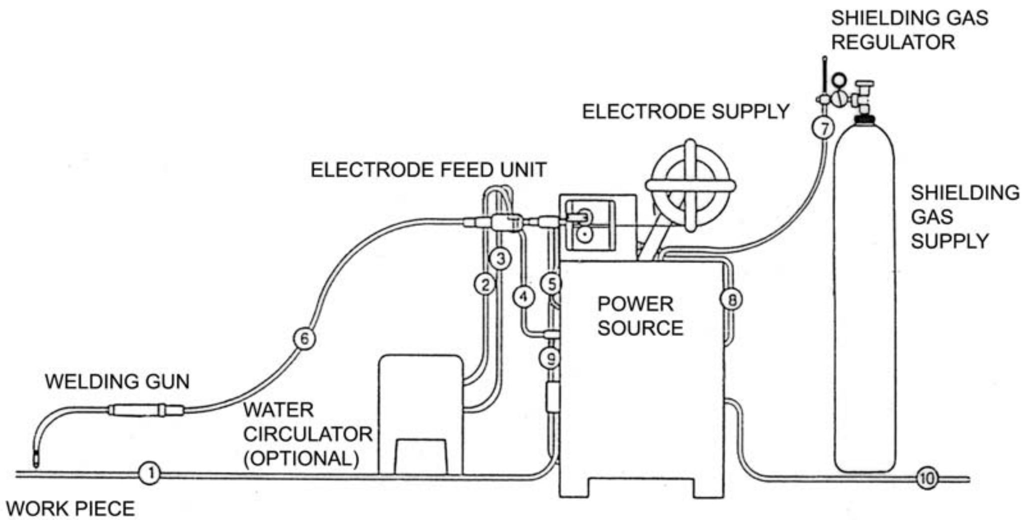
[7] As structures in field cannot be manipulated in this manner during repairs of structures, the process is not generally feasible in field.

[8] There is another process called MIG welding (Metal Inert Gas) in which an inert gas like Helium and Argon are used. The inert gases are stable at high temperature and the electrode need not be alloyed in this case. But in this case, the gases are costlier and the cost of fabrication will be very high.

The components of CO_2 welding equipment are shown in Fig 2.12. The electrode in this case is uncoated steel wire similar to the one used for SAW and is fed though a reel. This process is semi automatic. The setting of electric arc and feed of wire is automatic, but the equipment is hand held and does not move automatically as in SAW. The welding equipment has to be manipulated and moved by welder like in MMAW. As has already been pointed out, no flux is used in this case and the arc /molten metal pool are shielded by CO_2 gas. At elevated temperature, the CO_2 becomes active as carbon and oxygen separate. This oxygen dissolving in molten weld can cause oxidation of metal and can cause weld to be weak. Therefore, electrodes used for CO_2 welding are alloyed specially for preventing oxidation of steel.



1. WORK LEAD
2. WATER TO GUN
3. WATER FROM GUN
4. GUN SWITCH CIRCUT
5. SHIELDING GAS TO GUN
6. CABLE ASSEMBLY
7. SHIELDING GAS FROM CYLINDER
8. WELDING CONTRACTOR CONTROL
9. POWER CABLE
10. PRIMARY INPUT POWER

Fig. 2.12 CO_2 Welding Equipment

The electrode used for railway structure fabrication shall conform to IRS M-46. The electrode wire is of alloyed mild steel, (copper coated to prevent rust and to have better electrical conductivity) of diameter 0.8mm to 2.4mm. The small diameter of electrode and high current used in this process will result in high metal deposit and deep penetration. The CO_2 gas shall have a purity of 99.87 %. Nitrogen should be totally absent. Parent metal should be absolutely dry as presence of moisture may cause spatter and hydrogen embitterment of weld, which will make the weld prone for fatigue failure in service

- **Advantage of CO_2 welding**

a) Due to use of long uncoated electrode, this process has a major advantage over MMAW as it can produce uninterrupted long length weld required.

b) CO_2 welding process has a hotter arc, hence deeper penetration than MMAW. These welds can take more shear loads and hence smaller size welds are required.

c) Better output and speed of welding due to it being a semi-automatic process reduces distortion of members during fabrication as compared with MMAW.

d) Weld metal is having lower hydrogen content than low hydrogen electrode of MMAW.

e) Gas is used for shielding hence the weld will not have any defects such as slag inclusion and lack of fusion.

f) No slag is required to be removed. Lesser defects due to external impurities.

g) The equipment is less bulky than the SAW equipment.

h) The process can be used to make welds in any position as against SAW weld which can be used only in flat and horizontal positions. This method can also be used in field.

- **Disadvantage of CO_2 welding**

a) Cooling rate is not controlled like in MMAW & SAW hence medium carbon and alloy steel cannot be welded satisfactorily by this process.

b) Weight of welding gun is more than MMAW process, hence it will cause more fatigue to welder for long duration work.

c) Highly trained and skilled welder is essential for proper manipulation so as to get sound, defect free welds.

- **Use of CO_2 welding in Railway Girder Fabrication:** In view of above advantages and dis-advantages, this process can be used in lieu of MMAW for heavy structure subject to static loading like columns, cover sheds, Gantry girders and foot over bridges for getting better quality welds. For dynamically loaded structures, this process is suitable for doing some short length welding in workshop at locations where SAW cannot be done due to space limitation or the structure cannot be laid for flat horizontal position of welding required for SAW. **CO_2 welding can also be used for repairs of structures in field. It may, however be remembered that as per WBC, clause 14.1, the permission of Railway Board is required if field welding is to be done in track bridges.**

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Chapter III

WORKSHOP FACILITIES FOR FABRICATION OF BRIDGE GIRDERS

3.1 General: Good fabrication of girders requires good work shop facilities. While field fabrication of railway loading girders and field welding are not permitted, the contractors can set up workshop near the work site for fabrication of girders. These workshops shall be well equipped for the job they are supposed to perform and RDSO carries out registration of fabricators for fabricating steel girders for railway bridges. RDSO has issued guidelines **Schedule of Technical requirements (STR)** for the requirements of equipment and arrangements that have to be there in any workshop taking up the steel girder fabrication for the railway loadings. This is available on the website of RDSO in B & S Directorate as form no BS/REG/GIRDER. In absence of such registration, if a contractor quotes for some work, the tender committee has to satisfy the availability of these facilities with the tenderer before the offer can be considered. **The complete current STR is placed at Annexure III.** Some of these requirements are discussed below:

3.2 Space Availability: The workshop which has to take up girder fabrication has to carry out different activities:

a. Raw material receipt and storage
b. Inspection of material
c. Cutting and storing of steel members in various stages of fabrication.
d. Inspection of fabricated articles.
e. Painting / metallising of articles.
f. Storage of finished articles till dispatch.

The workshop, therefore, must have:

- Sufficient space with appropriate covers available to store the material at various stages of fabrication, commensurate with the work order to be placed.
- Covered bay area served by EOT cranes or by mechanically operated machines should be provided to handle day to day fabrication of girder components
- A separate line for inspection and testing of girders should be provided for final inspection and testing of bridge girders by railway's inspecting engineers.

- Covered shed area protected from rain, dust etc. should be provided for surface preparation/ painting/ metallising of steel girders.
- For full scale layout of drawings to which girders are to be manufactured, template shop with steel/concrete floor should be available. For symmetrical girders, half of the layout may be done and for non-symmetrical girders full-length layout shall be required.
- Sufficient space for trial erection of the girder after manufacture shall be available. For this purpose, proper handling equipment, stacking space and other facilities shall be available.

A most important requirement in a workshop is that the layout of various activities shall be such that the material flow is unidirectional i.e. material moves from one activity to the next in logical order without any need for cross handling. This will ensure speedier fabrication.

Fig 3.1: Typical workshop arrangement for receipt of material

3.3 Equipment Availability: The workshop shall have the following machinery and plant:

- EOT/Portal/mobile crane of min. 10t capacity or suitable material handling facility to serve the handling of material for fabrication of girders, unloading of raw material and loading of finished product. (Fig. 3.2)

Fig 3.2: Material handling with road crane

- Compressors of adequate capacity suitable for riveting and for other simultaneous applications.
- Oxy-Acetylene gas cutting equipment
  a) Profile cutting equipment of adequate size.
  b) Self propelled straight cutting equipment preferably consisting of multiple torches.
- Radial drilling machines of adequate capacity to drill holes of 12 to 50 mm diameter.
- End milling machine.
- Plate & structural sections straightening machine.
- Pneumatic/hydraulic yoke riveting machine.
- Welding transformers/rectifier for Manual Metal Arc Welding (MMAW)
- Inert gas (CO_2) welding equipment sets.
- Automatic sub-merged arc welding equipment.

- Suitable welding manipulators
- Edge planing Machine for edge preparation before welding.
- Adequate number of portable pneumatic tools such as grinders, drilling machines, chipping machines, wrenches etc.

3.4 Minor equipment which are required:

- Elcometer for measuring thickness of paint.
- Steel measuring tape duly calibrated
- Dumpy level or theodolite instrument for recording of camber/ deflection of trial erected girder.
- Macroetching /Dye Penetrant or Magnetic Particle testing facilities
- Tongue tester for measuring current and voltage
- Gauges for checking weld size, throat thickness and edge preparation etc.
- Adequate infrastructure and facilities like checking gauges, templates etc. during fabrication required from time to time so as to ensure that the finished product is as per requirements of IRS: B1 and Welded Bridge Code.

3.5 Following facilities for testing of material can be in-house or may be arranged from external agencies:

- Arrangement for radiographic test
- Equipments required for testing of mechanical properties, chemical composition and microstructure etc.
- Ultrasonic flaw detection testing facilities for checking internal flaws and thickness of section.

3.6 Other Requirements: Workshop that has to take up fabrication work must also have other arrangements in place to take up the fabrication work:

- Organization for functions of purchasing of raw materials and consumables etc and maintaining related inspection certificates, test certificates etc.
- Procedure for maintenance of records for receipt and consumption of material
- Adequate power supply
- In-house jig manufacturing capabilities
- Adequately equipped and staffed drawing office for preparation of fabrication drawings

- System for periodical maintenance of M & P.
- System shall be in force for analysis of defects noticed during internal and external inspections, with a dynamic system for checking internal flaws and for rectification.

3.7 Equipment Commonly Used in Workshops:

Some of the equipment used for fabrication of steel girders are shown below for the information of the reader:

- **Radial Drill machine (Fig 3.3):** This machine has a drill machine that is attached to a vertical column through an arm and swivels on vertical axis. This machine can drill many holes at different locations without need for shifting the job or the machine. This is as opposed to the stationery machine which can drill holes at only one location and after every hole either the machine or the job has to be shifted. Use of this type of machine promotes quality as the accuracy of work is quite high with this type of machine. A radial drill machine mounted on travel arrangement can make holes in entire job without any need for shifting the job.

Fig 3.3: Radial Drill Machine

- **Straightening Machine (Fig 3.4):** The steel can be obtained in workshop as cut plates or in coils. Coils are straightened by passing them repeatedly through rollers. The fig. 3.4 shows a steel plate being straightened. The steel shall be straightened without use of excessive force and there shall be no residual stresses in the steel plate when straightened.

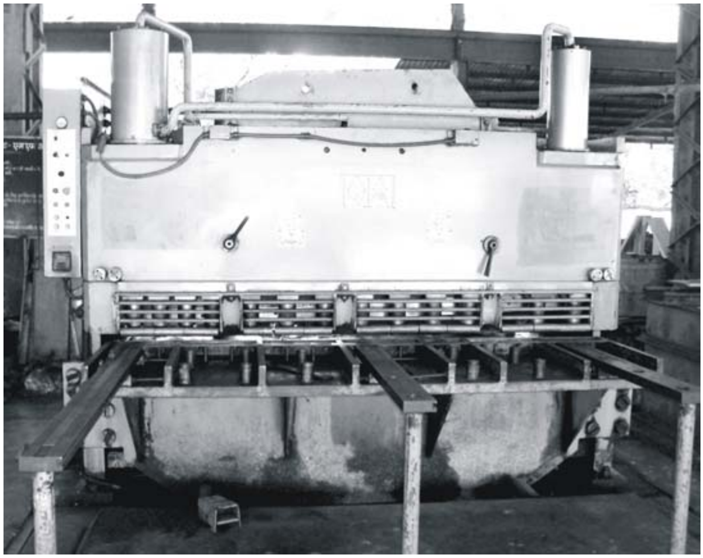

Fig 3.4: Straightening Machine

- **DOUBLE HEAD PUG CUTTING MACHINE (Fig 3.5):** These are used for cutting of steel plates. Pug cutting machines are available with single cutters also and the cutting equipment can be operated by

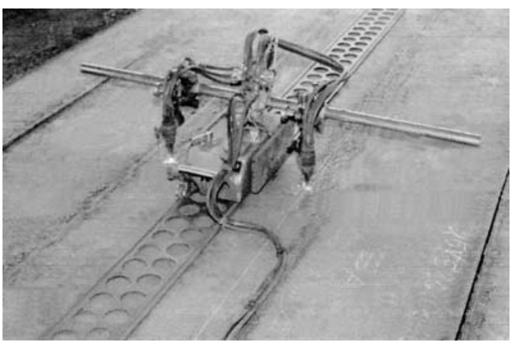

Fig 3.5: Double head pug cutting machine

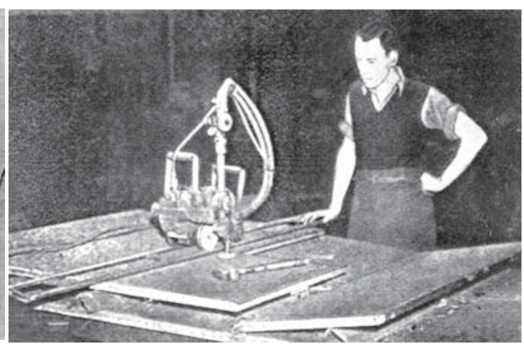

Fig 3.6: Portable straight-line flame cutting machine

hand also. The longer cuts can be made accurately with the pug cutting machines whereas hand cutting may be resorted to for smaller lengths only. Portable straight line flame cutting machine with single cutter is shown in fig 3.6.

- **Edge Planing Machine(Fig 3.7)**: The edges of steel plates are required to be ground to proper size and to ensure proper fitting of the members, without gap. For this, planing machines are used. While planing machines do not give as fine finish as grinders, these are having cutting tools and can remove large parts of metal in a single pass, if required. These are actuated by a crank-pin and a connecting-rod which moves the entire workpiece on a table beneath the cutter to and fro in the desired path. The cutting tool is held stationary. **Shaper machines**, which are smaller than the planar machines, have the opposite action, namely, the cutting tool moves while the job is held stationery.

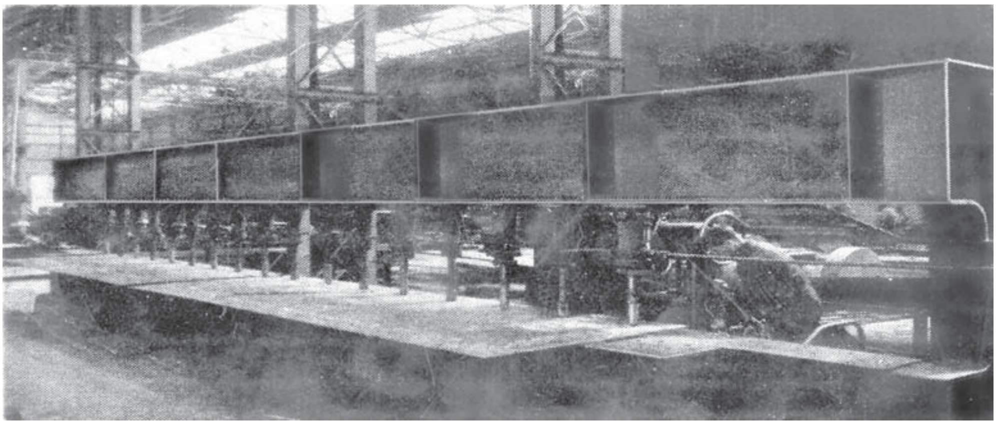

Fig 3.7: Edge Planing Machine

- **End Milling Machine:** This is used for grinding of the cut ends of the steel components (Fig 3.8).

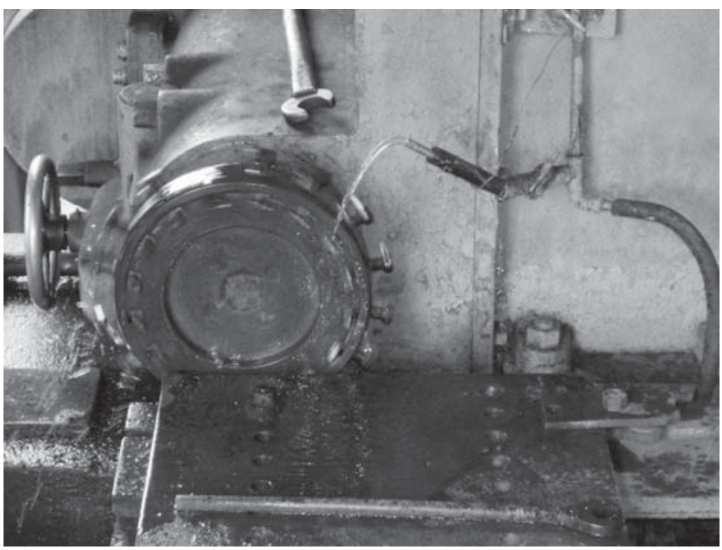

Fig 3.8: End milling machine

- **Welding Fixture/ Manipulator (Fig 3.9):** For holding the article for welding in proper position, various fixtures are used. The fig above shows the fixture used for holding the steel plate girder at 45^0 so that the fillet weld connections between web and flanges are made in flat position.

Fig 3.9: Welding fixture for composite girder fabrication

3.8 Advanced Equipment available: The equipment for steel fabrication has changed quite a bit over the years and some very advanced equipment is available which can be employed for greater accuracy, speed and economy of construction. Some of these include:

- **Computerized Numerical Control (CNC) Machine:** This machine can be programmed to make cuts, holes etc to precision. (Fig.3.10) This machine eliminates the requirement of jigs and fixtures for making holes.

Fig 3.10: Multi-flame cutting using CNC machine

- **Plasma cutting machine:** This type of cutting machine involves blowing an inert gas (in some units, compressed air) at high speed out of a nozzle; at the same time an electrical arc is formed through that gas from the nozzle to the surface being cut, turning some of that gas to plasma. The plasma is sufficiently hot to melt the metal being cut and moves sufficiently fast to blow molten metal away from the cut. This cutting machine can cut large thicknesses without too much wastage and without adding too much heat to the sections, thereby reducing the distortion. This machine is very suitable for cutting thin sections that cannot be cut by normal gas cutting and also to cut in curved or geometrical shapes.
- **Abrasive Jet machining:** Abrasive jet machining is a process where material is removed from a work piece using large number of small abrasive particles. The accuracy achieved in this type of machine is very good.

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Chapter IV

CONCEPT OF CAMBER AND METHOD FOR ASSEMBLY OF OWGs

4.1 What is camber[1]?

Camber has two components which are normally clubbed together and expressed as a single parameter. Even the SBC uses the term camber interchangeably for both the following:

1. Up ward deflection in the girder
2. Predeformation (or prestressing).

Literally, the word camber[1] shall refer to the upward deflection only. The predeformation is a completely different concept. The method of providing predeformation is also different. The 'upward deflection' and 'predeformation' are not really related to each other except that both may be provided in girders in a single operation.

In the context of Railway Girders, let us examine what the term camber means:

4.1.1 Camber in Plate Girders: Beams or plate girders (riveted or welded construction) have very little deflection due to the solid web plate duly stiffened. There is no need for any camber in such spans. In any case, fabrication of slightly curved plate girder is very difficult and costly (Plate gets wasted if it is cut in cambered shape). These are, therefore, not cambered.[1] **Clause 4.16.1 of SBC** states that **Beam (directly rolled RSJ) and plate girder (Built up riveted or welded shop construction) spans up to 35m (115'-0) need not be cambered.** Since plate girders are constructed for spans upto 30.5 m only, these are not cambered.

4.1.2 Camber in Foot Over Bridges: FOBs having trusses are provided with camber for the following considerations:

- The loads will cause downward deflection. If the girder is given upward deflection or camber, the same will compensate for the

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[1] As per "Free On Line Dictionary", the word 'camber' means 'A slightly arched surface' or 'The condition of having an arched surface'.

[2] **Note:** In few plate girders of old vintage, camber has been noticed especially when the channel sleeper work was taken up, but those are exceptions and all plate girder fabrication in last 50-60 years has been done without any camber.

deflection due to load. In this situation, **the bolts connecting the FOB truss to the column will be subjected to pure shear** and there will be no bending tension in the same.

- **Psychologically**, camber is helpful in visually assuring the layperson regarding the soundness of the structure.
- Slope due to camber helps in **drainage along the span**.

4.1.3 Camber in OWGs: Camber is provided in OWGs for the following reasons:

- In OWGs, when the girder deflects the shape of truss changes and the angles of intersection of the members also change. Upon deflection, the stresses in members will also change as these are dependent on the resolution of forces at joints which depends on the angles of intersection known as secondary stresses. This will introduce extra stresses in members. **To avoid these secondary stresses,** the girders are fabricated with upward deflection, such that the girder assumes the nominal shape under load. In loaded condition, stresses in girder are as computed for the nominal shape.
- **Psychologically**, camber is helpful in visually assuring the layperson regarding the soundness of the structure.
- The railway vehicles are very sensitive to the track geometry and one critical requirement from track side is that **when train passes, the rails shall be level.** Trusses consisting of open web with verticals and diagonals are flexible and deflect more compared with the plate girders. Also, the spans of OWGs are comparatively longer and under train loads, the same will sag appreciably. To avoid the problems due to the same, the girders are given upward deflection (or camber), equal to the deflection under design loads.
- For a fabricator, camber is very important as getting the full camber is **an indicator of good fabrication practices and good quality control** being followed in the work.
- Steel is a ductile material and can deform appreciably without showing any cracks etc. In service, if the members or joints are getting over-stressed, the girder can start sagging and will lose camber. This, camber is a parameter which is regularly observed in OWGs to get **early warning of signs of distress in girders in service.**

4.2 What is Predeformation or Prestressing?

4.2.1 Predeformation or prestressing in OWGs: The OWGs are designed with certain assumptions. As per clause 3.3.1 of SBC:

1. All members are straight and free to rotate at the joints;
2. All joints lie at the intersection of the centroidal axes of the members;
3. All loads, including the weight of the members are applied at the joints.

The above assumptions are substantially true but the actual girders cannot but have some deviations as follows:

1. There are eccentricities in joints due to manufacturing and assembling tolerances.
2. The actual joints are rigid riveted connections instead of being pure pin connection and member are not completely free to rotate at the joints.

   These stresses, together with the stresses due to deformation of structure described in para 4.1.3 above are called **deformation stresses.**
3. Loads such as self weight and wind loads etc are applied to the members directly and not at the node points. These induce some amount of bending is there even though we assume the truss to be axially loaded in design.

Extra stresses in members due to all of the above reasons, including deformation stresses are collectively called **secondary stresses** in the girders. As per clause 3.3.5 and 3.3.6 of SBC, in all cases of truss members for railway loading, these stresses shall be, either

- Computed, Or
- In the absence of calculations, be assumed to be not less than $16^2/_3$ per cent of the dead load and live load stress including impact.

Clause 3.3.7 of SBC provides that in prestressed (or predeformed) girders, the deformation stresses may be ignored. Manual computation of secondary stresses is cumbersome and complicated. In older days, it was preferred, to have some mechanism to induce stresses which will counter the secondary stresses so that these cumbersome computations are avoided. Therefore, the methods for providing prestressing or predeformatrion in OWGs were evolved. As per clause 3.3.9 of SBC, "**all OWG for Track Bridge of span 30.5m (100') and above shall be prestressed**".

The girders get prestressed when members with shorter/ longer length than required to form the nominal shape of truss are forcefully assembled together. The prestressing forces counteract the secondary stresses. In old times, this method was chosen to tackle the issue of secondary stresses as manual calculations were complicated, and not possible in those days. If we wish to fabricate the girders without prestressing, the secondary stresses have to be computed and incorporated in the computations.

To conclude, the basic principle of a predeformed girder is that the girder is made in deformed shape such that when the girder is not loaded, members are subjected to the dead load stresses as well as deformation stresses whereas under full load, members are subjected to the dead load, live load and impact only (as the members assume nominal lengths under full load).

4.2.2 Predeformation or Prestressing in Other Girders: The predeformation is not given to the plate girders as most of the secondary stresses mentioned above are not there. In case of FOBs, these considerations are there, but the loads in FOBs are quite less and the considerations of fatigue are not there. Also, FOBs are less critical structures. Further, fabricating girders with predeformation is a very complicated process which raises the cost of fabrication. Therefore, the predeformation is not given to the FOB OWGs.

Note: Steel truss girders for FOBs are given camber only whereas the open web track girders have camber as well as predeformation. Therefore, in the former, the camber is called geometrical camber whereas in the latter, there is camber along with pre-deformation.

4.3 How to compute Camber and predeformation in OWGs? Appendix A of SBC gives the rules for prestressing/ camber. Clause A-3.10 therein states that when cantilevered method of erection is used, the erection procedure explained below does not apply[3]. The design and fabrication drawings for OWGs shall include camber diagram, indicating camber lengths and nominal lengths of members as well as camber at each panel point. For any new drawing, following steps are involved:

- Preparation of camber sheet as per provisions of clause A1 of Appendix A of SBC.
- Preparation of fabrication drawing for each member as per provisions of clause A2 of Appendix A of SBC.
- Trial assembly of first span as per provisions of clause A3 of Appendix A of SBC.

For standard span drawings issued by RDSO the camber sheets and fabrication drawings are already available. Trial assembly is to be done only once in a workshop whenever a girder to a drawing is taken up for fabrication for the first time in a workshop.

[3] There is no change in fabrication procedure i.e. the same drawings and components are used for cantilever launching as well as erection on ground.

4.3.1 Computations for Predeformation or prestressing: To work out the camber lengths of the members to induce the predeformation, as per clause 4.16.3 of SBC, where OWGs are prestressed, the camber change should be based on **full dead load and live load including impact.** Following steps are followed for the same:

1. Change in length of each member shall be worked out. The stress shall be calculated on gross area of the member. For members where there is reversal of stress such as in diagonals, the maximum of the compressive or tensile stresses is considered to work out the change in length.
2. The change of the length of the member worked out shall be incorporated with opposite sign to get camber lengths. i.e. This shall be the amount by which the nominal length shall be **increased** for **compression** member[4] and **decreased** for **tension** member. The members fabricated to camber lengths shall assume the nominal lengths when full load comes on the girder.
3. Due to the presence of stringers and cross girders, the loaded chord (On which the train load is imposed on the girder) is very stiff. The change of length of the stringers cannot be easily done. Therefore, **the loaded chord lengths are kept the same in nominal as well as camber layout.** For this the camber lengths of all the members worked out as above are **modified by a factor** given below, as per Clause A-1.4:

$$Modified\ Length\ of\ member = \frac{Loaded\ Chord\ Extension / Contraction}{Loaded\ Chord\ length}\ x\ Length\ of\ the\ member$$

In through type spans, this change will be an increase in the lengths of all members while in the case of deck type spans, this change will be a decrease in the lengths of all members.

4. **The lengths altered as above are the camber lengths to be used for the fabrication purpose.** The nominal as well as camber lengths are indicated in the drawings as shown in fig 4.1 below. (All sketches for camber are for half span only as the other half is mirror image of this).

[4] Under load, the length of compression member will **decrease**.

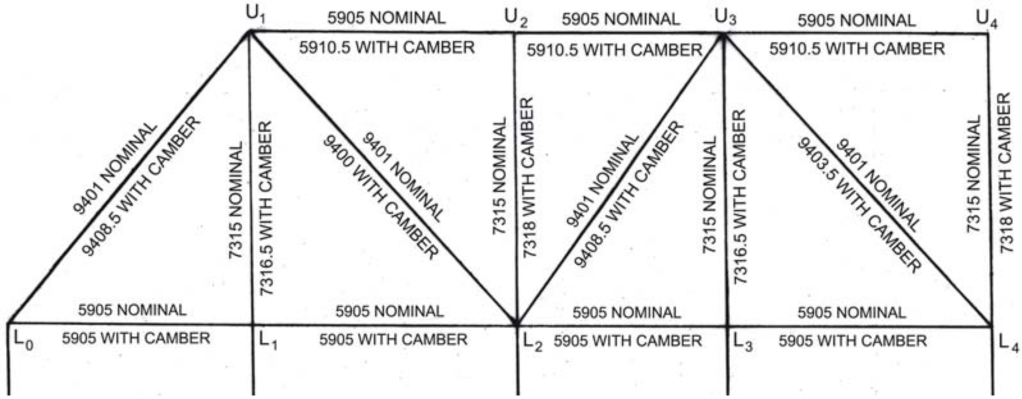


Fig 4.1: Drawing showing Nominal as well as Camber lengths of members for a 45.7 m span (The bottom chord length does not change)

5. The change in camber length will also necessitate changes in the lengths of bracing of the top chord in case of through type girders and bracing of bottom chord in case of deck type OWGs. For computing the lengths of these members, the average of nominal/ camber length of the main chord members shall be considered.

4.3.2 Computations for Camber (Upward Deflection): Clause A-1.8 of SBC states that Williot Diagram shall be drawn to get the downward deflection of all nodes under design load.[5,6] In order to ensure that the girder assumes nominal shape under the design load, the girder must be given upward deflection opposite to this value.

Procedure for drawing Williot diagram is shown in fig 4.2 below for a simple truss ABCD. The logic can be extended further and diagram for bigger trusses can also be drawn. The extension/shortening of members under load has been separately worked out and indicated against each member.

[5] As per clause 4.16.2 of SBC, in non prestressed open web spans, the camber of the main girders and the corresponding variations in lengths of members shall be such that when the girders are loaded with full dead load plus 75 per cent of the live load without impact, the girder shall assumed nominal shape. This is applicable for FOBs.

[6] As per clause 4.16.3 of SBC, camber for prestressed open web spans shall be based on full dead load and live load including impact. This shall be applicable for OWGs for track.

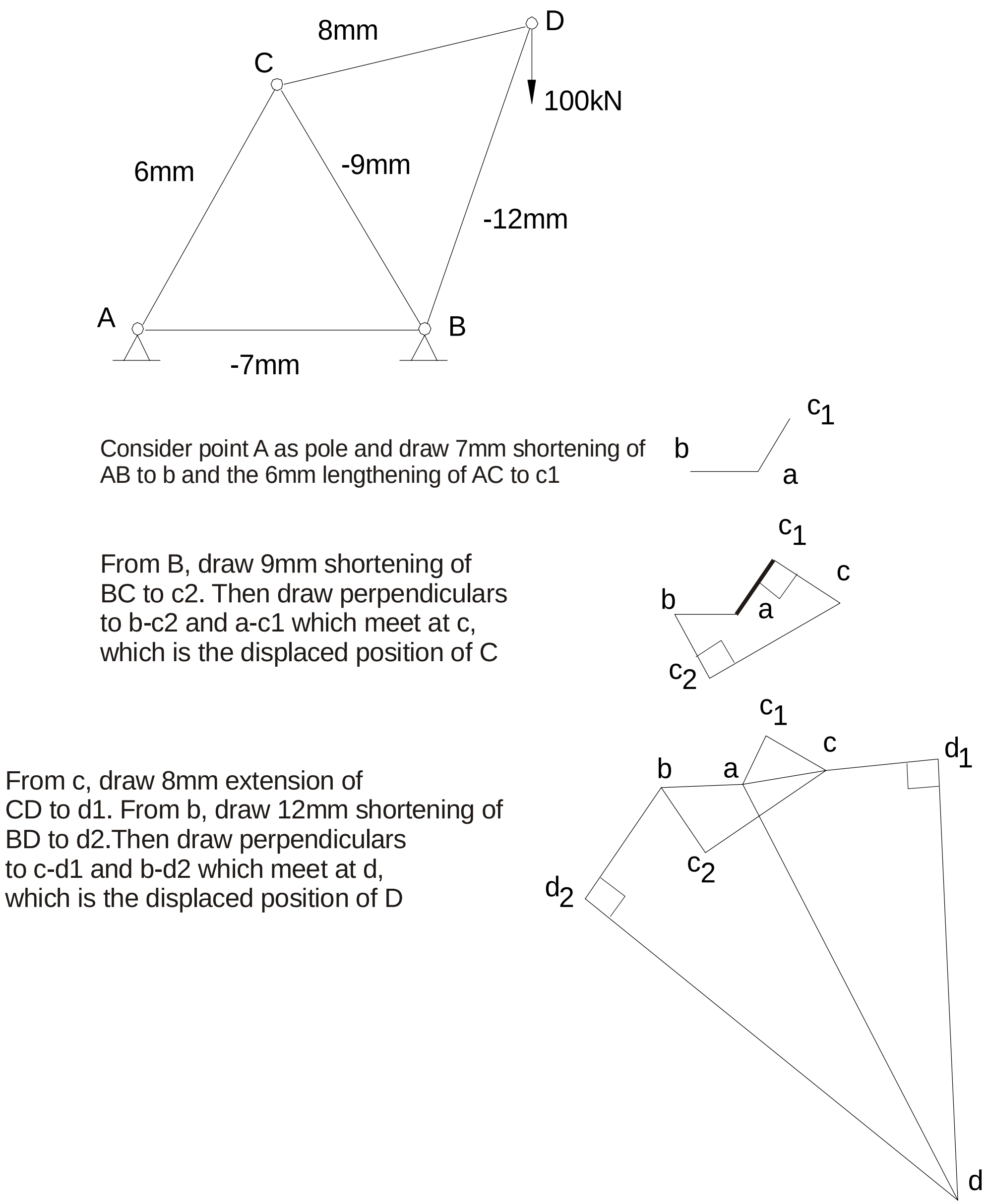


Fig 4.2: Method for drawing Williot Diagram

The fig 4.3 below shows the final camber diagram which corresponds to the downward deflection worked out for the truss at design load, but in opposite direction.

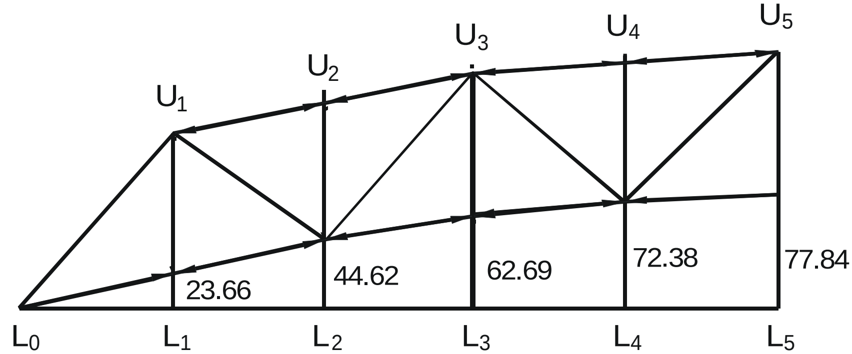


Fig 4.3: Upward deflection for a through type track girder

Important Note: The girder which is supposed to be flat is given the upward deflected shape as shown above. This will also require some change in lengths of the members. However, the upward deflection amount is very small compared to the span length and the corresponding change of lengths of members are too small to be appreciable.

4.3.3 The combined camber diagram: showing the camber (fig 4.3) as well as the change of lengths (camber lengths, fig 4.2) in the drawings which is normally drawn on railway drawings is as shown in fig 4.4 below:

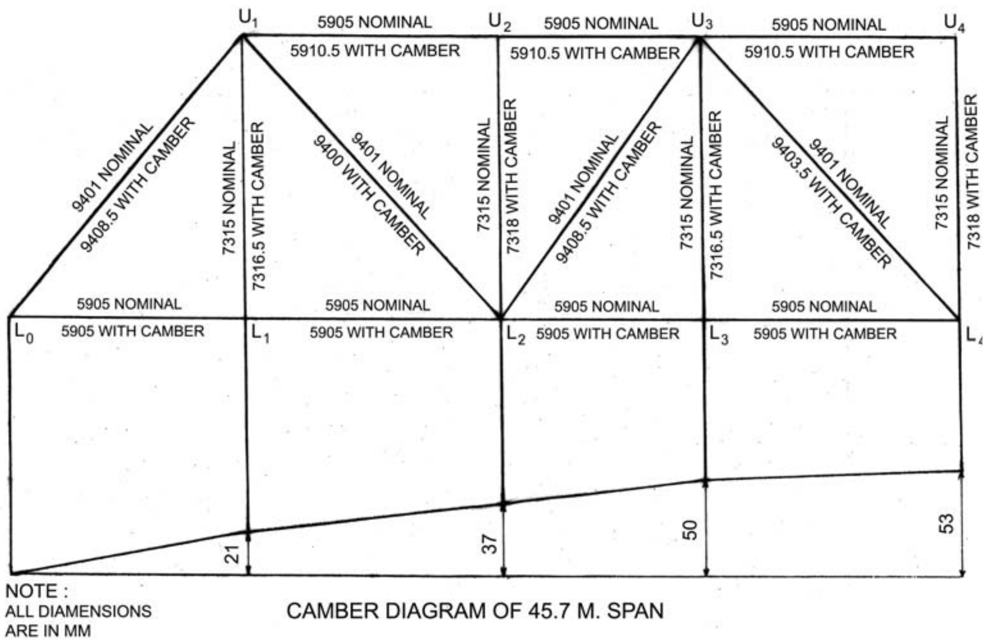


Fig 4.4: Camber Diagram of a 45.7 m span

4.4 Different Types of Camber:

Camber can be of different types:

- **Design Camber:** The theoretical upward deflection which is mentioned in the camber sheets worked out on basis of the design loads is called the design camber. This is the camber which is to be given to the girders during assembly.
- **Dead Load camber or working camber:** The net upward deflection measured in any girder which has no live load is called dead load camber. The dead load camber is the camber which can be measured when the girder is subjected only to dead loads. This camber is checked after assembly to ascertain the quality of fabrication/ assembly and also monitored during the service of the girder to ascertain the health of girders.
- **Live Load camber:** The transient upward deflection which will be there during the passage of live load over the girder is called live load camber. This is difficult to measure and monitor. However, in certain cases, might be measured to get an idea of the behaviour of the girder under load as a diagnostic procedure for girders having some problems.
- **Negative Camber:** This is not a separate type of camber but if the measured camber value is negative, it means that the girder is deflected downwards rather than upwards and the measured value is called negative camber. This condition of girder might sometimes indicate serious internal problems in the girders.

4.5 Steps required during fabrication to get prestressing in OWGs:

To provide the prestressing in open web girders, the member lengths have to be altered to camber lengths. The procedure for fabrication of gussets and members is explained in para 5.3.3.4 in chapter 5 of this book.

4.6 Assembly of Girders: The assembly of girders is done either at site before launching or for trial assembly in workshop. The only difference in the two is that the girder is not riveted during trial assembly. The procedure for assembly of girders on ground is explained below:

4.6.1 Equipment Required for assembly:

- C C cribs or steel packing
- Wooden sleepers and blocks
- Chain pulley blocks, winches, tirfors etc
- Derricks

- Guy wires
- Jacks, including camber jacks, if required.
- Crane (Optional, else derrick can be used)
- Turned bolts, drifts in adequate numbers
- Compressor
- Riveting equipment

The equipment shall be in good condition, tested before start of work and shall be properly used/ maintained during the course of work. Sufficient standby shall be there so that the work does not suffer in the event of some failure.

4.6.2 Care to be taken in Assembly: The girder assembly at site of work shall be done carefully to get the desired geometry. The following care shall be taken during assembly:

- The availability of complete set of girder parts shall be ensured as per the shipping list given by the workshop. The shipping marks on the parts shall be checked with the shipping list and the material segregated.
- The girders parts shall be checked for their physical condition i.e. it shall be checked that no girder parts have been damaged during transportation.
- Any minor misalignments/ bends etc shall be corrected by applying small amounts of force which shall not damage the steel. Parts having more damage may have to be rejected and new parts may have to be ordered from workshop.
- The match marking of the members shall be checked as per the list given by the workshop. In case there is any confusion, the fabricator may be approached for clarification.
- The girder assembly shall be done on hard, level area which shall not settle when the load of girder comes. If required, some preparation such as hard moorum/ concrete or wooden/steel packing may be provided over which the girder assembly shall be commenced. The top of all packing shall be verified to be in one level.
- During assembly, the individual girder parts shall be erected with suitable set of stays/ lateral restraints so that these do not topple over.
- The erection shall be done systematically in proper sequence. The members shall be handled from proper location for lifting/ assembly so

that these do not get damaged.

- During erection, the match markings shall be matched so that the holes match and the members seat properly adjoining/over other members.
- Drifts/ turned bolts shall be inserted in the holes to ensure that the members matched once do not slip/ move out of place again.
- Excessive force shall not be applied to match the members. If the holes are not matching, the reasons can be any of the following:
    a) Burrs left in members after cutting.
    b) Holes not dressed properly.
    c) Member dimensions not proper. Some longer member (may be by 1-2 mm) can interfere with the assembly.
    d) Bent/damaged members or gussets
    e) Members/ gussets not kept with proper match markings. (Sometimes the problems come from members kept upside down by mistake)
- Layout must be given with properly calibrated tape and following the principles of working from part to whole. One common mistake in layout during assembly is to assemble the girder to proper dimensions but as a parallelogram. To avoid this, during assembly, checking diagonal lengths will help cross check the accuracy of the layout given.
- Another common problem is to assemble the girder with uneven heights. This problem can be avoided by checking the levels regularly to ensure that the girder parts are at one level and no settlement is taking place.

4.7 Assembly of Foot Over Bridges (How to provide Geometric Camber): The assembly of FOB girders is normally done one truss at a time in sleeping position. Both trusses are then turned up and bracing/ flooring etc are provided to form the FOB girder. As per clause 4.16.2 SBC for unprestressed open web spans, the camber of the main girder and the corresponding variations in length of members shall be such that when steel girder is loaded with full dead load plus 75% of live load without impact. Since the FOBs are non prestressed, **the camber is given by laying out the bottom chord in cambered shape** and other members, viz, verticals, diagonals, top chord members etc are all erected on the cambered bottom chord members by welding without application of any force. When the truss is turned up, it has upward deflection (camber) as per shape given to the bottom chord members.

4.8 Assembly of Open Web Steel Girders (How to provide Camber and Prestressing): Camber and prestressing in OWGs makes the task of fabrication and assembly of OWGs typical, which has to be done carefully. It goes without saying that the proper camber and prestressing will not come if the fabrication of the girders is not done to close tolerances and with adequate care required. In order to check that the workshop which starts fabricating girders with new jigs has done a proper job while fabricating jigs, Clause 36 of IRS B1 – 2001 provides that "**when fabrication of standard spans with new jigs are carried out or non standard span is to be fabricated, trial assembly of 1st span at fabrication workshop is carried out to ensure the correctness of standard of workmanship before starting fabrication of 2nd span**".

The steps in assembly of OWG are given below which incorporate the steps required to provide camber as well as prestressing.

Steps in assembly of span: The OWGs are required to be assembled either at site before launching or for trial assembly. The procedure for assembly of the open web through type girders as per provisions of Appendix 'A' Clause A-3 (Erection) of SBC is explained below:

4.8.1 Step-1 Level ground in workshop or at site, size- (span length + 8 meter) X (width of span + 5 m) has to be prepared for assembly of each girder.

4.8.2 Step-2 Depending upon the span dimensions, the ground below each panel points i.e. L_0, L_1, L_2, L_3, L_4, L_5, L_6, L_7 and L_8 etc of both truss has to be prepared by removing loose earth and providing hard moorum bed of 150mm thick duly rammed by wooden mallet in order to get a compacted ground to avoid settlement due to dead load of span during assembly. (Fig 4.8). Lean concrete can also be provided.

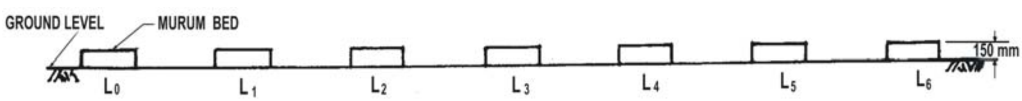


Fig 4.8

4.8.3 Step-3 On prepared ground, two nos CC Cribs of 0.6 m x 0.6 m x 1.8 m are erected at each panel point location, ensuring that the top level of all CC Cribs is same. Place wooden blocks below CC Crib as well as on top of CC Cribs. If necessary, adjustments may be done with suitable wooden packing. This platform arrangement is meant for providing working/moving space for workers for crossing under rather than by climbing over the girder while working. (Fig 4.9). Wooden sleeper crib can also be provided.

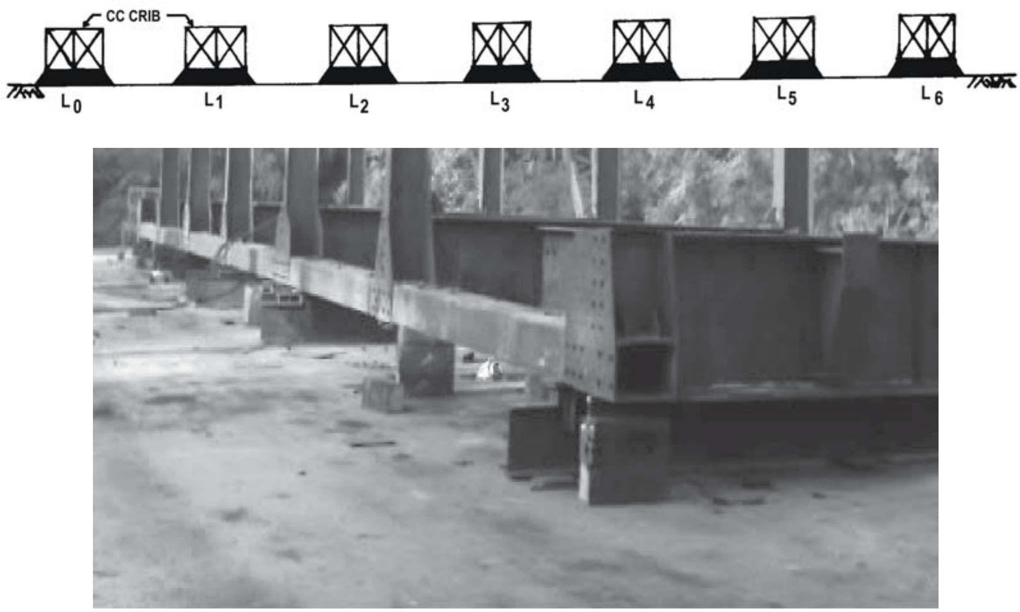


Fig 4.9: Platform at the node points

Leveling instrument shall be used to check that all CC Cribs are in one level.

4.8.4 Step-4 One camber jack is provided on each C C Crib platform prepared as above if the span is less than 61.0 m. For 61.0m and longer spans, 2 camber jacks are placed at each C C Crib platform. A camber jack is a simple screw jack (can also be hydraulic jack) of 5 ton or 10 ton capacity which is used to provide camber to truss during assembly. The camber jacks are lowered for giving the camber as it has been found to be convenient. Therefore, the camber jacks should be provided in such a way that all jacks are in ram-out condition except the jack at central node point. The ram of jacks shall be kept out by at least 15 mm more than amount of lowering required at every panel point to provide design camber shown in camber sheet.

4.8.5 Step-5 All bottom chord members of both trusses over camber jacks are placed and gusset plates are connected with 'Turned Bolts'. It must be ensured that all bottom chord members of both trusses are in one level by checking with Leveling instrument. 50% turned bolts and 50% service bolts are provided. Since bottom chord camber length is equal to nominal length, the holes in the bottom chord members match with the holes in main gusset both of which are fabricated to nominal layout and, turned bolts can be easily provided. To match the holes, drifts may have to be passed through the same.

4.8.6 Step-6 Cross girder and rail bearer of entire span are provided and connected with turned bolts. Also the bottom lateral bracing are fixed with 20% turned bolts and 40% service bolts. Again check and ensure that entire bottom chord is in one level. Now the girder assembly is in stage I (Fig 4.10)

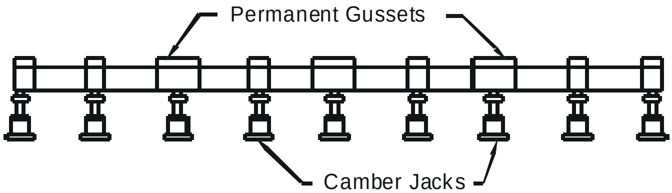


Fig 4.10: Stage – I in erection of girder

It is very important to frequently check that all bolts are tight and entire chord is in one level and no settlement of ground has taken place.

4.8.7 Step-7 Now, all web members i.e. vertical and diagonal except end raker (or end post) are erected and provided with turned bolts for bottom panel points. The erection shall be done using derricks/ cranes etc. If cranes are used, the time as well as labour is saved. The holes of verticals will match those in the bottom chord members as the holes are made from the same master gussets in both. The verticals and diagonals will not be self standing as these are slender. Some lateral support in the form of guys/ stays etc shall be provided with. It will be desirable to connect the top ends of the verticals/ diagonals together to provide some stability to the partly assembled girder. But since the verticals and diagonals have been fabricated to camber lengths, the holes cannot match. The holes will match only when the members are elastically strained. Therefore the top end of these members cannot be fitted in the regular gussets. To join the members together, if regular gussets are planned to be used, smaller bolts 12/14mm dia may be used. If the difference in the holes is more, then temporary gussets are to be fabricated for holding the member ends together. Now the girder assembly is in stage II (Fig 4.11). Check the level as well as tightness of bolts of bottom panel joint.

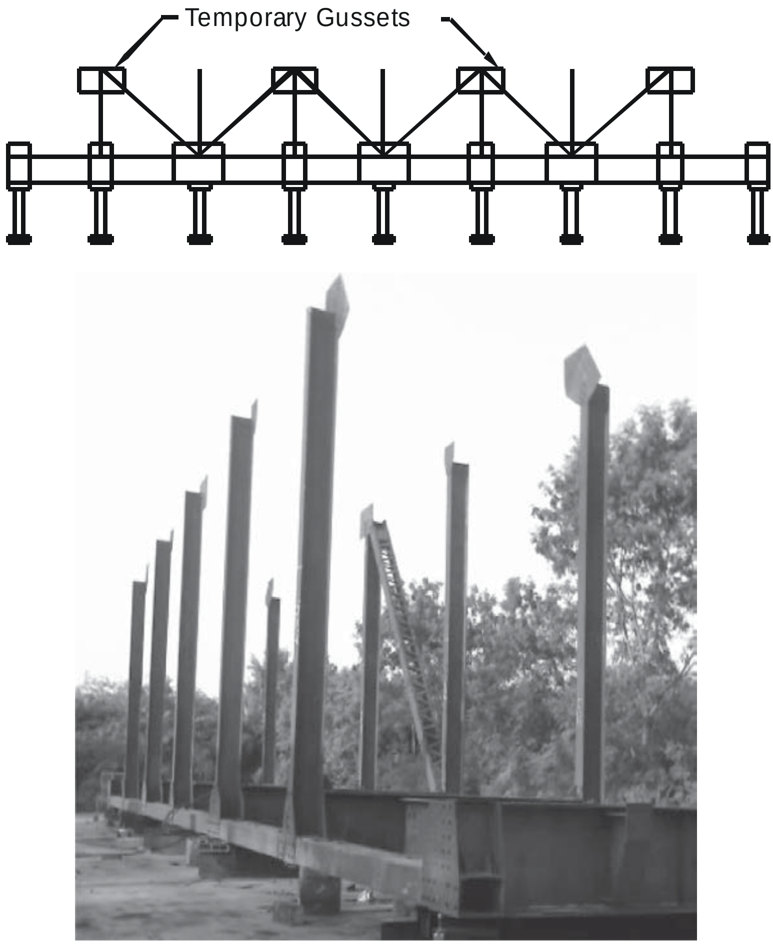


Fig 4.11: Stage – II in erection of girder

4.8.8 Step-8 Now the bottom panel points, stringers and cross girders are riveted if the assembly is being done in field. In case of trial assembly in workshop, tightness of bolts is checked to ensure there is no slip in the drifts/ turned bolts when the cambering is done.

4.8.9 Step-9 Camber to each panel point is provided by lowering jacks by requisite amounts. All jacks except centre jack are lowered by an amount equal to camber in central panel point minus the amount of camber shown in camber sheet at each panel point. Both the trusses are lowered simultaneously. Maximum lowering is in the jacks at end node points. Check levels at each panel point of both trusses by leveling instrument again to ensure correct camber as per camber sheet. Now the girder assembly is in stage III (Fig 4.12)

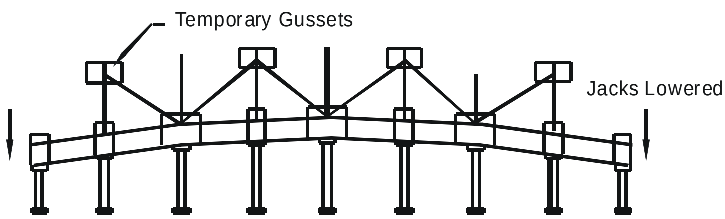


Fig 4.12: Stage – III in erection of girder

4.8.10 Step- 10 Top chord members are now erected one by one. The top chord and web members are to be elastically strained by external force so that all holes get faired (i.e. holes start matching) at the top chord joints. The elastic straining is started from the central node point and it shall proceed outwards, symmetrically in both the directions. For straining, one end of members is riveted (in case of assembly in field) or drifts are provided and the other end is slowly strained using drifts.[7]

Any temporary gussets used in step 7 are replaced by the permanent gussets before the drifting is started. The members are pushed (Reduced in dimension) or pulled (Increased in length) progressively as drifts start coming in position. Heavy drifting cannot be done as the same can elongate the holes in members and cause loss of camber/ predeformation in the erected girder. Therefore, only 1kg hammers are allowed to be used. To get more straining force, large numbers of drifts are driven simultaneously. Sometimes, if the members are not getting strained by drifting, external assistance using jacks/ chain pulley block etc may also be given.

For straining the girder, erection of top chord members shall commence from the central panel point of top boom and shall proceed

[7] The drifting procedure is explained in Annexure IV.

outwards either side. Now the girder assembly is in stage IV (Fig 4.13)

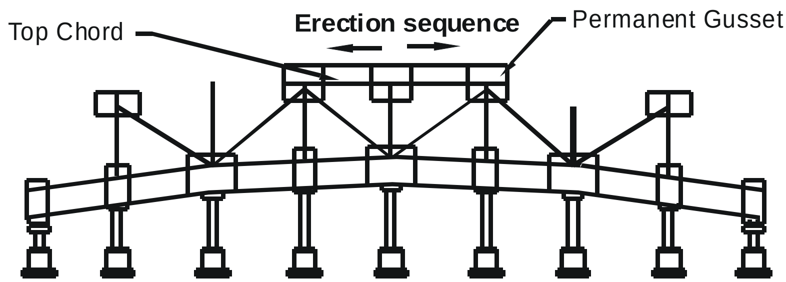


Fig 4.13: Stage – IV in erection of girder

In this way, all top joints are drifted from centre to outside on either side but continuous check has to be kept that the camber in bottom panel point is intact during entire assembly work. Now the girder assembly is in stage V (Fig 4.14)

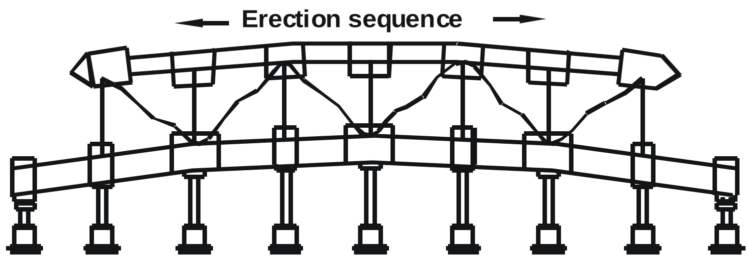


Fig 4.14: Stage – V in erection of girder

4.8.11 Step-11 Finally to complete the girder assembly, either side end post (or end raker) is erected. The upper end of joint is first drifted and bolted in all holes. Lastly lower end of end post is drifted to provide with turned bolt. If there is a joint in the middle, then the middle joint is drifted last of all. This is the most difficult part of the erection process as all the errors in fabrication will accumulate at the last joint. The girder assembly is now in stage VI (Fig 4.15)

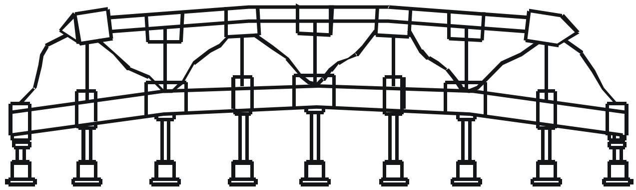


Fig 4.15: Stage – VI in erection of girder

4.8.12 Step-12 Then portal, sway, top lateral bracing are provided and this completes the assembly of span. In field erection, all the balance rivets are applied.

4.8.13 Step-13 Now the span is assembled completely and can take its own load at ends. Four end platforms capable of taking dead weight of girder shall be provided and the entire weight of span is transferred by jacking to these platforms. Then the camber jacks are removed.

4.9 Dimension check: Then the dimensions as well as manufacturing tolerances of the assembled girder shall be checked. The camber retained under dead load (called dead load camber) shall also be checked. As per Appendix II of IRS B1, the tolerances for the plate girders and open web girders after assembly are given in fig 4.16 a & b below:

1.	**Plate girders**				
			Tolerances in mm		Notation in the **Figure No.1**
			(plus)	(minus)	
	(a)	Overall length of the girder	6	3	a
	(b)	Distance between centres of bearings	1	1	b
	(c)	Depth over angles	3	1	c
	(d)	Corner of flange angle to edge of web at any place	0	2	d
	(e)	Diagonal at either end of the assembled span	3	3	e
	(f)	Centres of intersection of diagonals with girder flange measured along the girder flange	3	3	f
	(g)	Butting of compression ends			
		i) throughout	0	0.15	g
		ii) locally	0	0.25	g
	(h)	Butting edge at web splices	0	1	h
	(i)	Straightness of girder bottom laid on the ground and checked with piano wire:			
		(i) vertical plane			
		Convexity	0	3	j
		Concavity	0	0	j
		(ii)Horizontal plane	2	2	j

Fig 4.16 a

2.	**Open web girders**				
	(a)	Over-all length of girders	1	1	k
	(b)	Distance between centre to centre of bearings	1	1	l
	(c)	Cross diagonals of assembled bays	1	1	m
	(d)	Centre to centre of cross girders	1	1	n
	(e)	Centre to centre of rail bearer	1	1	p
	(f)	Panel length in lateral bracing system	1	1	q
	(g)	Distance between inter section line of chords vertical and horizontal	1	1	r
	(h)	Butting edges of compression members:			
		(i) throughout	0	0.15	s
		(ii) locally	0	0.25	s
	(i)	Twist in members	0	0	t
	(j)	Lateral distortion between points of lateral supports	.001 L	.001 L	u

Fig 4.16 b

The values a,b,c etc in the last column above are defined in fig 4.17 below:

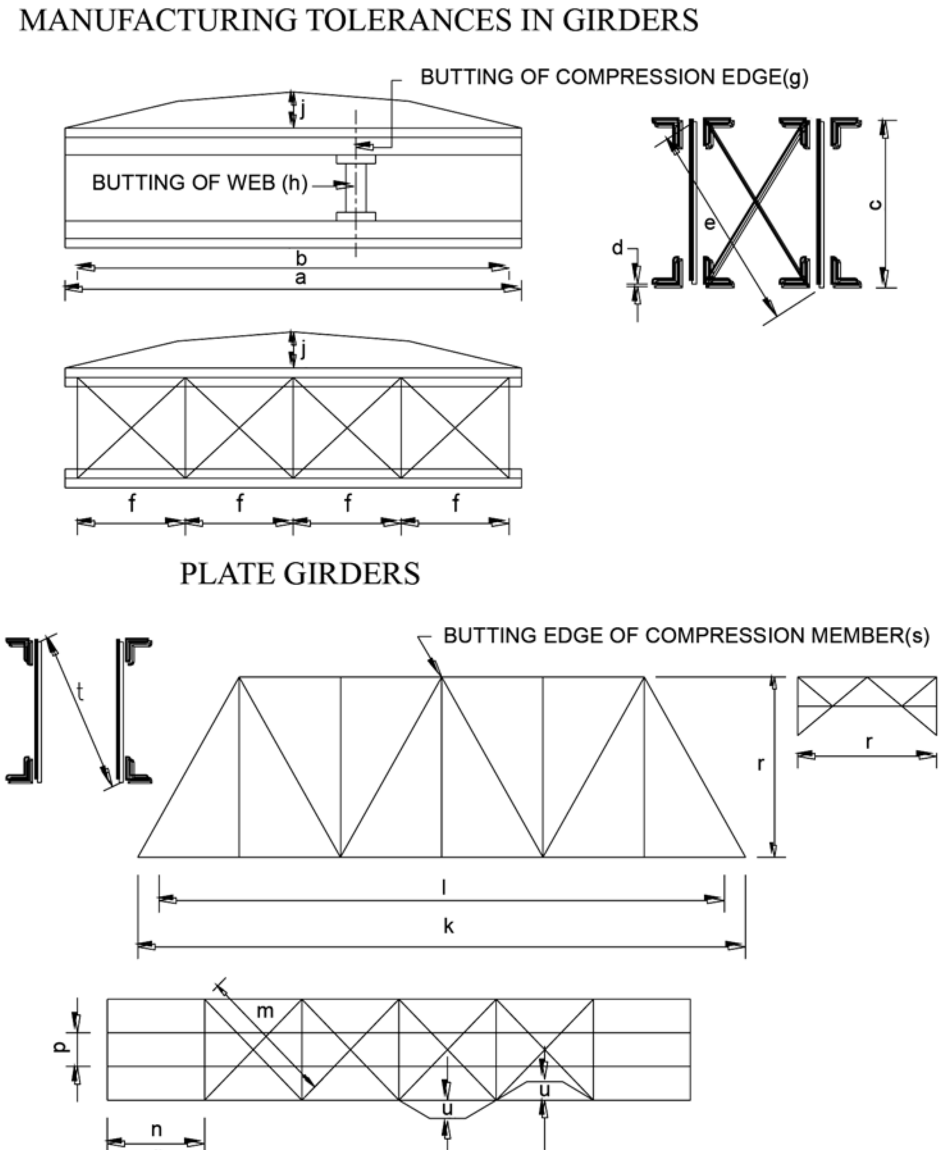


Fig 4.17

❑ ❑ ❑

Chapter V

FABRICATION OF STEEL GIRDERS

5.0 General: Fabrication is the process involving building up or putting together components to the required shape and size. This chapter describes in detail the various processes which go in fabrication of steel girders for railway loading. The basic principles are same when we fabricate other steel structures but the quality control and tolerances are much relaxed for the structures not subject to heavy train loads with impact.

5.1 Components of girders Fabricated for Indian Railways:

5.1.1 Rolled Steel Girders: In Indian Steel rolling mills, maximum rolled 'I' sections (RSJ) are of 600x210mm. Therefore, earlier, spans up to 6.1m were fabricated with rolled I section with additional flange plates and cross bracing / diaphragms were used to make spans.[1] Fig. 5.1 shows a 6.1 m rolled section earlier used.

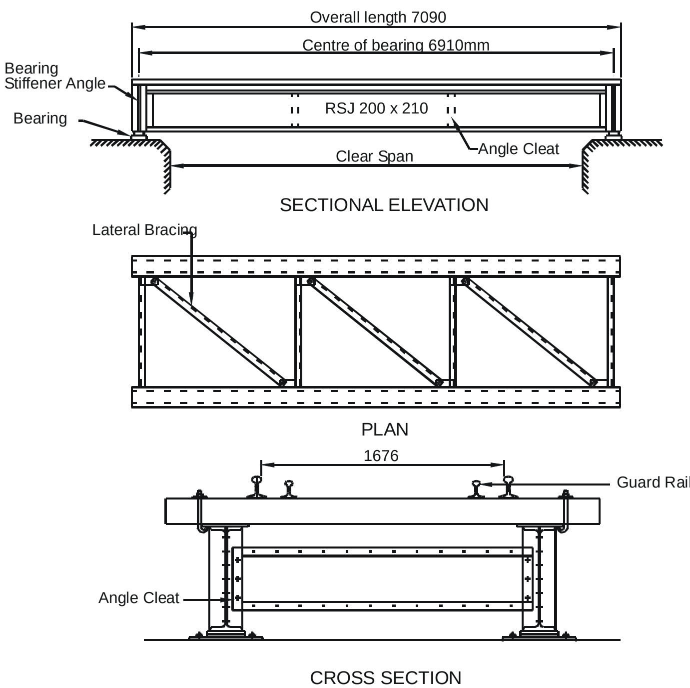


Fig 5.1: ROLLED STEEL GIRDER- 6.1 m SPAN

[1] The spans up to 6.1m are no longer fabricated in steel. As per latest policy, RCC / PSC slabs only are to be provided for spans up to 6.1m

5.1.2 Built- Up Steel Girders:

a) **Riveted Plate Girders:** The riveted steel plate girders are fabricated using steel plates as web of the girders and angles as top/ bottom flanges of the girders. In addition, to provide extra flange area, one or more flange plates shall be provided. As per SBC 5.5.2, where flange plates are used, they shall preferably be of equal thickness and at least one plate of the top flange shall extend the full length of the girder, unless the top edge of the web is finished flush with the flange angles. (This is required so that the track sleepers have proper seating on the top flange of the girder).

Fig 5.2 shows a riveted girder.

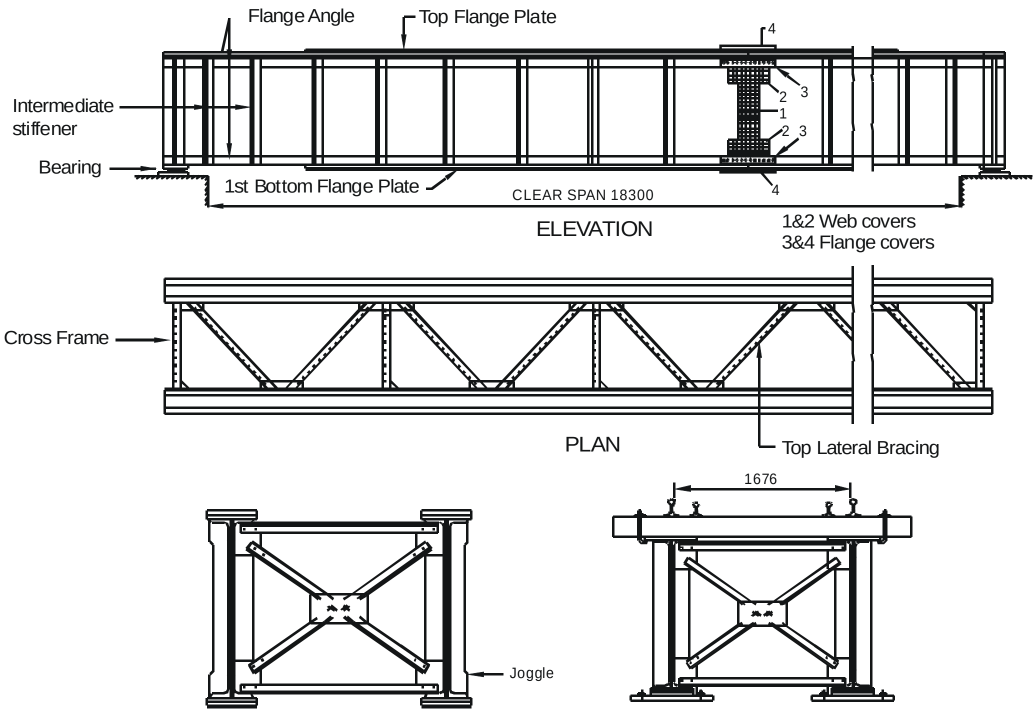


Fig 5.2: 18.3 m SPAN (RIVETTED)

- **Curtailment of Flange Plates:** As the bending moment is maximum at the center and reduces towards the supports, the flange plates may be curtailed where these are no longer required.
- **Change in web thickness:** The shear is maximum at supports and zero at the middle, so web plate thickness may also be sometimes changed for economy. The web plate thickness is changed usually at

the splice locations and packing plates are provided under the splice to make up for the difference in thicknesses of the plates. But the **standard spans given by RDSO have uniform thickness/depth throughout the length.**

- **Splices:** The girders longer than 12.2 m spans are usually made in pieces, to be assembled at site with riveted splices.
- **Bearing Stiffeners:** These stiffeners are provided in the form of duplicate angles back to back. These have to act as struts to transfer the concentrated load at the bearing locations to prevent web buckling and therefore, these have to be straight and snug-fit in top/ bottom flanges. Therefore, the ends of the bearing stiffeners are machined for close fit. These are provided with packing in the web equal to the thickness of the flange angles.
- **Intermediate Stiffeners:** The intermediate stiffeners in riveted girders are connected by riveting and are made up of single angle joggled to fit the shape of the top and bottom flange angles or straight where packing is provided between web and the stiffener angle. Intermediate stiffeners shall be snug fit with the top and bottom flange and the same are machined during fabrication.
- **Bracing:** The top/bottom bracing, cross frames, diaphragms etc are made up of flats/rolled sections with riveted construction and are connected to the main girders by riveting.

b) **Welded Plate Girders:** Welded girders are fabricated using plates for both web as well as flanges. There are no overlaps like the ones used for connecting members in riveted girders.(Fig. 5.3) The comparison of the riveted and welded girders is given in Annexure I of this book.

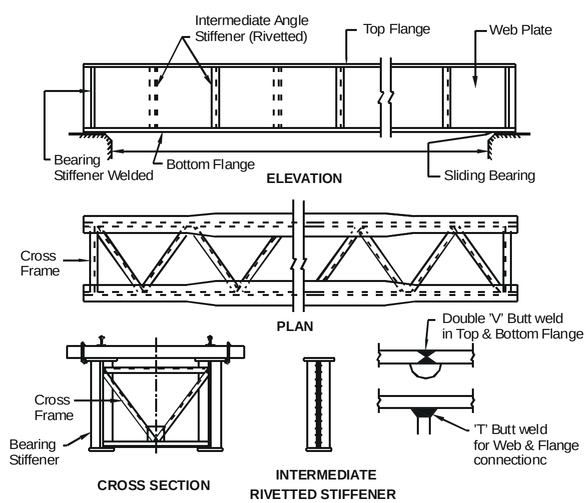


Fig 5.3: 12.2 m SPAN (WELDED PLATE GIRDER)

- **Curtailment of flange plates in plate girders:** For economy sake, in riveted girders, since multiple plates were used, some of the plates could be curtailed at locations where these were no longer required to have some economy. In welded girders, we use single plate as flange plate and this method of curtailment is not suitable. But, we can vary the width of the flange plates as shown below (Fig 5.4):

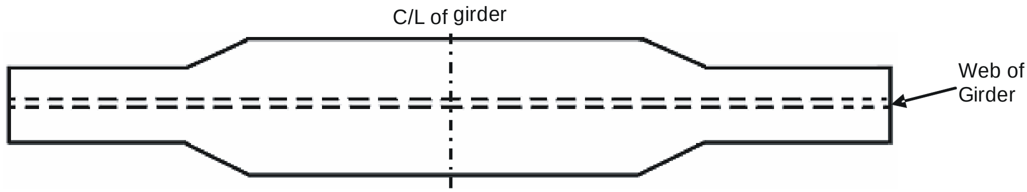


Fig 5.4: Flange plate curtailed towards the ends

Changing flange width necessitates two different lengths of sleepers (at ends and in middle). The junction of the two widths can be butt welded or the curtailment can be done at the splice location or the plate can be cut to change the plate width. If the arrangement is deemed difficult and wasteful in fabrication, plate width can be kept uniform throughout the length as shown in **Fig 5.5** with approval of RDSO-LKO.

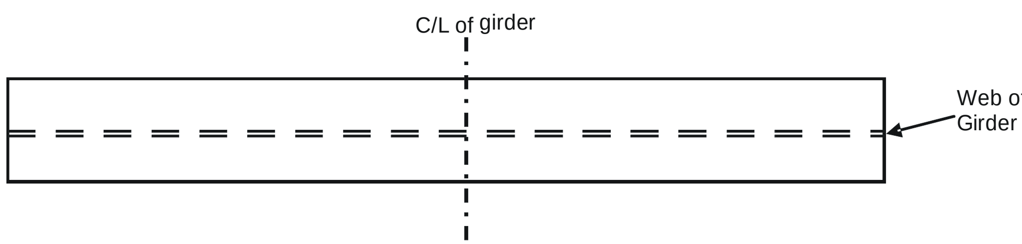


Fig 5.5: Top Flange Plate With Same Width Throughout

For bottom flange plate, if the flange width is changed, it has to be done by cutting to the shape and 'Butt' joint shall not be made as the butt welds subjected to tensile forces will be highly susceptible to fatigue failure if there any flaws in the welds.

- **Change in web thickness:** The shear is maximum at supports and zero at the middle, so web plate thickness may also be sometimes changed for economy. The web plate thickness is changed usually at the splice locations and packing plates are provided under the splice to make up for the difference in thicknesses of the plates.

- **Splices:** The girders longer than 12.2 m spans are usually made in pieces, to be assembled at site. The site welding is not permitted and the field connection is done using rivets.

- **Bearing Stiffeners:** These stiffeners are in the form of back to back plates and are welded to the girder. These have to act as struts to transfer the concentrated load at the bearing locations to prevent web buckling and therefore, these have to be straight and snug-fit in top/ bottom flanges. Therefore, the ends of the bearing stiffeners are machined for close fit. In case of riveted girders, these are provided with packing in the web equal to the thickness of the flange angles. In case of welded girders, these are provided with weld all round, including in connection with the top flange.
- **Intermediate Stiffeners:** Even in welded girders, the intermediate stiffeners are made up of single angles by riveting but joggling is not required as there is no flange angle. For composite girders, welded stiffeners have been given in standard RDSO drawings. In these, welding is done only in the web and not in connection with the top flange. Welded intermediate stiffeners have been given shorter length than the depth of girder and do not touch the bottom flange in composite girders.
- **Bracing:** The top/bottom bracing, cross frames, diaphragms etc are made up of rolled sections or welded to form the cross section. These are connected to the main girders by riveting.

c) **Open Web Girders:** In open web girders, number of components in a span is more and the components are transported loose to site where these are assembled. The various members in open web girders are:

- Bottom chords (Tension member)
- Top chords (compression members)
- End Rakers (compression members)
- Verticals (Tension)
- Diagonals (Tension/ compression)
- Floor system:
    - ✓ Cross girder at every panels of bottom boom
    - ✓ Stringer or rail bearer between cross girders.
- Bracing:
    - ✓ Top lateral bracing
    - ✓ Sway bracing and knee sway
    - ✓ Portal bracing and knee portal
    - ✓ Bottom lateral bracings
    - ✓ Bracing for stringer girders

- Other members such as:
  - ✓ Cantilever bracket
  - ✓ Bearings

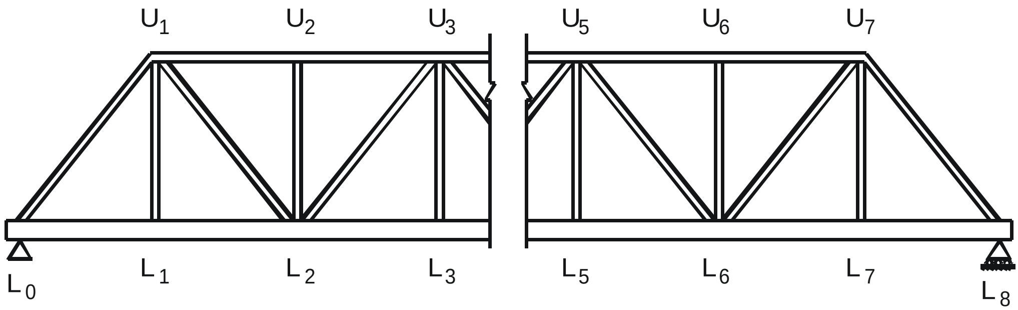


Fig 5.6: General Arrangement for 61.0 m span open web girder

As per numbering system for the node points, given in chapter 1, para 1.3, the members are identified as:

Bottom chord L_o- L_1, L_1- L_2 etc.

Top chord U_1-U_2, U_2 – U_3, U_3 – U_4 etc.

End Raker L_0-U_1

Diagonals U_1-L_2, L_2-U_3, U_3-L_4 etc.

Verticals L_1- U_1, L_2-U_2, L_3-U_3, L_4 - U_4 etc.

- **The members and gussets shall be fabricated using jigs**. The clause 33.1 of IRS B1 states that all standard open web girders for prestressing shall be made completely interchangeable by the use of steel jigs and hard steel bushes controlled by master gauges. If this is done, only the first span is to be erected to check the accuracy of the jigs, otherwise all the spans fabricated have to be temporarily erected for checking the camber as well as match marking.

5.2 Steps involved in fabrication: For fabricating any welded steel girder for railway loading, whether plate girder, composite girder or open web girder,[2] the following basic steps (with some modifications, discussed subsequently in this chapter) are involved:

1) Making specifications for welding and qualification of welders.

2) Templating – preparation of material list.

---

[2] The procedure of fabrication is same whether the open web girders are erected after assembly on ground or are erected by cantilever method. Only method of erection changes.

3) Cutting of materials

4) Straightening of cut material

5) Edge planing and welding

6) Tack assembly

7) Full welding

8) Drilling of Holes with jig

9) Initial assembly (and riveting, if required)

10) Final assembly

11) Painting and dispatch

The riveted steel girders drawings for 25 T and DFC loading have not been issued and hence the steps riveted girder fabrication has not been discussed in detail but some difference in procedure for riveted and welded constructions is explained briefly in the relevant paras below. The fabrication of riveted girders is, of course lots simpler than the welded girders.

5.3 Making specifications for welding and qualification of welders: The first step in fabrication of girders by welding is to establish the parameters to be used for welding different type of joints involved in fabricating one span and ascertaining if the welders will be able to make the welds to proper quality and strength.

5.3.1 Welding Procedure Specification Sheet (WPSS) preparation: The welding parameters are decided using through Welding Procedure Specification Sheet (WPSS) preparation. The WPSS is a document which gives the complete details for making a weld. One WPSS each is prepared for each type of joint. The parameters of welding differ with:

- Base metal specifications.
- Combined thickness of steel parts to be welded
- Type of weld viz., fillet weld or butt weld etc
- Size of weld
- Welding process to be used and position of weld.
- Electrode and flux combination

The WPSS is prepared in Quality Control (QC) section or metallurgical section of the workshop. The proforma for the same is given in Appendix V of IRS B1, as shown in fig 5.7.

APPENDIX - V
(Ref. Clause 26)

1. **Proforma for Welding Procedure Specification Sheet**

Name and address of Fabricator:
Welding procedure specification No

1. Weld joint description:
2. Base Metal :
3. Welding Process :
4. Welding position :
5. Welding consumables :

5.1 Electrode/wire
Class :
Dia :
Drying method:

5.2 Flux
Class :
Type:
Drying method:

5.3.1 Shielding gas:

6.0 Base Metal preparation:

6.1 Joint design details:
(Give sketch showing arrangement of parts, welding groove details, weld passes & their sequence etc.)

6.2 Joint preparation:

7. Welding current:
Type:
Polarity:

8. Welder qualification:

9 Welding parameters and technique:

9.1 Welding Parameters:

Weld Pass No.	Electrodes/ wire dia.(mm)	Current (amp)	Arc Voltage (volt)	Wire feed speed (m/min))	Travel speed (m/min)	Electrical stickout (mm)	Gas flow rate (litre/min.)
1	2	3	4	5	6	7	8

9.2 Welding sequence and technique:
(Give sketch showing sequence and direction of welding).

10. Provision of run in and run-off tabs:
11. Cleaning of weld bead before laying next weld bead:
12. Root preparation before welding other side of groove weld:
13 Preheating and inter pass temperature:
14 Peening
15 Post weld treatment:
16 Rectification of weld defects:
17 Inspection of weld.
18. Any other relevant details

Prepared by
Signature______________________________
Designation ___________________________
Date _________________________________
(for & on behalf of Fabricator).

Fig 5.7: Proforma for Welding Procedure Specification Sheet

In case of plate girders, the different type of joint welds for which WPSS are required to be developed are:

- All plate girder spans will have
  - Fillet weld connecting web to flanges (Top and bottom flange)
  - Weld connecting Bearing stiffener to web
  - **In addition to the above,** 12.2m span may have
    - Butt weld in web plate
    - Butt weld in Bottom flange
    - Butt weld in top flange
    - **In addition to all the above,** the composite girders will have
      - Welds in shear connectors
      - Welds connecting intermediate stiffeners to web

In case of open web girders, the number of weld joints for which WPSS are to be developed are:

1	End raker	Top flange to side plate	a) outside b) inside
		Bottom flange to side plate	a) outside b) inside
2	Top Chord	Top flange to side plate	a) outside b) inside
		Bottom flange to side plate	a) outside b) inside
3	Bottom Chord	Top & Bottom flange to side plate	a) outside b) inside
4	Diagonal	Top & Bottom flange to side plate	a) outside b) inside
5	Vertical	Top and bottom flange to web plate	————-
6	Cross girder	- Top and bottom flange to web plate - Intermediate Stiffeners welded to cross girders	————-
7	Stringer	- Top and bottom flange to web plate - Intermediate Stiffeners welded to Stringers	————-
8	Remaining joints	i) Portal bracing ii) Top lateral bracing iii) Bottom lateral bracing iv) Sway bracing	————-

To make WPSS, the metallurgist collects data regarding the different "weld type- steel thickness" combinations required for fabrication of a girder. The variables which control the WPSS are type/size of electrode, flux, current, voltage, speed of travel etc. Based on the experience, the metallurgist proposes WPSS for each of the combinations and gives the same for making sample specimens for testing.

A sample WPSS is shown below in fig 5.8.

WELDING PROCEDURE SPECIFICATION SHEEP

Second Railway Bridge No. 544 over river Mahanadi
on Hawrah - Madras Broad Gauge line

BBJ Construction Co. Ltd ,
27.R.N. Mukherjee Road. Kolkata -700 001

Welding Procedure Specification No : BBJ/QA/SBF-W/2119/ADB-RVNL/OI

1. Drawing no. : 2119/O8. Rev. RO,# End Raker Mkd. ER, ERX & Portal Brcg. Mkd. PB
Top Flng. Plt. To Side Plt. - Outside Location :

2. Weld joint description : Single Bevel Butt

3. Base Metal : IS 2062 - 99 ,Gr. B. fully killed and control cooled (normalized)

4. Welding Process : S.A.W

5. Welding Position : Flat

6. Welding Consumable

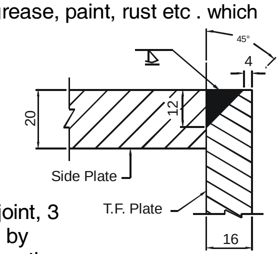
6.1 Electrode/Wire : Class: W1 of IRS M.39 - 2001
Type : Caper coated solid Wire Drying method : N.A

6.2 Flux : Class. F1 to IRS M.39 - 2001
Type Agglomerated
Drying method : 250° C for one hour before use

6.3 Shielding Gas : N.A

7. Base metal preparation : Fusion faces and adjacent surfaces are cleaned and made free from cracks, notches, mill scale, grease, paint, rust etc . which might affect weld quality.

7.1 Joint design datasheet :
(Sketch showing arrangements of parts.
Weld groove details, weld passes & their sequence etc.)



7.2 Joint preparation. If Oxy-acetaline cut edge becomes fusion face of joint, 3 mm depth metal of gas cut edge to be removed by edge planning/planer machine throughout the length part, to remove heat affected metal to ensure sound weld and dead contact throughout length of member to avoid initiation of fatique crack during service life.

8. Welding current Type : DC
Polarity : Reverse

Fig 5.8: Typical WPSS.

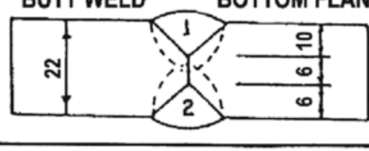
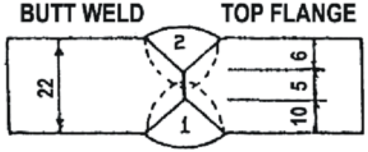
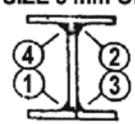
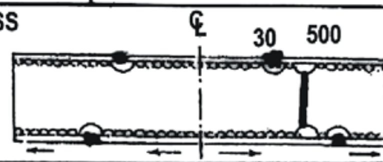
5.3.2 Weld Procedure Qualification Record (WPQR): After the WPSS is issued to the shop for fabrication, the welders who will actually carry out the fabrication work are asked to make sample specimens using the parameters in WPSS.

5.3.2.1 Preparation of sample joint specimen: Sample joint specimens are prepared with steel plates having similar specifications, edge preparations and also welded in similar position of welding, welding process and wire-flux combination. These samples along with welders' name and parameters are filled in Performa for WPSS. Weld sample and WPSS are then sent to M & C directorate of RDSO/LKO for NDT and destructive test for qualification and for approval. After test, if specimen joint is passed, the Welding Procedure Qualification Record (WPQR) is prepared. If the sample fails, the WPSS is modified and samples are tested again.

5.3.2.2 Full Welding of components as per WPQR: Welding shall be done as per approved WPQR only. If there is any change during the actual fabrication such as due to changes in steel specifications or welding process or position of the weld or change in wire-flux combination or joint details and also if increase/decrease in combined thickness of the plates being welded by more than 10 mm(As per IS:9595) etc, the welding shall be done only after a new WPSS is prepared, tested and approved for revised WPQR. **In no case shall the deviation from approved WPQR shall be accepted.**

Sample WPQR for 12.2m span is shown in fig 5.9.

WELDED BRIDGE GIRDER - ESTABLISHED WELDING PARAMETERS
REF : DRAWING 12.2 m R.B.G. PLATE GIRDER R.D.S.O. DRG : BA 11083
THE WIRE FLUX COMBINATION USED IN SUB MERGED
ARC WELDING - AUTOMELT GRADE 'A' WIRE (4.0 mm DIA)
GRADE - II FLUX .... APPROVED BY RDSO

Sr. No.	JOINT FIT UP	WELD PARAMETERS					POSITION
		STEP	V	AMP	CARR, SPEED m/mm	WIRE FEED m/mm	
1	BUT WELD ON WEB 	1st 2nd	32 32	550 600	0.4 0.4	1.25 1.25	FLAG DOWN HAND
2	BUTT WELD BOTTOM FLANGE 	RUN 1st 10 mm SIDE RUN 2nd 6 mm SIDE	32 32	650 700	0.5 0.5	1.50 1.50	do do
3	BUTT WELD TOP FLANGE 	RUN 1st 10 mm SIDE RUN 2nd 6 mm SIDE	30 32	650 700	0.5 0.5	1.50 1.50	do do
4	FILLET SIZE 8 mm ONE PASS  		30	500	0.3	1.25 	

Remarks :1 Following limits of permissible variation shall be observed during the course of welding. For this suitable records during actual operation of welding shall be maintained.

Welding Current ± 10% Voltage ± 7% Speed of Travel ± 15%

2. All the records of radiograph exam rating with obervation shall be properly maintained for future reference.

Fig 5.9: WPQR for 12.2 m span Plate Girder

5.3.3 Templating: Templating means setting out the drawing to-the-scale on the floor of the girder. This exercise is required for the open web girders. For plate girders, this step may be skipped and girder fabrication may be done without templates by taking direct measurements as no camber is to be provided. Templating helps in the following:

- To find out errors in drawings and to find out overlaps in members or obstructions which might hinder the girder assembly. This is especially required for locations where many members are meeting.
- To find out unknown length of any member which cannot be worked out from fabrication drawings.
- Position of holes in web & flange plate for field splice joint, top lateral bracing, and intermediate stiffeners.
- Profiles of gussets, cross bracing angle ends etc.

5.3.3.1 Template shop– Template shop is nothing but steel (or concrete) floor laid to dead level required to draw sketch of girder with help of string and white chalk (**Fig 5.10 and 5.11)**. The first time any standard girders are taken up for fabrication to any new design, (or if any new agency starts fabrication of girders for first time) fabrication drawings are to be templated, otherwise it is not required. (Once templating has been done, the same templates/ jigs etc can be used for fabrication of any number of spans as the measurements are not going to change.)[3]

Fig 5.10: General view of Template shop

[3] **Note**: Templating can also be done on computers, using any of the various CAD softwares available, such as AutoCAD and there is no need for physical plotting of the girder on ground for templating.

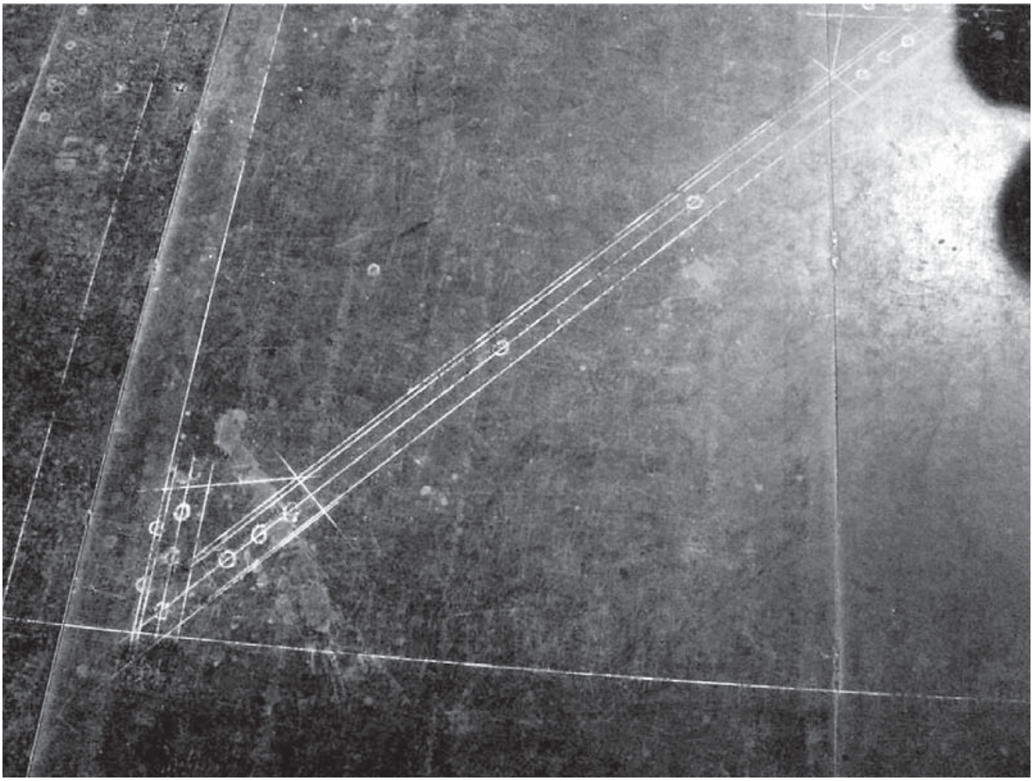


Fig 5.11: Girder plotted with chalk on template shop floor

5.3.3.2 Special tools for templating:

- Steel tape duly tested called as "Master Tape" shall be used for taking measurements. This tape shall not be used for any other work except fabrication of master gusset, jig manufacture and checking of master gussets and jigs. (Fig 5.12)

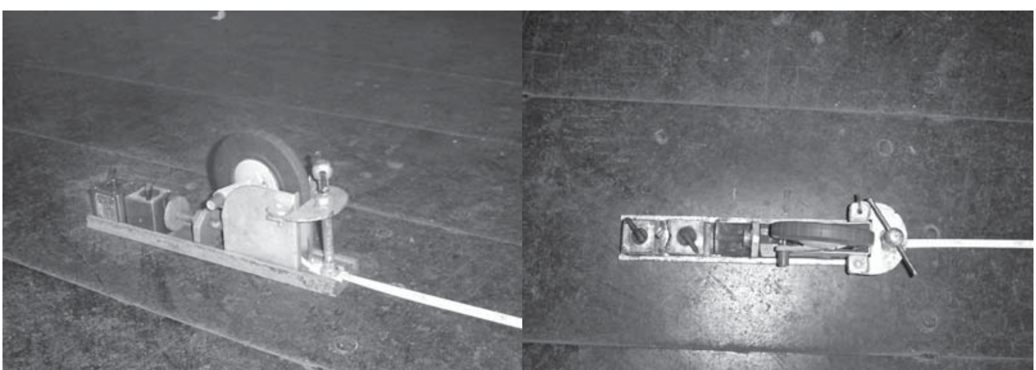


Fig 5.12: Standard tape for templating with standard tension load

- Specially manufactured tension attachment to have 1.8kg stretch on the master tape all the time shall be used while taking measurements for template.
- Correction for temperature shall be applied as all measurements in RDSO drawing are given at 20^0 C.

5.3.3.3 Master Gussets, Working Gussets and Member Jigs: The basic aim of templating is to fabricate the jigs which are used for actual fabrication of members. Jigs help in rapid fabrication of identical members without any need for measurements and help ensure error-free fabrication. The measurements taken from the templating floor or CAD software are used for manufacturing what are known as **Master Gussets**. The master gussets are gussets made up of sturdy steel plates of adequate thickness so as to avoid damage in service and these are manufactured with great care under the supervision of skilled staff to close tolerances. A typical master gusset (Fig 5.14) based on the templating (Fig 5.13) is shown here.

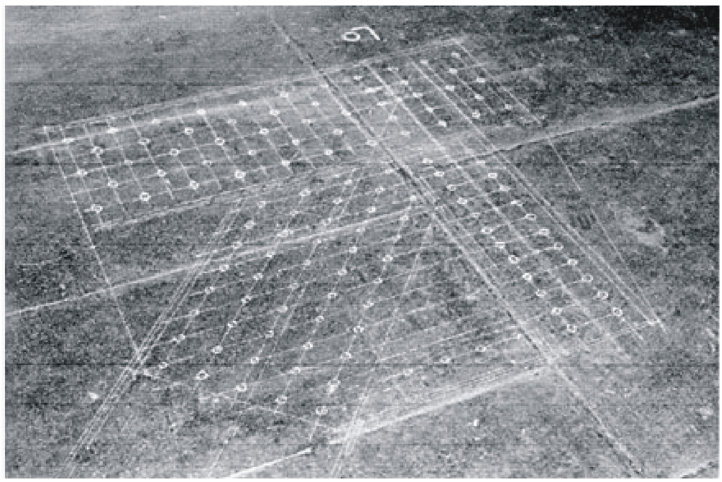


Fig 5.13: TEMPLATE OF GUSSET PLATE

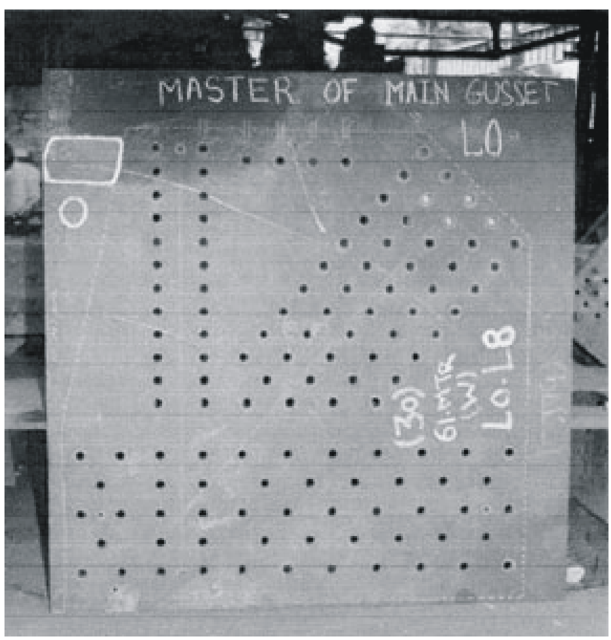


Fig 5.14: MASTER GUSSET

The master gussets are not used for girder fabrication directly. These are stored carefully in workshop and used for fabrication of **Working Gussets** and **Member Jigs**.

The working gussets are similar to the master gussets except that these are to be used for making holes in gussets. In order to prevent the holes from getting elongated, the holes in working gussets are protected by providing extra bushes. The bushes to be provided in holes shall have internal bores “case hardened” by suitable heat treatment (e.g. oil quenching). The bores of bushes shall initially have a tolerance of -0mm, +0.1mm. A working gusset is shown in fig 5.15 below:

Fig 5.15: Working Gusset

Riveted fabrication jig contains different diameter holes as follows:

i) **Holes for Field connections,** 23.5mm dia for 22mm rivets

ii) **Holes for Shop rivets,** 21.5mm dia for 20mm rivets

iii) **Holes for Bracing rivets,** 19.5m dia. or 17.5m dia. for 18mm or 16mm rivets.

To eliminate mistakes, for guidance of the drill machine operator, colour code shall be provided to identify bushes of different diameters.

Member jigs: Holes similar to those in gussets are to be made in member ends also but if these holes are made using working gussets, length measurements between the ends will have to be taken physically each time which can lead to mistakes. Therefore, **member jigs** are used to make holes in members which will require no physical measurements. The characterstics of member jigs are:

- These are fabricated in lengths equal to or more than the member lengths.
- These shall be made quite sturdy as not to be easily bent/ distorted while being transported or being fixed/removed from members.
- These shall have simple placement method.
- Member jigs are of two types:
  - Box type Jigs
  - Plane type Jigs

Box type jigs are used for making holes in the different faces of the members simultaneously (Fig 5.16a) whereas the plane type jigs are used for making holes on one face only (fig 5.16b).

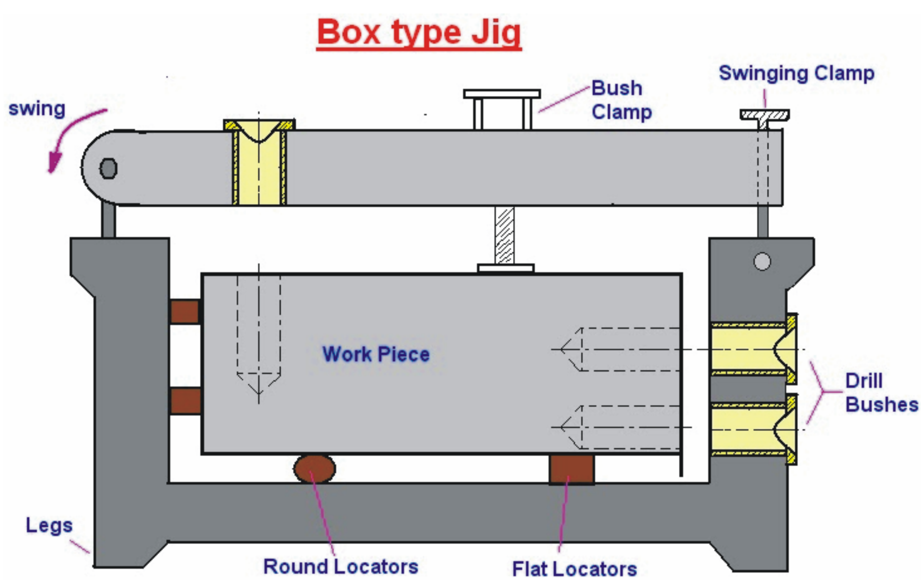


Fig 5.16a: Box type jig which can be used to make holes on two faces of the member simultaneously.

Fig 5.16b: Plane type Jig for making holes on one face of member

5.3.3.4 Method for Preparation of working gussets and member jigs:

- **Plate girders:** The member jigs and gussets for plate girders are simple to make. From the template shop (or AUTOCAD etc), the measurements are directly used for the jig fabrication.
- **Open web girders:** The fabrication of member jigs and gussets for the open web girders is bit more involved as the members of these girders have to be fabricated for predeformation or prestressing. If drawing is new or non standard, for which fabrication drawings have not been issued by RDSO Lucknow, the fabricator has to first prepare the fabrication drawings. The rules for prestressing as per Appendix A of IRS B1 have to be followed. The camber sheet mentions the nominal as well as camber lengths to be followed for fabrication. (Already explained in Chapter IV)

The steps in preparing the working gussets/member jigs for open web girders are as follows:

a) First the fabricator has to prepare drawing for the joint details of all top and bottom panel points of truss **on nominal layout** indicating pitch of rivet holes, gauge of rivet holes, edge distance, profile of gussets and number of rivets for each component connection at joint (gusset). Sketch of each joint also indicating intersection line of each of the components (along their centers of gravity) meeting at a joint are prepared (shown in **Fig.5.17 and 5.18)**, based on which fabrication of master gusset will be carried out in template shop. These master gussets are used to directly prepare working gussets as well as member jigs.

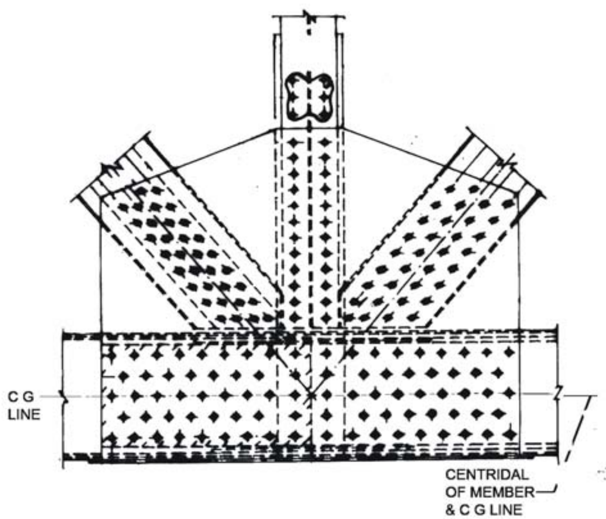


Fig 5.17: GUSSET FOR BOTTOM BOOM - L_2

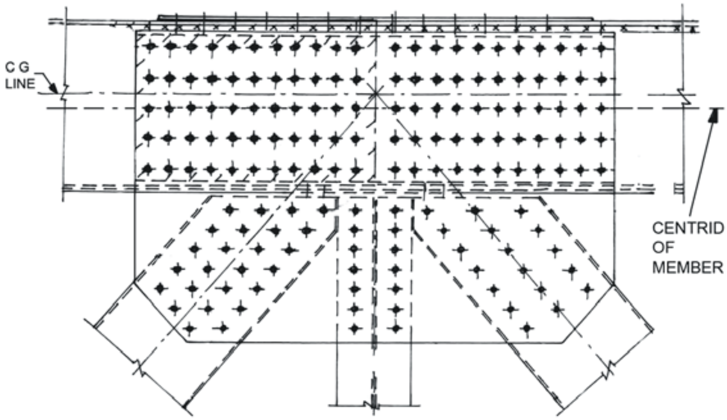


Fig 5.18: GUSSET FOR TOP BOOM - U_2

b) The working gussets are prepared by drilling holes through master gussets.

c) Each member of the truss has to be fabricated to camber length between intersection points of the joints at either ends. Hence fabrication drawing for each member showing details of camber length, field rivets, stitch rivets/welds, batten plates, lacing systems, diaphragm etc. is to be prepared.

d) **Computations for Member Jigs: To meet the provisions of Appendix 'A' of steel bridge code, the compression members of truss are fabricated longer than their nominal lengths whereas the tension member are to be fabricated shorter than the nominal lengths.** The fabrication drawings indicate the nominal as well as camber lengths as shown in fig 4.1/4.4 in chapter IV. As an example, preparation of detail drawing for fabrication is explained for one member (U_3-U_4) of 61.0m span shown in Fig 5.19 below.

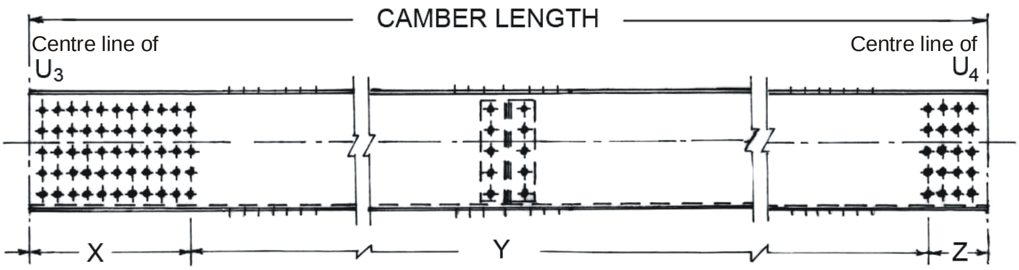


Fig 5.19

Now, Camber length = Distance between intersection points between (U_3-U_4)

In fig 5.19, Camber Length= X+Y+Z, where

Distance X is distance between centre of last rows of holes and centre line of U_3 (i.e. same as on U_3 joint gusset)

Distance Z is distance between centre of last rows of holes and centre line of U_4 (i.e. same as on U_4 joint gusset)

In order that the holes in gussets and member ends match, the distances X and Z cannot be changed. This leaves only length Y to be adjusted for obtaining the camber length of member, and is worked out as:

Y= Camber length of member (U_3-U_4) - (X+Z)

e) **Requirement of Member Jigs:** Minimum one jig for one member will be required to make holes in member ends. Two such jigs are shown in Fig 5.15 and 5.16 above. Different type of member jigs required for a girder are:

Top Chords	U_1-U_2, U_2-U_3, U_3-U_4, etc
Bottom Chords	L_0-L_1,L_1-L_2, L_2-L_3, L_3-L_4, etc
End Racker	L_0-U_1
Diagonals	U_1-L_2, L_2-U_3, U_3-L_4, etc
Verticals	L_1-U_1, L_2-U_2, L_3-U_3, etc
Cross Girders	End cross girder, Middle Cross Girder
Stringers	One end riveted, both ends riveted.

f) **Fabrication of Member Jigs:** The member jigs are prepared as follows (Let us consider U_3-L_4 as the member for which jig is to be fabricated):

i) Take a plate longer than the length of member U_3-L_4 to fabricate a sturdy frame for making the jig.

ii) Drill holes at one end of member (say U_3 end) by clamping master gusset for U_3 to the member.

iii) For placing the other master gusset, for L_4, the camber length, Y, as computed above has to be used (fig 5.19 above) and the master gussets for L_4 is fixed accurately at a distance equal to camber length of member.

iv) Drill the holes in the jig through the master gussets in the master jig for L_4.

v) Mark holes for any other rivets such as for stitch rivets (In case the girder is riveted) and other members such as battens, lacing, bracing etc attached to the member (as per drawing).

5.3.3.5 Monitoring Gussets and Jigs: Accuracy in fabrication and getting effective pre-stressing of open web steel girder span depends solely on accuracy of holes and camber lengths, which in turn depends on quality of gussets/jigs. Hence, when first time jigs are manufactured, these are checked and approved by RDSO inspection team. A register has to be maintained in accordance with Appendix I of IRS-B1 for the inspections. This Register shall be maintained for keeping record of details of each jig for their approval and modification/rectification to jigs. One page should be allotted to each jig and details mentioned in following performa shall be filled up:

1) Description of jig:
2) Jig No:
3) Shipping mark of the component for which jig is made:
4) Drawing no. for the component

Date of inspection	Observation/ Inspection Notes	Compliance action	Initial of Supervisor-in-Charge
1	2	3	4

In the beginning of register, a statement of jigs shall also be placed in the following Performa.

Jig	Description of Jig	Shipping mark of the component.	Drg.No. as per which jig is made/modified	Inspecting officia's approval details
1	2	3	4	5

Jigs are the essence of the quality control for fabrication, especially for the prestressed open web girders. To ensure quality of fabrication using jigs:

- The jigs shall be checked by fabricator and inspecting officials for their accuracy during work, especially when the jigs are taken up for fabrication of a new span.
- The jigs shall be handled carefully during work and shall not be dropped/ damaged as to change their dimensions.
- The holes in jigs shall be monitored. When the jig loses shape or the holes get beyond the tolerances, as given in para 5.3.10 below, the jigs shall be fabricated afresh using the principles given above using the master gussets which shall be preserved carefully.

5.3.3.6 Fixtures: In addition to the jigs, fixtures are also required for fabrication. The fixtures support and hold members and jigs in position without relative movement between them. These also help avoid sagging of longer members due to pressure applied during drilling. Fixtures are also used for holding and manipulating the girder parts for getting the best position for welding.

5.3.4 Preparing Material Lists: Before taking up fabrication of any steel girder, the complete material requirement shall be worked out. The exact cutting lengths for each member shall first be worked out, based on which the requirement of basic sections such as plates, angles, channels etc shall be worked out. Due allowance for the wastage, cutting margins etc shall be made in computations and then steel shall be ordered. The steel received shall be inspected for the following:

- **Material Test Certificate Register:** Details of Cast mark number/heat mark number and span to be fabricated for all steel received shall be entered in register as stipulated in item 7 of Appendix-1 of IRS B1-2001.:

Statement of Material Test Certificates

Name of work:

Contract /order No.

Span No.

Girder Component description and identification No.	Type and size of rolled section	Material test certificate No.	Cast No.	Steel quantity as per the test certificate	Steel Manufacturer or supplier	Initial of Supervisor In-Charge
1	2	3	4	5	6	7
One page should be allotted for each span.						

- If there are any doubts in quality of steel or small lots of steel which are not accompanied by Material test Certificates, the testing of steel in lab separately shall be got done. Routine independent testing of steel may also be got done as per contract conditions.
- All angles and channels used for open web girder fabrication shall be checked for rolling tolerance as to be within limits as stipulated in IS-1852. If care is not taken at this stage, the entire member can be rejected later on if the fabricated member does not fit or is out of shape or does not meet the tolerances specified.
- Steel supplied shall be accompanied with the rolling marks, lot number and cast marks etc. identifying the steel right from manufacture stage to supply.

- As has already been told in para 2.6.1, Chapter II, the steel sections required for railway girders shall conform to IS: 2062 grade B or C. The grade B steel is suitable for the locations where the temperature does not go below 0^0C and the grade C steel is used where the temperature goes below 0^0C.
- In addition, visual inspection shall be done to ensure that steel is free from surface defects like pitting, segregations & twists and recorded in the register.

5.3.4.1 Substitute Members: If a particular steel section is not available in stock and the workshop does not expect the same to be supplied in near future, in order to proceed with girder fabrication, sometimes it is essential to use some substitute sections. The substitution can be done only with the approval of the design office of the zonal railways which shall see the design aspects before allowing such substitution. It will be prudent for the fabricators to respect the drawings and not to take liberty to arbitrarily substitute the sections, even if the substitute members have equal or more area than the member in drawing. This problem is more common in riveted girders where the inventory of sections required is large and some sections may not be available. In welded girders, since limited number of plates is required for fabrication, this problem is very less.

5.3.5 Cutting of Material: Cutting of steel is to be done in the cutting section. The visual examination of steel shall once again be done to ensure that the steel being cut does not have any obvious problems. The following points shall be kept in mind:

- Required quantity steel of approved quality shall be brought to cutting sections as per material list. It must be ensured that steel is tested one.
- While marking widths and lengths, cutting allowance @3mm upto 12 mm thick plates and @5mm for more than 12mm thick plates shall be made so that after cutting / grinding / machining, required width and length shall be available (+ 1mm – 0.00mm).
- It shall be ensured that after cutting, edges are reasonably clean, square and without drag line.
- Angle or channel section shall be cut by circular saw machine or hand gas cutter by qualified welder.
- Material cut as per cutting list for each span shall then be transferred to straightening section.

5.3.5.1 Controlling deformation while cutting: When we cut plates using gas, heat is imparted to the members, which often leads to deformation of the plate. Cutting for long members like flange plates has to be done with special care to avoid lateral deformation. The deformation problem is very serious one because once the plate deforms during cutting, it can not be rectified easily. The deformation can be avoided by using multi cutter automatic machine. Controlling the rate of cutting to minimize the heat input can also reduce the deformation. A single pug cutter is shown in operation in fig 5.20 below.

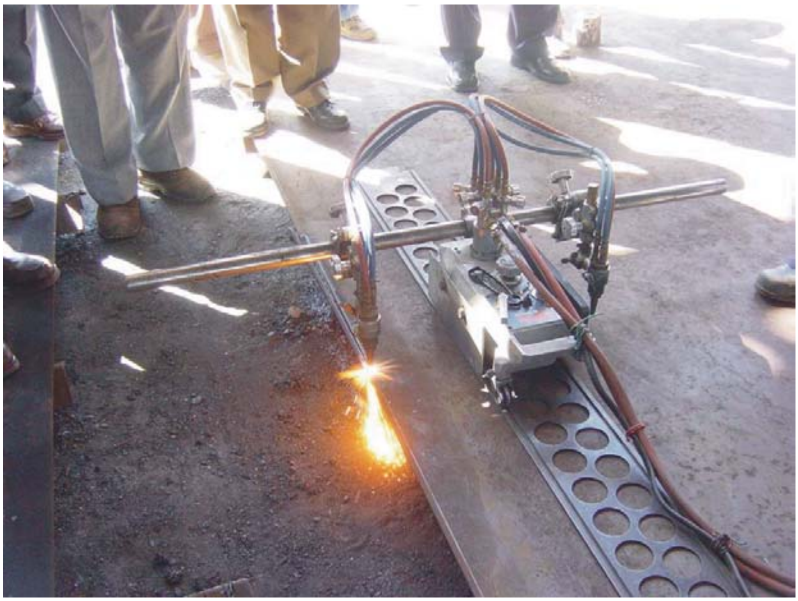


Fig 5.20: Single pug cutter for cutting plate

If single pug cutting (automatic) is to be used, the problem can be avoided if we drill 12.5mm hole on the line beyond the plate length required (see fig 5.21). The cutting is started from the hole on one side, up to the other end hole. The uncut plate at ends will not allow lateral deformation of the cut plate[4]. After the cuts are completed as required, the portion beyond holes can be cut using hand held flame cutting torch.

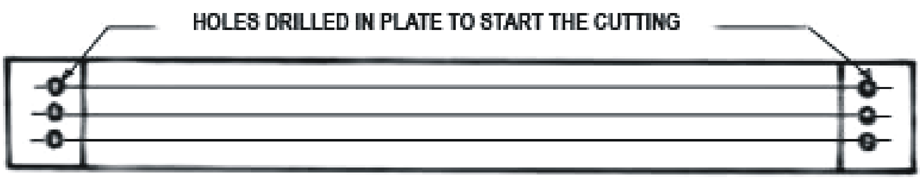


Fig 5.21: Cutting of plates through the holes made near the ends.

[4] There may be small vertical deformation of plate which can be easily straightened later on in plate straightening machine

5.3.5.2 Factors to be kept in mind while Cutting of Steel: While cutting of steel, the following factors must be kept in mind:

- Due cutting allowances shall be made to get the member slightly longer than required so that the final dimension of the member can be brought to the tolerances desired with minimum grinding.
- Undercutting/Overcutting shall both be avoided. The undercutting will necessitate large amounts of grinding which is costly as well as time consuming affair. The overcutting will reduce the dimension available and may lead to wastage of steel or the fabricator may be tempted not to grind away the heat affected zone completely (which might lead to bad quality welds and poor fatigue performance of the structure).
- The cutting shall be planned by the fabricator for optimum utilization of steel plates. Different members shall be plotted on steel sheet as to reduce the wastage to minimum.
- Where web plate for fish bellied girders or variable width flange plate is required, the designer may be asked if the splice can be provided at this location to reduce the wastage, else these are to be cut from wider plates and alternate use for left over pieces have to be found out.

5.3.5.3 Re-entrant Corners: There are many members which have to be cut with corners, such as top flange plates for the stringers. In such cases, providing proper root radius to the corner is critical and the problem of re-entrant corners has to be avoided. A re-entrant corner means an internal corner or a corner with angle less than 90°. It has very high stress concentration and is liable to fail in fatigue very early. In service, this type of corners have been known to result in cracks in such members very early.

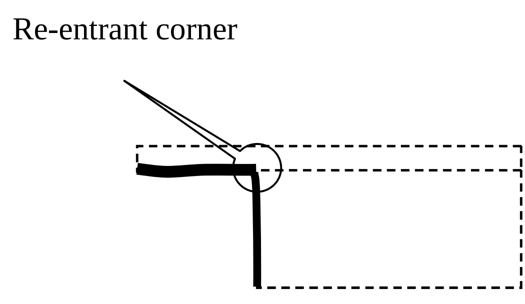


Fig 5.22: Re-entrant corner due to gas cutting

When member is cut by gas, 3 to 5 mm area around the edge become the heat affected zone and is hard and brittle. This area already has micro cracks. At a corner made by two gas cuts, the overlap is a re-entrant corner even if the same is not visually apparent. The re-entrant corner in gas cut edges is shown in a member in Fig 5.22 above. To avoid this problem, one of the following actions may be taken:

- The cut can be made using shaper machine instead of gas cutting. This eliminates heat affected zone and proper root radius can be easily provided.
- The gas cut can be made leaving some margin from the final profile required and the excess material left from gas cutting shall be ground out in shaper machine with a proper smooth radius at the corner, thus removing the heat affected zone, avoiding re-entrant corner and reducing stress concentration.
- Alternately, the corner can be given proper profile by first drilling a hole with drilling machine near the corner(Fig 5.23). The gas cutting shall be done only on either side of the hole, thus avoiding the re-entrant corner. The drilled hole provides a readymade proper root radius to the corner.

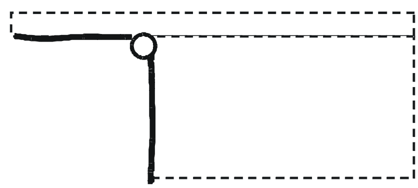


Fig 5.23: Avoiding Re-entrant corner by making hole before gas cutting

5.3.6 Straightening of Cut Material: The cut material is to be straightened in the straightening section of the workshop. All the cut plates shall be straightened in plate straightening machine and angles in rolled section straightening machine. Pressure applied for straightening or flattening shall be such as it would not injure the material. Hot straightening is not permitted unless authorized specifically. The straightening shall be done to tolerances specified in Appendix II of IRS B1. Deformed/ bent plates or angles will not allow the assembly of girders to required tolerances.

5.3.7 Edge planing and grinding: The fillet welded web connections with top and bottom flanges in plate girders/stringers etc. resist not only the shear force but also the cross bending of top flange plate, on account of sleeper resting on top flange. Therefore, these welds fall in butt welded 'T' joints as per clause 5.6 of WBC. This weld is to be made carefully. Care is required to be taken during welding to ensure that the two fillet welds on either side fuse together at the root by minimum amount. A typical weld detail is shown in fig 5.24 below:

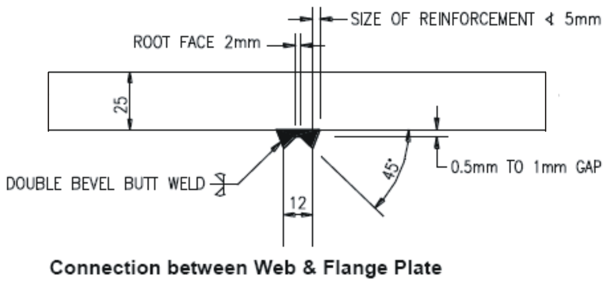


Fig 5.24: Welded connection between flange and web

If there is non uniform gap between the flanges/web, the weld will be subjected to extra stresses and may also have improper fusion. These two effects cause such welds to have severe stress concentration and this can severely affect in-service performance of the girders. Therefore top and bottom edge of web plates are to be planed by planing machine to ensure uniform contact throughout the length of 'I' section which is 9 to 11 meter long.[5] Edge planing is, thus, a very important activity, especially affecting the performance of welded plate girders in field.[6]

Other parts of the fabricated members are also required to be ground so that the rough edges are smoothened and there is no problem in fitting the members at site due to the burrs etc. Fig 5.25 below shows a member whose edges have been ground.

Fig 5.25: Edges finally finished by grinding

[5] Web plate may also be prepared using grinding machines but this is tedious and not feasible for mass production. For longer girder lengths, this process will surely leave non uniform gaps at some locations.

[6] It may be noted that if weld cracks in service, repairs are not easily feasible in situ and sometimes, the span may have to be taken out from the track for repairs.

5.3.8 Tack Assembly: Tack assembly is the next step in fabrication which assembles the components to get the form of component or girder. This activity is to be done carefully so that the final components/ girders are fabricated to correct geometric shape and the size is within the tolerance specified.

For tack assembly, the components shall be kept on a firm hard bed (Fig 5.26) and shall be held in position using suitable fixtures so that once the measurements are taken to set a component at proper location, these shall not move till the final tack assembly is done. The entire work shall be done in area where arrangements for manipulating the member such turning over, shifting etc can be conveniently done using EOT or other type of cranes and suitable covered shelter for sufficient protection against the weather is available.

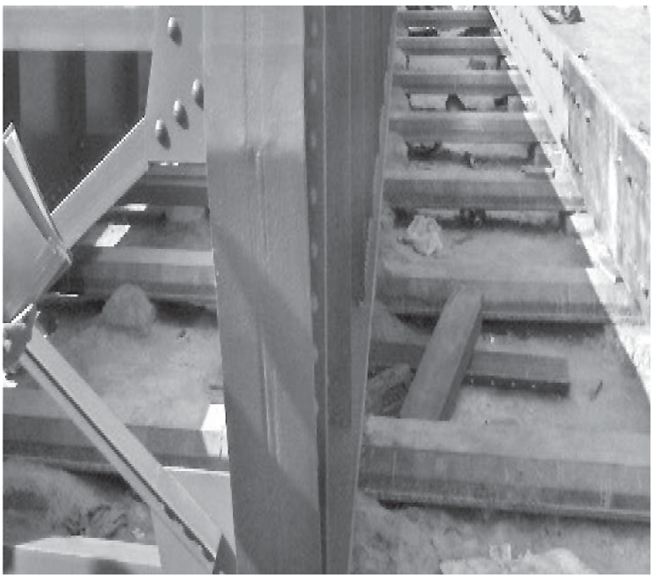


Fig 5.26 Firm bed for assembly

In case holes are to be made, as in the components of open web girders, the jigs too have to be mounted on the member during the tack assembly. For this, jig shall be placed over tacked component coinciding X- and Y- axes for correct placement with help of location guide marks on jigs and fixtures.

5.3.8.1 Quality of tack Welds: As per clause 24 of WBC,

- Tack welds shall be not less than the throat thickness or leg length of the root run to be used in the joint.
- Length of the tack weld shall not be less than four times the thickness of the thicker part or 50 mm whichever is the smaller.

- Where tack weld is incorporated in a welded joint, the shape, size and quality shall be suitable for incorporation in the finished weld and it shall be free from all cracks and other welding defects. Tack welds, which have poor quality and can crack, shall be cut out, ground and re-welded.
- Tack welds shall not be made at extreme ends of joints.
- Tack welds are equally important in the overall quality and performance of the girder and these shall also be made by qualified welders.
- The most common method for making the tack welds is by using MMAW.[7] After the tack assembly is complete, the girder/ component shall be checked for dimensional accuracy as per clause 13 of IRS B1.

5.3.8.2 Run-on and run-off pieces: To ensure good quality weld, it is desirable that the welding shall commence on run-on piece/tab and finish on run-off piece/tab. Whenever welding is commenced or stopped, the current/ voltage parameters of the welding machine are disturbed The initial and final small lengths of weld, thus, are not of very good quality. To tackle this problem and to get weld with full throat thickness, clause 5.7 of WBC provides that in case of butt welds, run-on and run-off pieces shall be provided in all cases of parent metal more than 20 mm thick and preferably in other cases also, by extending the ends of the butt welds past the edges of the parts joined. The run-on and run-off pieces are seen in fig 5.27 below. These can be extra plates tack welded to the member being welded with similar joint preparation and of reasonable thickness, not less than the thickness of the part joined and of length not less than 40 mm. If it is found convenient, the length of the member itself is increased so that the extra length is considered as run-on and run-off piece. Run-on and run-off pieces shall be removed afterwards by hacksaw or abrasive cutting. The run on and run off pieces are very useful to check the quality of welding and can be used for non destructive as well as destructive tests for quality control.

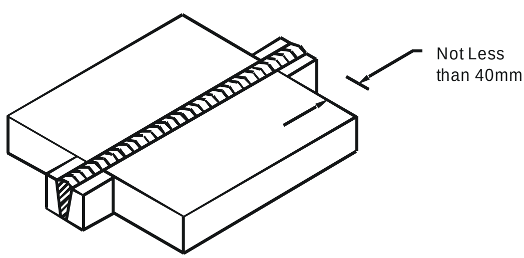


Fig 5.27: Butt weld with run-on and run-off pieces

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[7] CO_2 welding can also be used but it is not so common in Indian workshops.

5.3.8.3 Tack Assembly of Plate Girders/ Composite Girders: Either special fixture as shown in Fig 5.28 or manipulator has to be used to form the 'I' section. The fixture/ manipulator shall have suitable set of screws using which fine adjustments to the plates can be made so as to get the desired shape/ orientation of the members.

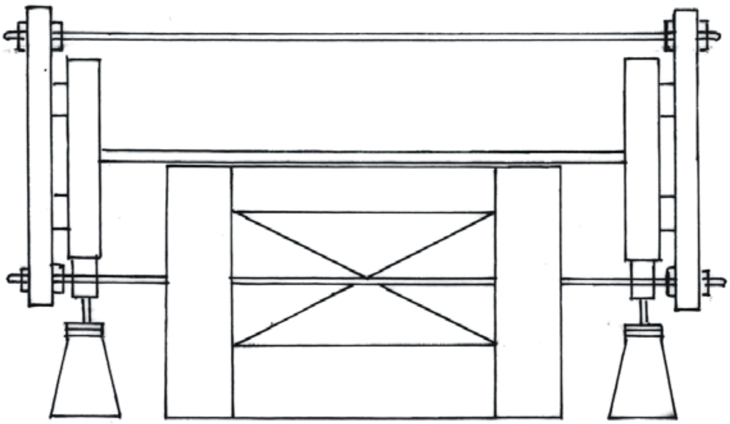


Fig 5.28 ASSEMBLY FIXTURE

In the fixture, firstly the positions of web plate connection are marked with chalk and string on the inner side of top and bottom plates. Both top and bottom plates are then kept vertically in fixture at required distance depending on depth of girder (or width of web plate). Web plate is placed in the fixture horizontally, matching the chalk marks made on the top and bottom flange plates and adjusted with help of screw jacks. At proper position, the web/flanges are clamped as shown in Fig 5.29.

Fig 5.29: Tack Welding of Plate/ Composite Girder

Following checks are necessary to be carried out before tack welding:

(i) Check that top and bottom flange plates are perfectly vertical and web plate in horizontal position with coinciding marked position throughout the length of 'I' section to avoid any displacement of vertical axis of the web with reference to flange.

(ii) Check the square ness i.e. 90° angle between flange and web of top and bottom flange plate to avoid out of squares flanges.

(iii) Check the outside to outside distance of top flange to bottom flange at regular interval to ensure that depth of girder at ends and at centre is same.

(iv) Check with filler gauge throughout the length of top and bottom flange plate connection that there is uniform contact throughout the web plate.

The 'I' section should then be tack welded by qualified welder approved in WPQR by MMAW process with electrodes confirming to IRS M28, A3 grade, in flat position. Fillet weld of 50mm length at interval of 500mm for top and bottom flange shall be made. Entire 'I' section shall be turned upside down for tack welding other side at staggered locations after once again checking all the items mentioned above.

5.3.8.4 Tack Assembly of members for Open Web Girder Members: In case of open web girders, the tack assembly is done using fixtures to hold the individual plates in position so as to get the proper shape of member. The main members of the open web girders are slender and the main problem in tack assembly come in getting proper fit along the length of the members for which extra care in planing/grinding the edges as already mentioned for plate girders has to be ensured. Tack assembled component shall be placed in fixture properly in one level throughout length and width. The stringers and cross girders are similar to plate girders albeit with lesser lengths and these can be tack welded on similar lines as in case of plate girders.

5.3.8.5 Tack Assembly in case of Riveted girders: In case of riveted girders also, tack assembly is done before hole drilling is taken up so that the members do not shift during drilling of holes.

The precautions to be taken in MMAW to ensure good quality are given in Annexure II of this book.

5.3.9 Full welding: Tack welded members of welded girders are shifted to jig and fixture or manipulator for full welding after thorough cleaning of web and flange plate.[8] Minimum width of 75mm to 100mm throughout

[8] Riveted girders will go to initial assembly and hole drilling section.

the length shall be cleaned to ensure that the surface is free from dust, mill scale, grease, oil and paint to ensure sound quality of weld.

5.3.9.1 Position of welding: Full welding shall be carried out in flat position with SAW process as per sequence mentioned in WPQR (shown in Fig 5.30(a)) using manipulators or special welding fixtures. Welds in inaccessible locations or minor welds shall be made by CO_2 welding, shown in fig 5.30(b) below, if approved in WPQR.

(a) **(b)**

Fig 5.30(a): Full Welding by SAW in progress; (b)CO_2 welding in progress

5.3.9.2 Welding plate girders: The most important welding in case of plate girders is the one connecting the flange plates with the web plate. This weld is fillet weld and has to be done on either side of the web plate at top as well as bottom. If only one welding set up is available, the best position for this weld is flat position for which the girder shall be kept at 45^0 angle and the machine shall be set as shown in fig 5.31. The 45^0 angle helps in getting equal leg lengths of the fillet welds.

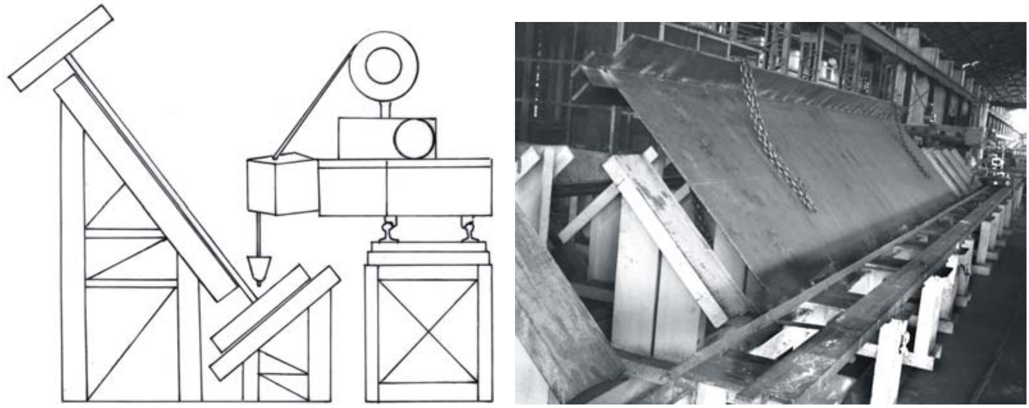


Fig 5.31: Plate girder on fixture for SAW welding of the fillet weld between web and flange plates

The sequence of welding shall be as shown in fig. 5.38, marked ‘1’, ‘2’, ‘3’ and ‘4’ in the order of welding. If multiple passes are required to make a weld, the sequence shall be repeated. If two welding setups in single machine or two machines separately are available, the “Double Head Welding” can be taken up. The double head welding can be done in two ways:

i) **Girder laid flat:** In this method, immediately after tack welding, the two welds marked ‘1’ on one side are taken up (Fig 5.32) before the girder is turned over for making welds marked ‘2’ on the other side. In this method, the welds are made in flat horizontal position only and need for turning over is minimized.

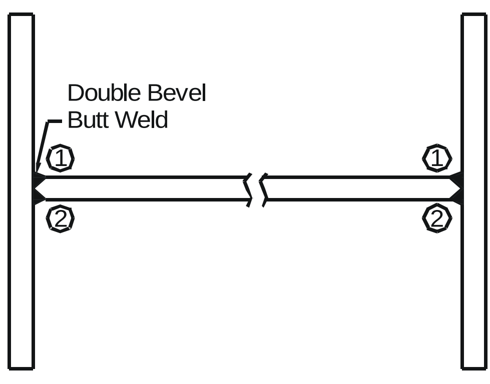


Fig 5.32: Application of Double Head Welding in girders laid flat

ii) **Girder in Vertical Position:** In this method, the girder is removed from the fixture after tack assembly and fixed in appropriate manipulator for the welding. The welding of both welds in one flange marked '1A' and '1B' are made simultaneously ensuring that there is a gap of 600 mm between the two heads on either side of the web as shown in fig 5.33 below. The girder is turned over and other two welds marked '2A' and '2B' are made similarly. The maximum size of weld in a single run in this case shall be limited to 6 mm only.

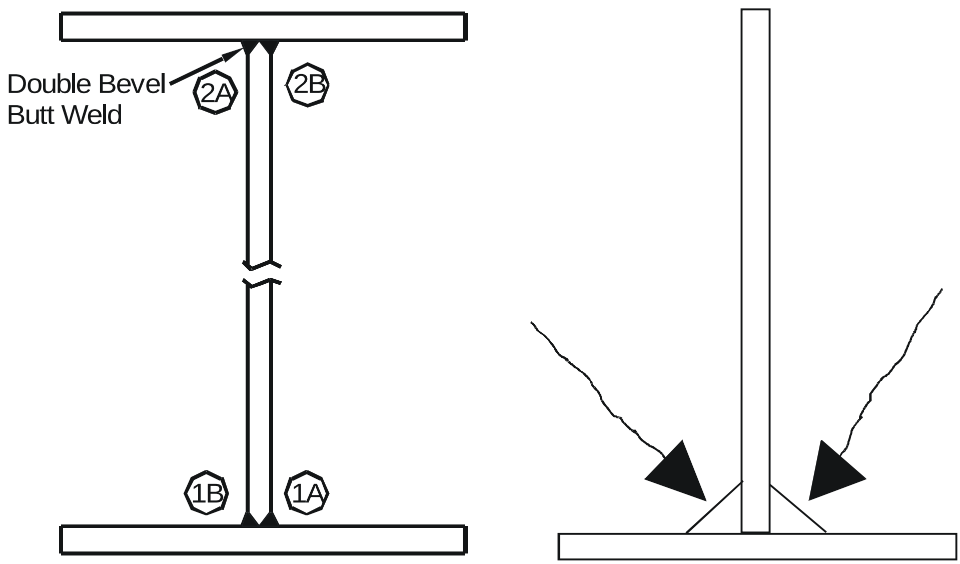


Fig 5.33: Double Head Welding from either side simultaneously in girder laid vertical

The welding has to be done in proper sequence and the girder is required to be turned over after each pass of welding and the fixture shall be set at an area where EOT Crane is available since this is most convenient way of turning the girder over. Care shall be taken as to not damage the girder during turning over.

Other type of welding which may sometimes be done in plate girders is the butt welding. As discussed earlier, butt welds are best avoided as these are subjected to direct stresses and any small defect will reduce the fatigue life of girder greatly. These welds have to tested radiographically for soundness. If the butt welds are used, **cope holes may have to be provided.** A cope hole is a semi circular notch used to disconnect junction of welds. Cope hole is shown in fig 5.34.

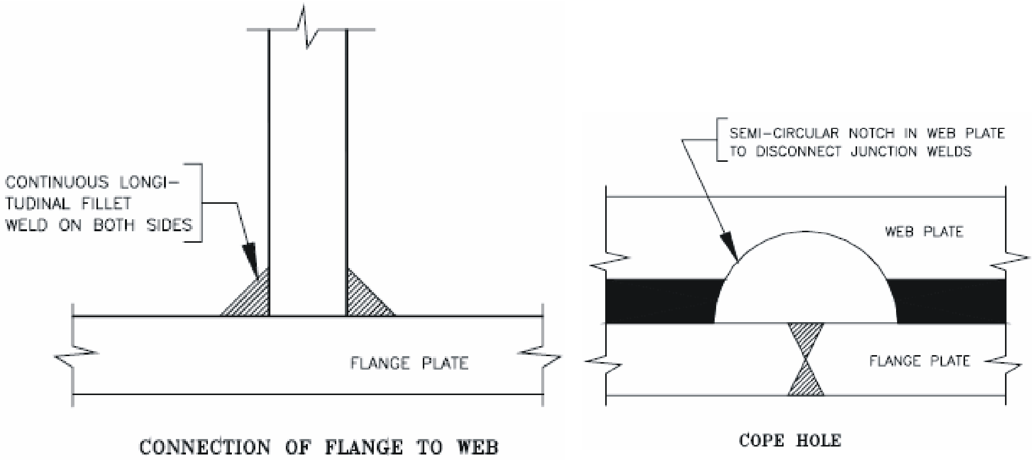


Fig 5.34: Cope hole at the junction of web-flange weld and the flange splice

As per clause 9.2 of WBC, Cope hole in welded girders is not required when the following conditions are satisfied;

i) Butt welds in flanges and web are made by automatic sub-merged arc welding prior to assembling web and flanges together,

ii) Weld reinforcement is dressed flush both at top and bottom by grinding/machining and

iii) Weld is tested by radiographic/ultrasonic method.

The above conditions are normally met with in the workshops and the cope holes are not usually provided.

5.3.9.3 Welding of Composite Girders: In addition to the welding in the main girders, the shear connectors are to be welded in composite girders. The shear connectors transfer the bending shear load between the RCC top flange and the steel girder and also ensures the composite action of the two dis-similar materials. Good quality welds are important and any problems in the welds can create distress in the girders. The shear connectors normally provided in composite girders are of two types:

(i) Channel Type Shear Connectors: In this type of shear connectors, channels are welded on the top flange of the girder. The welding of shear connectors shall be done by CO_2 welding. Fig 5.39 shows channel type shear connectors welded on a composite plate girder. Welding of these shear connectors with top flange before the girder is tack assembled.

(ii) **Stud Type shear connectors:** In this type of shear connectors, steel rods or studs are welded on the top flange of the girders. The welding shall be done all round the stud and this cannot be satisfactorily done by SAW or manual methods discussed earlier. This welding has to be done using Stud Welding Guns available in market and as shown in the fig 5.35 below. The heat input in stud welding gun is much less than in other processes, and the shear connectors can be provided after complete assembly and welding of the girder.

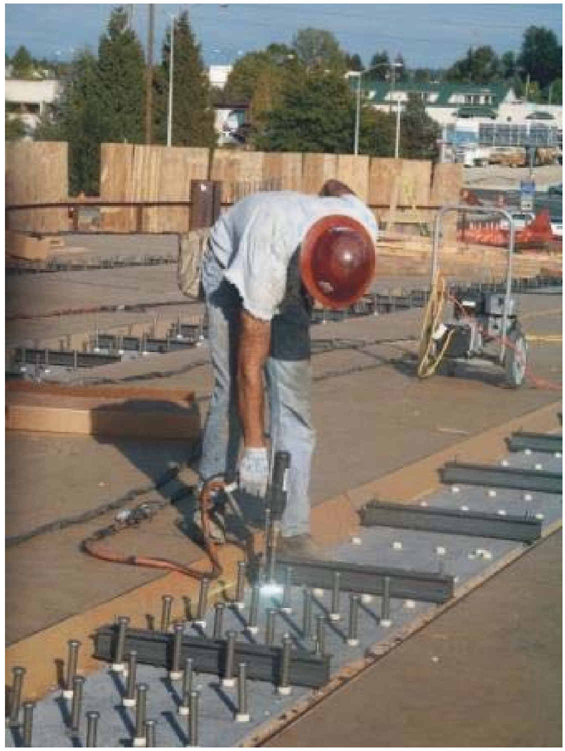


Fig 5.35: Welding of stud type shear connector with Stud Welding Gun

The welding shall be done in composite girders in down hand position only. The weld made by stud welding shall be subjected to the following tests:

- **Appearance Test:** The welds shall form a complete collar around the shank and shall be free from cracks, excessive splashes of weld material, free from injurious laps, fins, seams, twist, bends and other injurious defects. The weld material shall have 'Steel Blue' appearance.
- **Ring Test:** The head of stud shall be struck with a 2 Kg hammer. A ringing sound achieved after striking indicates good fusion whereas dull one indicates a lack of fusion (BS 5400-6).
- **Bend Test:** Head of a stud shall be displaced laterally by approximately 25% of the height using a 6 Kg hammer. The weld shall then be checked for signs of cracking or lack of fusion.

Note: 1. The stud shall not be straightened back as this is likely to damage the weld.

2. Testing shall be done @ 1 in 50 (BS 5400-6)

5.3.9.4 Welding components of Open Web Girders: There are two types of fabrication of open web girders. The stringers and cross girders are similar to the plate girders except that these are shorter in length and hence, easier to make. The welds in main members of open web girders are all fillet welds for stitching the members together. Cross section of some of the different type of members which are fabricated by welding are shown in fig 5.36 below:

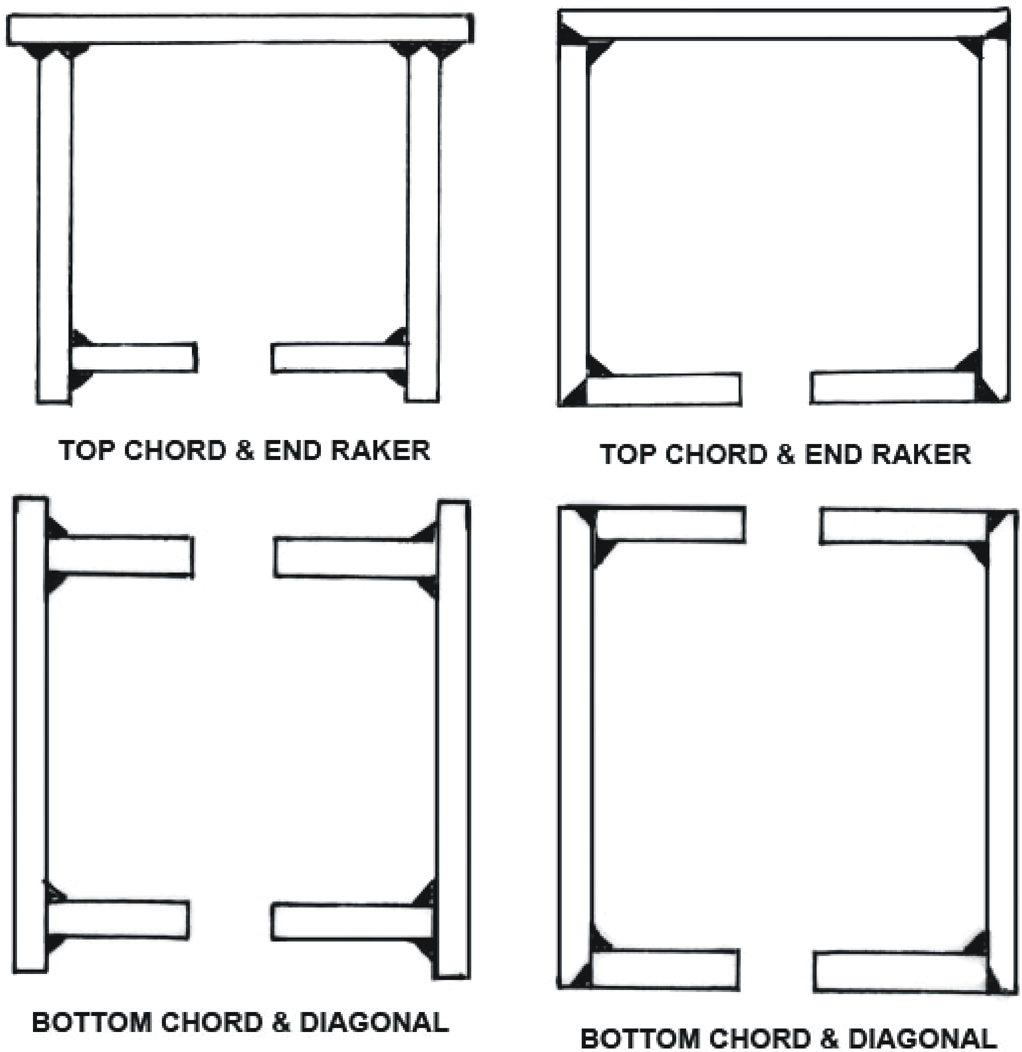


Fig 5.36: Typical main members of open web girders

The welding sequence shall be such that all welds can be made satisfactorily. If there is any problem in making welds, when the first drawing is received, matter may be brought to the notice of the designer and a request may be given to change the dimensions from welding feasibility angle. The battens and lacing etc are either welded or riveted as per detailed drawing in the case of welded girders.

5.3.9.5 Prevention of Distortion During Welding: Since welding is an activity which imparts large quantity of heat in the members, the members get distorted during welding and cooling thereafter. Fig. 5.37(a) shows a web of a member distorted during welding.

Fig. 5.37 (a): Distorted web of an I section

During welding, the distortion shall be checked regularly using straight edge as shown in fig 5.37(b)

Fig. 5.37 (b): Measurement of distortion on top flange

Distortion shall be minimized by taking various steps, such as:

i) Welding shall be done in minimum number of passes and maximum possible weld size shall be built up in each pass to minimize heat input. The method which imparts less heat to the members shall be preferred to reduce distortion.

ii) The members shall be pre-heated to reduce the heat gradient. As per clause 6.2 Note(2) of WBC, where the thicker part is more than 50 mm in case of steel to IS: 2062 special precautions like pre-heating as per IS: 9595 shall be taken to ensure weld soundness. This will also reduce the tendency of the steel section to develop cracks during welding.

iii) Clamping of members to forcefully restrain it from deforming during welding

iv) Pre-bending members in opposite direction to the one in which the distortion occurs so that the final member is fabricated properly.

v) Proper sequence of welding shall be followed. The heat input during welding in one step shall be compensated by the heat input given in the welding in the next step. For example, in plate girders, the sequence of welding when one head is used shall be as given in fig 5.38. The sequence of welding where double heads are available has been given in para 5.3.9.2 above.

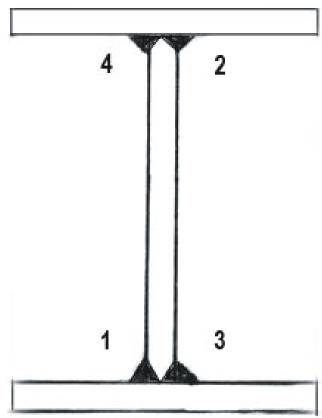


Fig 5.38: Sequence of welding in plate girder with single SAW

If multiple passes are required to gain the full size of welding, the above sequence shall be repeated and after each weld, the girder has to be turned over.

vi) Thinner members shall be welded before the thicker members are welded. The thinner members get distorted more than the thicker members but these can also be corrected more easily. Therefore, after welding thinner members, we can rectify any distortion before the thicker member components are welded.

5.3.9.6 Prevention of distortion in Plate Girders: The plate girders have long welds connecting the flange plates with the web plate and the size of these welds is also more to transfer the bending shear between the flanges and web. Large amount of heat is input in these members during welding and appreciable distortion will occur unless steps are taken to minimise the same. The steps which can be taken to reduce the distortion in this case include:

(i) Pre-bending of flange plates in opposite direction which requires special machine, may be done so that drooping due to welding restores the flange to acceptable geometry **(Fig. 5.39).** The amount of pre-bending required shall be decided by trial and error so that the girder is fabricated within tolerances for drooping (As per item 4 of Appendix II of IRS B1, maximum drooping shall be 1/200 or 3 mm maximum from edge, whichever is less)

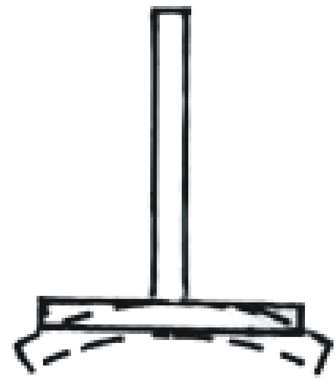


Fig. 5.39: Pre-bent shape (shown dotted) to get proper shape (shown solid) of bottom flange

(ii) Another method by which it can be prevented is by clamping the flange plate to fixture or manipulator during the welding. (Fig 5.40). Clamps are provided such that these allow longitudinal movement of plate[9] (as 5mm gap is provided between edge of flange plate and bolt with elastometric pads provided on top) but will prevent vertical lift beyond tolerance.

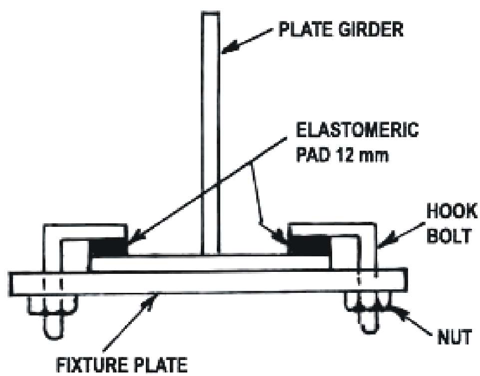


Fig 5.40

5.3.9.7 Prevention of distortion in Composite Girders: In addition to the precautions mentioned above, the distortion in the composite girders can be prevented by welding all the shear connectors on the top flange before the plate girder is welded (Fig 5.41). The welding of the shear connectors on top flange plate shall be done symmetrically starting from the center towards the supports. There will be some distortion of the plate which can be corrected by pressing the same in hydraulic press before the same is welded to the web plate. Use of stud welding gun minimize the heat input to the girders and also helps minimize the distortion.

[9] Longitudinal movement of plate is essential to avoid locked up stress in weld zone and HAZ.

Fig. 5.41: Channel Type shear connectors already welded when the main welds are taken up.

5.3.9.8 Prevention of distortion in Open Web Girders: Similar precautions must be taken in open web girder component welding. However, it must be said that members of open web girders are lighter and are easier to weld. The weld sizes are also less and hence the distortion can be controlled/ rectified more easily as compared to the plate/ composite girders. Precautions similar to the plate girders are, however, required during fabrication of stringers and cross girders. An arrangement to ensure proper geometry of a welded BOX section of an open web girder is shown in fig. 5.42 below.

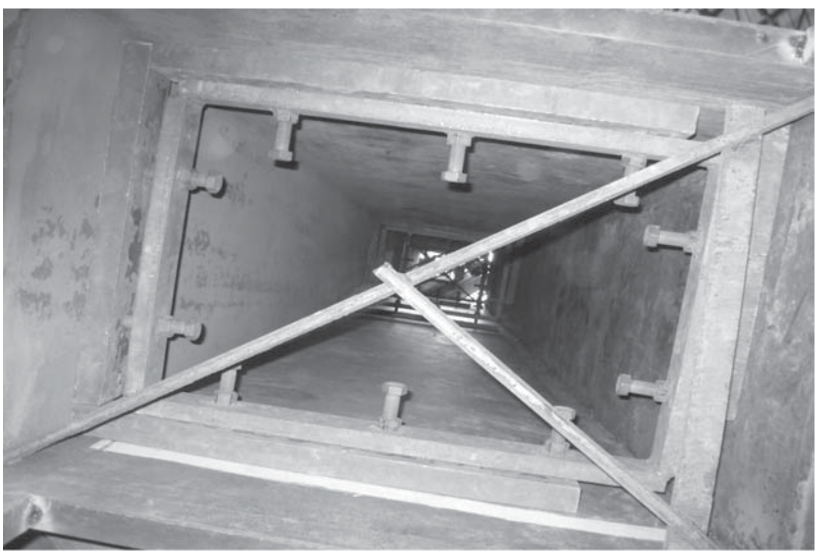


Fig. 5.42: Fixture to control distortion of BOX section

5.3.9.9 Rectification of distortion: Major distortion in members will render these unrectifiable and non usable. However, minor distortions can be corrected by using force from jacks, straightening machine etc. in a manner without damaging the member. Fig. 5.43 (a) and (b) below show the correction of distortion in progress. Special care is required in welding thicker plates like 50mm/63mm. If these plates distort, the force required for correction of distortion might not be available in the workshop.

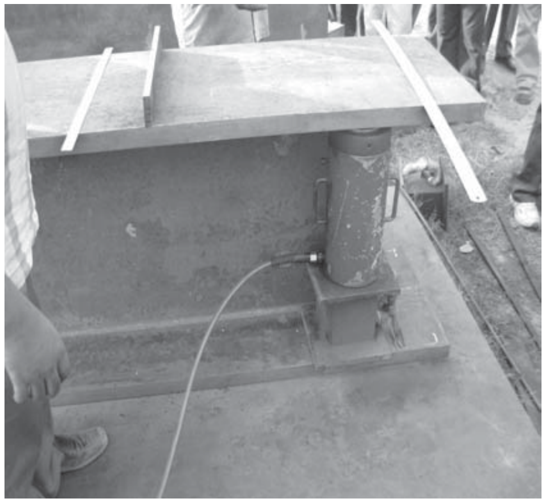


Fig. 5.43(a): Hydraulic jack being used for distortion correction in top flange

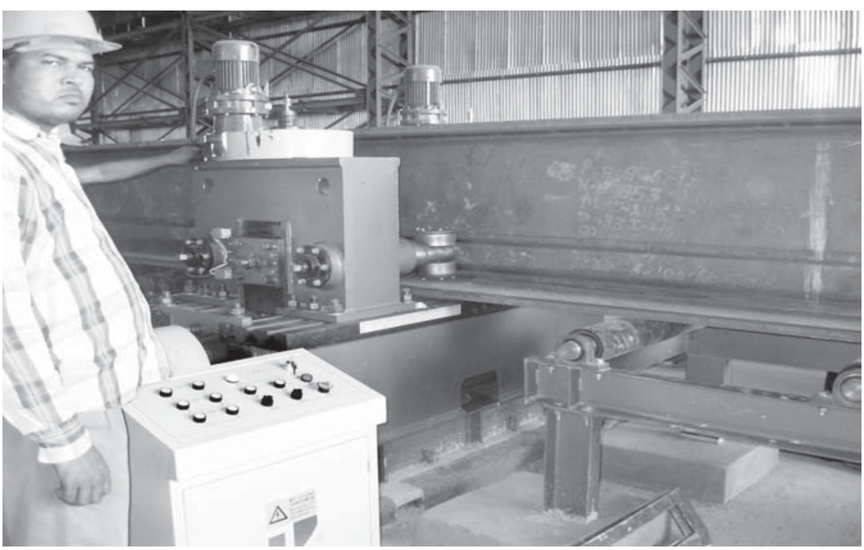


Fig. 5.43(b): Distortion correction using straightening machine

5.3.9.10 Precautions to be taken by Welders in SAW welding:

To get good quality weld by SAW process, the welder must ensure that

Before Welding:

- Run-on and run-off pieces are properly provided on either end of top and bottom flange.
- The SAW equipment is set properly as per WPQR with appropriate
  a) Current
  b) Arc Voltage
  c) Wire feed
  d) Travel speed of equipment
  e) Electrode Stick out
- The flux and wire combination conforming to IRS M-39 for submerged arc welding as stipulated in WPQR applicable is being used.
- Electrode Wire coil is fixed in machine after inspection to ensure no dent / bend or rust stain is there in the wire.
- Cleaning of 75mm width of flange and web plate on either side of the joint has been properly done. Best method is oxy-acetylene-flame cleaning which will ensure perfect cleaning as well as warm surface to ensure sound weld.
- Flux is dried in oven to temperature 200-250°C for one hour before use.[10]
- All gauges of equipments (to monitor parameters during welding) are in working order.

During Welding:

- Start welding on run-on piece.
- Ensure that the flux lid is open and flux shall be poured ahead of welding nozzle.
- Welder shall ensure that variation of parameters during welding (over the WPQR) shall not exceed the following limits:

  Welding current ± 10%

  Arch voltage ± 7%

  Speed travel ± 15%

[10] This is very essential as any slight moisture will cause embrittled hydrogen crack in weld or HAZ after cooling.

After Welding:

- After completion of weld, welding is stopped on run-off piece.
- Entire flux is removed by suction after allowing 10 to 15 minutes cooling.
- Slag is removed carefully without any injury to the weld
- The surface is cleaned with brush afterwards.
- As per clause 5.7 of WBC, before shifting, run-on and run-off plates are removed by abrasive cut or hacksaw blade to avoid thermal stress.
- Check the weld for surface defects using NDT methods.
- Inspect the weld size with appropriate gauges.
- Check any variation in shape of member during welding. (If the member is distorted, it can be sent to the straightening section for rectification. It may, however, be remembered that the straightening can be done in smaller members only and that too for small amounts of distortion. If member is large, the force required is excessive and might not be available. If the member is too distorted, the straightening will induce too much stresses in member and lead to its early failure in service.)

Note 1: *While making a long fillet weld, if due to any reason, power supply is abruptly cut off, end of weld to 50mm distance back side shall be removed by gouging or grinding machine to tapering thickness and the surface shall be cleaned thoroughly with wire brush. DPT shall be carried out to ensure no cracks exist. Then weld shall be re-started from 50mm back side (which is removed) and then continued further by SAW process.*

5.3.9.11 Testing of Welds: Welds shall be subjected to the following tests:

- **Visual Examination:** All welds shall be visually examined to ensure that the welds meet the specifications as given in Appendix C of WBC.

Dimensional Tolerances: All welds shall be checked for dimensional accuracy as per Appendix B of WBC. Suitable gauges shall be made to check the welds. The gauge and method of checking welds is shown in para a2.8, Annexure II of this book. These shall be used for checking the weld dimensions. It may be remembered that an undersize weld is not good as it will not develop adequate strength required from the joint but, contrary to what some engineers believe, the oversize welds are also bad for the structure. These might be strong enough in isolation, but can cause failure of the steel members nearby and may turn out to be ultimately deleterious to the overall health of the structure even though extra material is being put in such welds. Therefore, proper size of welds must be ensured while welding. Also, improperly formed welds shall not be accepted.

In addition, Macro Etching Test shall be done at the edges of welds especially in run on and run off pieces cut after welding to verify the fusion of the weld with parent metal and the complete profile of the weld. Fig. 5.44 shows cross section of a fillet weld which has been macro-etched.

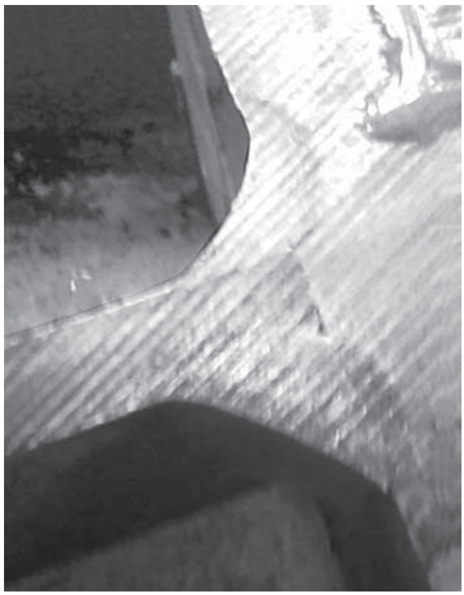


Fig. 5.44: Macro Etching of the weld after the run-on/ run-off pieces have been cut by hack saw

- **Radiographic Testing:** All the “Butt” welds shall be cleaned and additional throat thickness shall be ground. Thereafter, Radiographic test shall be carried out. If joints are passed and approved, same is recorded in Radiographic inspection register (as per detail item 6 of Appendix 1 of IRS B 1-2001). After approval only, the butt welded plates shall be used for tack weld for ‘I’ section.
- **DPT/ MPT:** All fillet welds shall be checked by Dye Penetrant Test (DPT) or Magnetic Particle Test (MPT): One defect found by the DPT is shown in fig. 5.45(a) below. The defective weld area shall be ground off, removed and the further welding shall be done to repair the area carefully. One defective weld area repaired is shown in fig. 5.45(b).

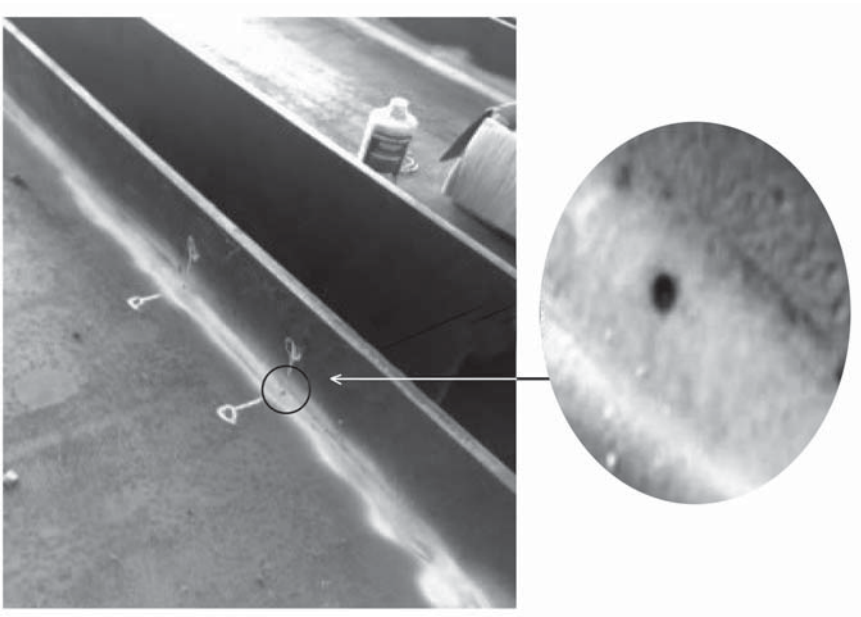


Fig. 5.45(a): Defect found during DPT testing of welded joint

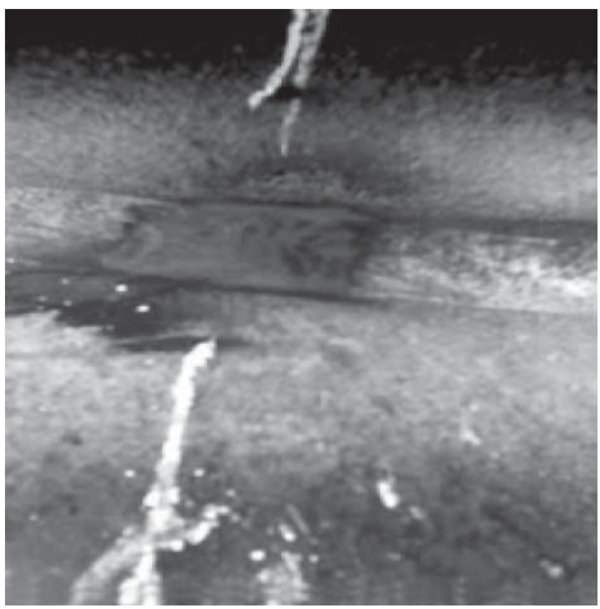


Fig. 5.45(b): Repaired weld

5.3.10 Drilling of holes: After the welding work is complete, holes as required are made in the members. The holes are required for the gussets in open web girders, for splices in field, for intermediate stiffeners etc. The holes are not made before welding as otherwise there can be stress concentration due to heating of the member during welding and cracks can develop at the periphery of the holes. For making holes, working gussets and member jigs described earlier shall be used. The jig shall be clamped to fixture and the component being fabricated to ensure no shifting during handling and drilling. After jig fixing is completed, an experienced Section-in-Charge shall check the jig on job thoroughly for correct placement and levels and sign the register to that effect to comply with clause 13.1 of IRS B1. Jig handling and fixing in this section dictates the accuracy of fabrication. The components are long and heavy hence after placing in jig and fixture it will be slow and cumbersome to shift job after drilling each hole. Therefore, radial drilling machine with trolley arrangement is preferable.

Note: *Before fixing jig to member, all bushes (welded on holes) in jig shall be checked for accuracy (to be within tolerance). The tolerance shall be checked from time to time and when the bores exceed a tolerance of, -0mm, +0.4mm, the bushes shall be rejected. For this purpose, go and no-go gauges are to be used. Tolerances for checking jigs from master plates shall be +0mm, -0.13mm.*

This can be checked with help of GO & NO-GO type of plug gauge for 23.5 mm diameter hole shown in fig. 5.46 having a tolerance of + 0.4mm / - 0.13 mm.

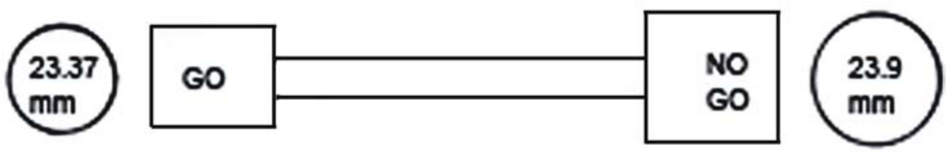


Fig 5.46 GO & NO – GO PLUG GAUGE

GO end of plug gauge is accurately turned to the hole diameter to be checked. If this goes in the jig hole, it means that the diameter of the jig hole is OK. NO GO end plug gauge is accurately turned to 23.9mm (for 23.5mm dia hole) so that this end should not go in bush (which means hole shall be less than 23.9mm). If NO GO end enters bush hole, bush has to be replaced with a new one.

Fig. 5.47 (a) to (c) below show the drilling in different members in progress.

Fig 5.47(a): Drilling with radial drilling machine in progress

Fig 5.47(b): Working Gusset being used for drilling of holes in gussets.

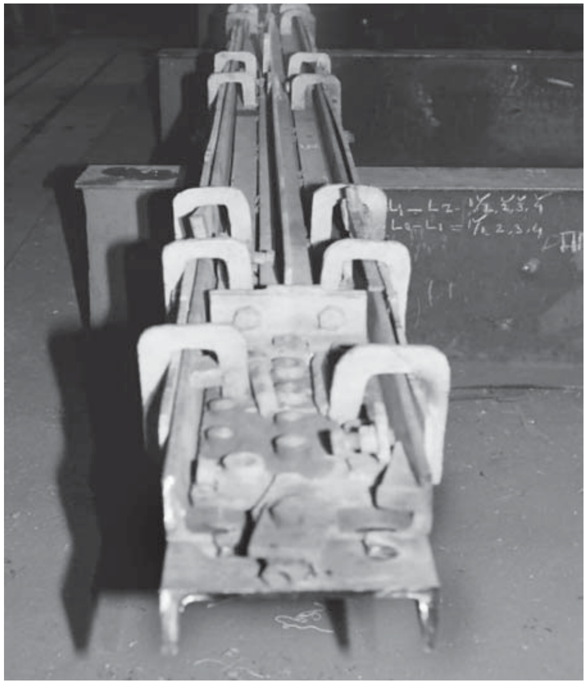


Fig 5.47(c): Jig mounted on member for drilling of holes.

The holes normally used are 21.5 mm dia for the workshop rivets and 23.5 mm for the field rivets. In addition, 17.5 mm/ 19.5 mm dia holes may be used for the bracing and secondary members. The following precautions shall be taken to ensure that the holes are made properly in members:

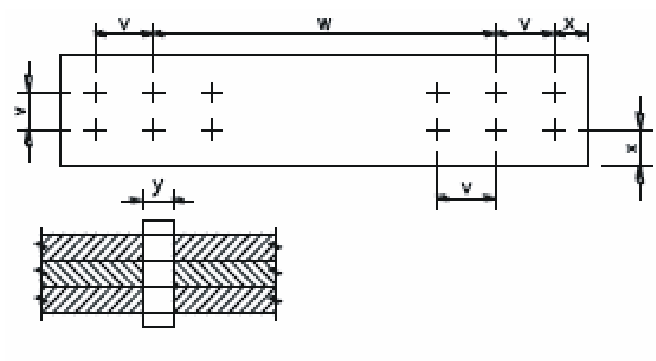
- The jig shall be held properly against the member by suitable clamping. There shall be no gap between the member and the jig and there shall be no possibility of the slippage of jig.
- Placement of jig and fixture in one level on trolley must be ensured. Drilling machine shall be properly set and shall move vertically over the member, else the holes will not be made at the proper location.
- The side from which holes are made shall be marked on the member fabricated for ease of assembly at site.
- The different dia holes shall colour coded in the jigs and while making holes, it shall be ensured that the wrong dia drill bit is not put in wrong bush otherwise the drill bit/bush /member can get damaged.
- A few random holes shall be first made and turned bolts shall be tightened in these to hold jig with the member.
- All holes shall be made in one go after the jig has been set. If some holes are left out, it will be very-very difficult to set the jig again at

precisely the same location. The fabricator shall, therefore, take extra care to see that no hole is left inadvertently before the jig is opened out.

- During drilling of holes, the borings shall be removed frequently especially while drilling holes in thicker section.
- Proper coolants are used while drilling to avoid wearing and over heating of bushes/drill bits.
- After drilling is completed, the match marking to guide the assembly shall be made. In this, the complimentary parts shall be marked identically. The marking can be painted or, better, punch marked on the member at appropriate location.
- The holes shall be made to the following tolerances as per Appendix II of IRS B1:

Holes-					
	(a)	Between any two holes in group	0.5	0.5	v
	(b)	Between holes of one group and another	1	1	w
	(c)	Edge distance	0.5	0.5	x
	(d)	Distance of 'GO' gauge open holes in two or more thicknesses	0	0.8	y
(On nominal diameter of hole)					

The dimensions v,w,x and y for the holes given in last column above are defined as follows:



HOLES IN MEMBERS

- Interchangeable parts shall be match marked identically.
- After every one span component drilling, jig shall be checked with master gussets fixed on both ends for intersection cambered lengths. This will ensure accuracy of fabrication to required standard.

5.3.11 Initial Assembly[11] : For riveted construction, after drilling and removal of jig, temporary tack welded member are brought to this section. In this section, the following activities are undertaken:

- Dismantle all tack welded components of member after match marking to help assemble back to same form and location. The dismantling shall be done carefully as to not deform / damage the members.
- All hole surfaces should be ground by grinding machine to remove burrs formed during drilling, especially at mating surface to ensure dead contact.
- Entire mating portion which are to be in contact permanently shall be cleaned of rust, mill scale and one coat of red oxide zinc chrome primer to IS: 2074 shall be applied. This is very important activity and will ensure sealing of mating parts and will prevent entry of water or moisture and help to prevent corrosion in hidden parts during entire life of the girder.
- With help of assembly fixture members are formed to final shape. Provide 50% service bolts and drifts at alternate hole (35% bolts + 15% drift) to ensure the provision of clause 19 of IRS B1. Clamping force is exerted by service bolts and alignment is provided by drifts will ensure proper fabrication. Fig 5.48 shows an initial assembly fixture.

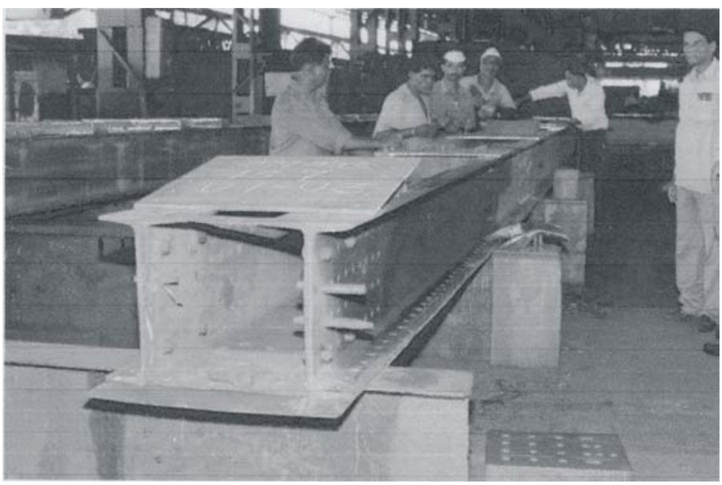


Fig 5.48 Initial Assembly

- Assembly fixture shall ensure co-axiality of field holes in both opposite components of chord.
- Now members shall be shifted to riveting section after 100% tightening of service bolts with impact wrench.

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[11] Welded girders might not be required to go to initial assembly section and riveting section if there are no rivets to be made. The flow of material shall be altered accordingly.

5.3.12 Riveting: The riveting shall be done as required in the members. Even in welded plate girders, riveting has to be done in intermediate stiffeners. All stiffeners are fixed and riveted properly in workshop itself. (See Fig 5.49). The fillet weld of main girder infringes the angle used as intermediate stiffener and for proper fitting, the root at end of angle has to be cut and machined. The procedure for riveting and care to be taken to ensure good quality rivets is given in Annexure IV of this book.

Fig. 5.49: Intermediate Stiffeners-Riveted in Welded Plate girder

5.3.13 Final finishing: Final finishing includes milling (grinding) of the ends of splices, removing burrs from the holes (See fig 5.50) and checking for any problems in the finally fabricated members/ girders.

Fig 5.50: Grinding for final assembly in progress

End profile of members of truss shall be machined by end milling machine (See fig 3.8). Particular care shall be taken in case of compression members to meet the provisions of clause 16.4 of IRS B1 which states: "*The butting ends of all booms and struts where spliced shall be faced in an end milling machine after members have been completely fabricated. In the case of compression members the face shall be machined so that the faces are at right angle to the axis of the members and the joint when made, will be in close contact throughout. At the discretion of the Inspecting Officer, a tolerance of 0.4mm may be permitted at isolated places on the butting line.*"

The dimensional tolerances shall be finally checked as per Appendix II of IRS B1. The tolerances after assembly for plate girders and for open web girders are given in para 4.9 chapter IV of this book. The fabrication shall be done such that these tolerances can be met with. Some tolerances exclusively to be checked during fabrication stages are given in fig. 5.51 and 5.52 below:

4 Special Fabrication Tolerances as applicable to Welded Plate Girder.		
	Description.	Tolerances in mm
1.	Depth at the centre of web	+2 to -1
2.	Flange out of square for compression member and beams	1/200 or 3 max From edge whichever is less.
3.	Displacement of vertical axis of the web with reference to flange.	2
4.	Box width of member	0 to +3
5.	Verticality of stiffener or diaphragm out of plumb.	2
6	Overall length of girder	+ 6 to -3
7	Depth of the girder at the ends	+ 3 to -1
8	Depth of the girder at the centre of span	+ 2 to -1
9	Distance between centre of bearings	+ 1 to -1
10	Diagonal at either end of assembled span	+ 3 to -3

Fig. 5.51: Tolerances during fabrication

11 An allowable limit for web buckling or undulation shall be flatness at right angles to plate surface measured parallel to longer side in either direction calculated from the formulae

$$\Delta_x = \frac{G}{165}\sqrt{\frac{\sigma_y}{355}} \quad \text{or} \quad 4\text{mm which ever is the lesser.}$$

Where

Δ_x = Maximum deviation from straightness within a specific gauge length other values are constant

σ_y = Yield stress of steel in N/mm^2

G = length of measuring gauge in meter

(G= a where a<2b and G=2b where a>2b)

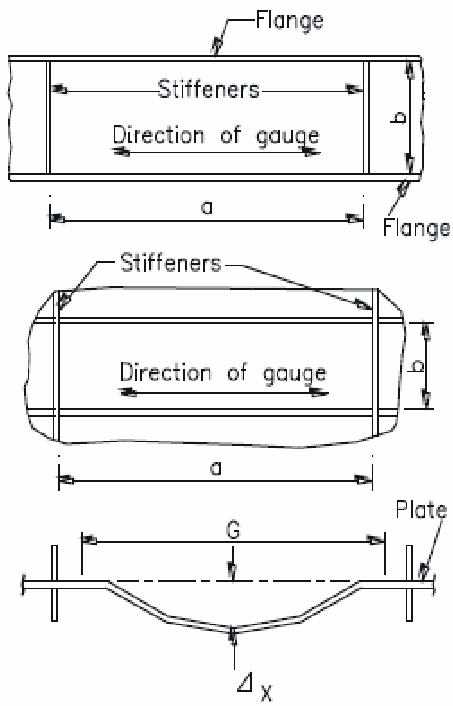

Fig. 5.52

5.3.13.1 Trial Assembly: For first span of any fabrication, made with new jigs, trial assembly in workshop to ensure correctness of fabrication within tolerances is a must. As per clause 33.2 of IRS B1, the interchangeability of the members shall be established by trial assembly. If the interchangeability has not been established, all the spans must be erected complete and all parts marked to their place. The procedure for erecting a girder on ground for trial assembly in workshop or in field before launching is given in detail in Chapter IV of this book.

5.3.14 Painting and dispatch: After the girder/ components are approved from quality control point of view, the parts shall be sent for painting or metallizing. The detailed specifications for painting/ metallising are given in Annexure V of this book. During painting, the match marking and part numbering etc shall be preserved. While dispatching a girder/ components, the shipping list shall be prepared. The shipping list shall indicate the parts, numbers and the identification markings on the members for the guidance of the field engineers during assembly. The shipping marks shall be at least 100 mm high or as high as the size of the member will permit.

The following care shall be taken in dispatch:

- During dispatch, proper part numbers in sets for fabrication of girders shall be ensured.
- The bigger parts shall be sent in trailer or railway wagons whereas smaller/ loose parts shall be sent properly packed in covered vehicles.
- During loading, care shall be taken to handle the material carefully to avoid damage by bending/ hitting.
- Between different members loaded one over other, suitable wooden packing shall be inserted to avoid damage to members.
- The members shall be secured properly so that these do not shift in transit.
- The holes of the members shall not be used for fixing tackles, wire ropes etc lest the holes get damaged. The holes may be used for handling girders only if it can be ensured that these will not be overstressed. It would be a good idea to use special fixtures that attach to a number of holes to avoid this type of problem.

Note: *After dispatch, if there are any problems during assembly, the fabricator shall associate and even go to the field to understand the reason for problems. If the fabrication is done properly with templates, most common problems faced are due to wrong match markings, match markings not visible, grinding not done properly to remove burrs and wrong dispatch of* *parts. Other reasons for the problems include mishandling of members in transit and wrong assembly methods. But, the fabricator must get a feedback if any step in fabrication or assembly or dispatch requires improvement.*

5.4 RDSO Inspections: As per clause 27.1 of WBC, inspection of the welded bridge girders carrying rail or rail-cum-road traffic whether of completely welded type or partially welded type except for foot over-bridges shall be entrusted to RDSO. Accordingly, **RDSO shall undertake inspection for the first 1000 tonnes of welded plate girders** after which the inspection shall be taken over by the respective zonal railways**. The inspection of all triangulated welded girders shall continue to be with RDSO.**

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ANNEXURE - I

DESIGN CONCEPTS FOR RAILWAY BRIDGES

a1.1 Basic assumptions for design of Steel Girder for Track Bridge:

Most of the steel girders for track are simply supported on Indian Railways. These have the following features/ assumptions:

- When loaded, spans deflect (steel being elastic material) downwards and rotate at supports.
- Shear force is maximum at the support and Zero at the middle of span.
- Bending moment throughout the span is positive and maximum at middle of span (same location where shear is zero). Bending moment is zero at the supports. (Fig a1.1)

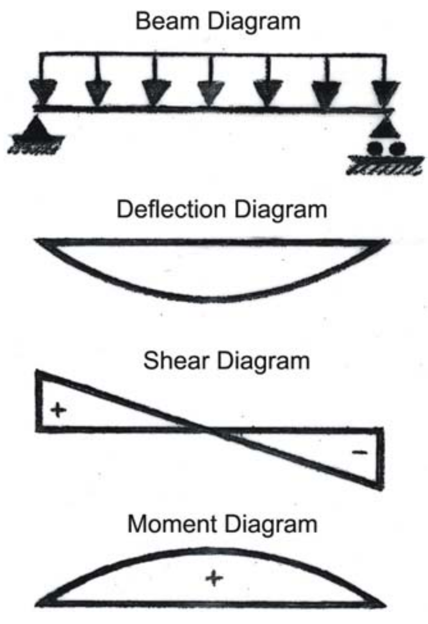

Fig a1.1 Typical action of simply supported span

a1.2 Deflection Control:

Clause 4.17 of SBC stipulates that designer has to ensure deflection for foot over bridge truss shall not exceed L/325 i.e. deflection to length of span ratio shall be less than L/325. For Track Bridges, the ratio of deflection to length of span shall not exceed L/600.

With the specific sanction of the Board, the limit of 1/600 may be exceeded for girders in permanent installations.

The deflection of girders can be changed by adjusting truss height or providing more cross sectional area in chord members.

a1.3 Proportioning of members in Open Web Girders: The open web girders are designed with certain assumptions, as per clause 3.3.1 of SBC:

1. All members are straight and free to rotate at the joints;
2. All joints lie at the intersection of the centroidal axes of the members;
3. All loads, including the weight of the members are applied at the joints.

The actual girders are not free to rotate at the joints as these are not pins but are riveted and are rigid. This is a violation of the assumption no 1 above. To ensure that the repercussion of this violation is not excessive in field, it has been laid down that the proportioning of the members shall be done such that these are slender. Under load, the joint may not rotate, but the members will rotate adjoining the gusset. **As per para 3.3.3 of SBC, the width to length ratio in plane of bending for chord members shall not exceed 1/12 of length and that for web members shall not exceed 1/24.**

a1.4 Fatigue consideration for fabrication of welded girder:

For steel structures subjected to heavy dynamic load, such as train loads, the major design consideration is **fatigue**. Fatigue means cracking of girders/members at a stress level lower than the yield stress. As per clause 3.6.1 of SBC, "Fluctuation of stress may cause fatigue failure of member or connection at lower stresses for dynamically loaded structure than those at which they would fail under static load".

The fatigue failure occurs due to minute metallurgical changes occurring under each application of the stress (called load cycle) which accumulate to cause the separation or crack. Number of cycles required at a stress range for initiation, propagation and formation of crack is called **fatigue life** of the member at the stress range. The fatigue life is defined by two factors:

(i) Magnitude of stress variation or stress range (S)

(ii) Number of Cycles (N)

The life of member is measured in number of cycles, which reduces as the stress range increases. A typical S-N curve is shown in fig. a1.2 below.

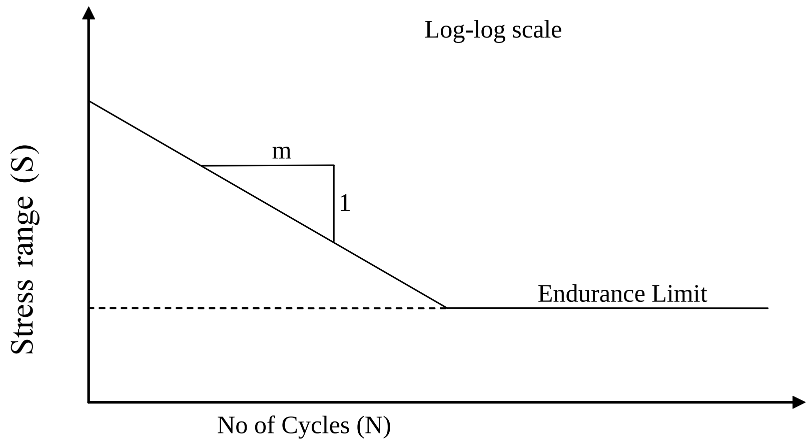

Fig a1.2: TYPICAL S-N curve

The slope of S-N curve (m) typically is -3 (can also be -5 for some stress ranges). This means that if stress range doubles (x 2), the number of cycles which the structure can take before fatigue cracks appear will reduce by one - eighth (x 2^{-3}). Due to the above behaviour of the structure under fatigue loads, uniform stress distribution, avoiding stress concentration[1] in the dynamically loaded structures is of paramount importance.[2] As we know, stress concentration occurs nears holes, connections, deflects in members etc. Fig a1.3 shows typical stress distribution with stress concentration around a hole/notch in a steel member.

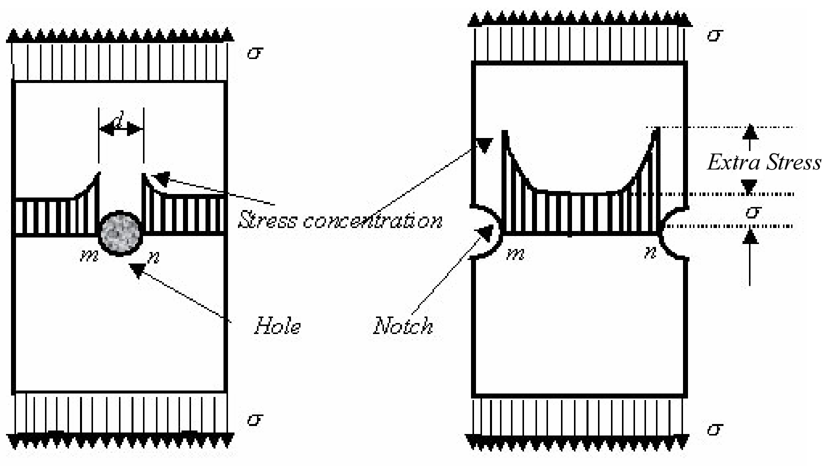

Fig a1.3: Stress concentration around a hole

[1] The term 'stress concentration' means increased local stress in a member due to the configuration features.

[2] The increased local stress due to stress concentration means higher stress range i.e. lower fatigue life.

The riveted connection necessarily means drilling of holes in members which are subjected to bearing/shearing action, raising stress concentrations, so **the fatigue performance of a riveted structure is relatively poor.** As far as welded structures are concerned, the performance depends on the quality exercised in welding. **A good quality weld has excellent fatigue performance, but a poorly made weld having inherent defects/ non-uniformity or one which has created local damage to the parent steel member(s) can have fatigue performance even poorer than a riveted connection.**

Over 30 to 35 years, number of welded steel girder have developed cracks in girder used for highways in USA but very few in Indian Railway due to fatigue failure. The probable reason for the same is use of riveted site connections, very conservative design of welds and lower than design loadings.

Fatigue failure process of member consists of three phases.

- Crack initiation
- Crack propagation
- Fracture

As explained above, cracks first initiate from points of stress concentration in structure. Common reasons for stress concentration other than normal connections are –

1) Flaws in rolled sections of steel or in weldment.
2) Geometrical details like sharp corner, re-entrant corner, sudden change of cross section, wedge or tearing action due to improper fitting and gas cut edges.
3) Out of plane bending/distortion.

Once fatigue crack has initiated for applied cyclic stress, the crack propagates across the section of member until it reaches a critical size when the member separates (Fig. a1.4).

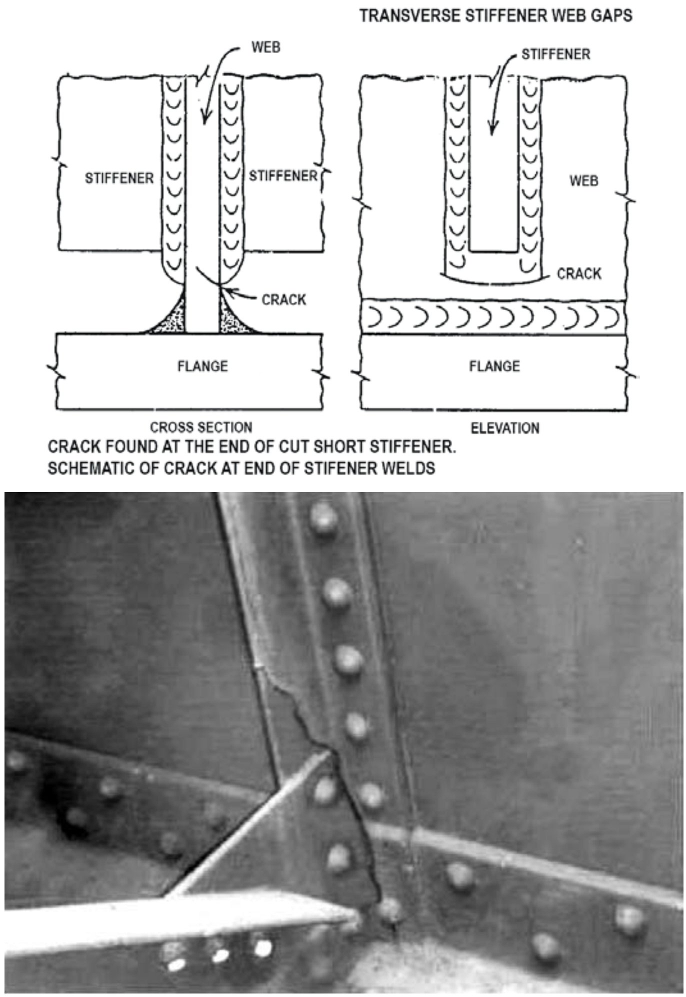

Fig a1.4 Fracture of members at end of weld, through hole.

Since the stress concentrations will guide the life of structure, it is essential to consider this aspect during design, detailing as well as fabrication.

It is concluded, based on above discussion, that:

1) Bridge components cannot be fabricated without locations which have some level of stress concentrations.
2) Good detailing to form members can reduce the number of stress concentration locations and severity of stress concentration.

a1.5 Welded vs Riveted Plate Girder:

a1.5.1 Design Issues: The fig.a1.5 gives the cross section of typical welded and riveted girders.

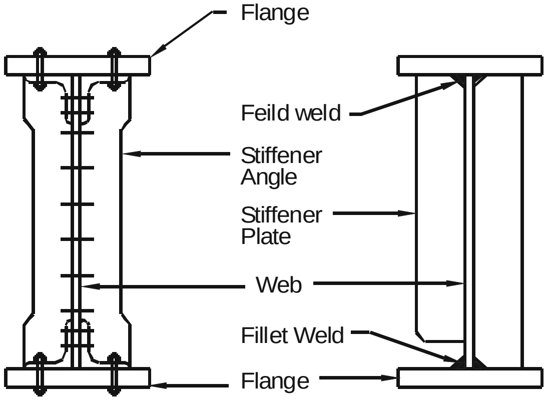

PLATE GIRDER (BUILT-UP)
Span 9.15m, 12.2m, 18.3m, 24.4m, 30.5m

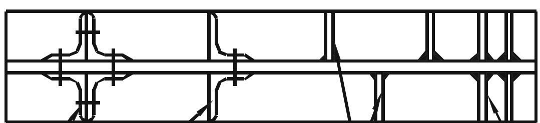

Fig a1.5: Typical welded and riveted girder cross sections

The main difference between the two types of girders is in the connections. The welded girders are lighter as compared to the riveted girders. The reasons for the same are due to design features, discussed as follows:

– The riveted connections require holes to be made in girders. These holes have to be deducted from the area of girder in tension to get the effective area. Hence the riveted girders require more area of main girder for same bending moment as compared with welded girders which do not have any holes.

– The riveted connections require overlaps and this requires extra steel. In welded girders, extension of any member can be easily done with butt welds and the girders are, therefore, much lighter.

– In riveted construction, rolled sections such as angles, channels, beams etc are used. These are available in certain discreet sizes only and if area required is slightly more than the available section, we have to per force go for higher section, which leads to use of extra steel without any addition to the load carrying capacity. On the other hand, the welded girders are fabricated from plates, which can be cut to any width required and wastage is much reduced.

a1.5.2 Administrative issues:

From earlier times, the connections were made with rivets and welding was considered unsuitable for the railway loading as the fatigue cracks used to develop in the welded members quite early. With time, welding technology advanced and most fabrication industry started using welded fabrication. To keep pace with other industry since 1985, Indian Railways have also started shop fabrication of welded girders.

The relative merits and demerits of riveted and welded fabrication is as under:

(i) Economy:

Rivets are less costly to make as compared to welds. However, providing rivets requires holes to be made in parent members. Therefore, effective area of steel section in tension is reduced by area of the holes. This makes riveted construction much more costly as compared to welded constructions. Further riveted construction is heavier as splicing / assembly of riveted members is by overlaps/ cover plates / angles which adds to weight of the structure whereas welded members can be welded together with minimum addition of weight. Overall welded girders are having 15% to 25% less weight compared with riveted girders. This also helps in keeping the sub structure design lighter.

(ii) Ease of construction:

The riveted construction is easier to make except that the proper matching of holes in the members fabricated has to be ensured. For this purpose, use of proper jigs, fixtures and templates for making holes is required. On the other hand, welded connections are easier to assemble together and can be tack welded but the quality of welds has to be monitored very closely. Further, heating of members for welding causes distortion which can be very acute unless proper sequence of welding and clamping of members is ensured. Overall, welded girder fabrication is more difficult than riveted fabrication but since no industry other than Railways is using structural steel fabricated by riveting and hence the skills required for riveting are not readily available.

(iii) Fatigue Performance:

The performance of steel girders depends overwhelmingly on the fatigue performance of the connections. The action of rivets involves making holes, and load transfer is through shearing or bearing. This makes the fatigue performance of riveted construction inferior as compared to welds where the load transfer can be gradual and without any stress concentration. However, welds include heating of members and subsequent cooling. If care is not taken, the welding process can damage the member by overheating, lead to non uniform stresses due to distortion and internal stresses can also build up. Therefore, if the welds are not made carefully, the performance of welded structure can be inferior even to the riveted structure. Therefore for fabrication of girders by welded joints, careful and close monitoring of various parameters alone can ensure better fatigue performance of dynamically loaded structures as compared to riveted construction.

(iv) Inventory:

Riveted members require a large variety of rolled sections like channels, plates, angles, beams, etc. of different sizes. These members have to be kept in stock resulting in higher inventory costs. On the other hand, welded construction fabricates members using a few plate thicknesses which are cut to required widths. Thus, the inventory is very much reduced in welded girders.

(v) Cost of Fabrication:

The fabrication of welded girders is more difficult and requires stringent quality control to ensure proper performance in service. The welds are to be tested rigorously and so the cost of construction of welded girders per unit weight is higher than the cost for the riveted construction. **Overall, however, the welded girders are more economical as compared with the riveted girders.**

However, till date we do not have adequate faith in field welding and most girders employ welding in workshop and riveting in field.

a1.5.3 Performance after crack: In case of welded girders there are few members, no overlaps/splices and consequently if a member cracks, there is no alternate load path and the load carrying capacity of girder might be severely reduced whereas in case of riveted construction, a number of individual components and overlaps are there. Since chances of all components cracking at same time are remote, so the performance of riveted construction after one component has cracked is quite superior to welded construction. Therefore welded construction requires much more care in inspection/maintenance and welded members are sometimes called “fracture critical members”.[3]

a1.5.4 Welding of intermediate stiffeners: The welded intermediate stiffeners mean the vertical weld for stiffener and the bottom web-flange weld

[3] Due to this reason alone, IRBM stipulates detailed inspection of welded girders by Bridge Inspector once in three years as compared to once in five years for riveted construction.

meet near the bottom flange which subjected to tensile stresses. The welds are rigid and attract stresses. This junction of welds can fail in fatigue and there have been instances of cracks near the bottom of intermediate stiffeners. (shown in fig. a1.4 also) **Therefore, for welded plate girders, the intermediate stiffeners are still riveted.**

a1.6 Comparison of Plate girders and Open Web Girders: The plate girders or solid web girders are designed with a vertical web plate which is meant basically to take the shear force and horizontal flanges which take the bending stresses. The moment of inertia of the plate girder is decided by the distance between the top and bottom flanges and to keep the distance between them as large as possible, the web is made of thin plate. The bending stress distribution in a typical plate girder is as shown in fig a1.6.

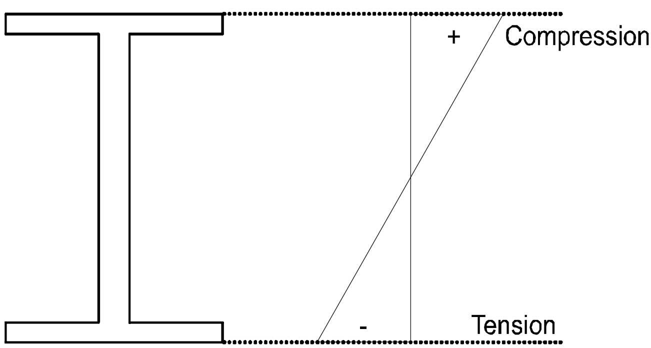

Fig a1.6: Bending stress distribution for a plate girder

The bending stresses are maximum near the top and bottom, and we design the girders such that these maximum stresses are within the allowable stress limits for the steel. But it is easy to see that a large part of the cross section is subjected to stresses below the allowable stress limits. This means this material is not optimally utilized.

On the other hand, a truss, loaded at the node points is subjected to primarily axial loads and bending is minimal. The sections in truss can be designed with more steel loaded closer to the allowable stresses. Therefore, the material is more optimally utilized in a truss, and **the weight of a truss for a span is always lower than a plate girder.**

From above, we can conclude that we must prefer trusses. But this is not the entire truth. The trusses, while efficient in carrying loads are difficult to fabricate and assemble. These require more labour, greater care and stricter tolerances to give good performance. **The cost of fabrication of trusses is therefore, more for a truss as compared to a plate girder.**

Looking at both the factors, it has been found that:

- For smaller spans, the saving in steel in trusses is not enough to cover the extra cost of fabrication. Therefore, the plate girders shall be more economical.
- For longer spans, the trusses are more economical.

The boundary line for economy between the truss and plate girder has been found to be 30.5 m. Below 30.5 m spans, the plate girders are designed and beyond 30.5 m, trusses are designed. For 30.5m span, both plate girder as well as trusses are designed and either can be used depending on the site conditions and convenience.

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ANNEXURE - II

GUIDELINES FOR GETTING GOOD WELDED FABRICATION BY MMAW

a2.1 Welding equipment for MMAW: Following are the welding equipment for MMAW.

a) AC transformer and DC generator:

AC welding gives smoother arc, no arc blow, arc can be easily maintained as well as controlled and is less costly hence, preference of AC welding over DC for fabrication or repair is given if power supply is available.

b) Electrode holder:

The jaws of the holder which holds electrode shall be with proper spring pressure. Electrode holder shall have to transmit current at 400 to 500 amps and shall be provided with heat shield to protect welder's hand during welding. Holder shall be light but sturdy to provide easy holding as well as handle shall be highly resistant to electricity.

c) Welding cable:

Cable conducting welding current from power source through electric holder to arc is called as lead cable and other cable connecting to the job (steel structure) back to power source / welding machine known as ground lead cable. Both cables shall be well insulated to avoid leakage of current for stable arc to get sound weld. For proper welding all parts of the electric circuit must have perfect connections with one another.

d) Hand shield and helmet:

Hand shield is protective device used in arc welding with filter lens and it is held in left hand of welder whereas Helmet is worn in head of welder. The use of hand shield or helmet is very essential to protect eye getting damaged due to ultraviolet and infrared rays during welding. When arc is struck, welder can observe proper manipulation of electrode & arc length through the shield/helmet.

e) Protective clothing:

Protective clothing like apron, hand gloves and shoes serve as safety to welders. Fig a2.1 shows a welder well equipped with protective clothing/gear.

Fig a2.1

a2.2 Welding electrodes

Electrode is a piece of steel wire covered with flux covering. It carries current from gripped end in holder to arc at the other end and job.

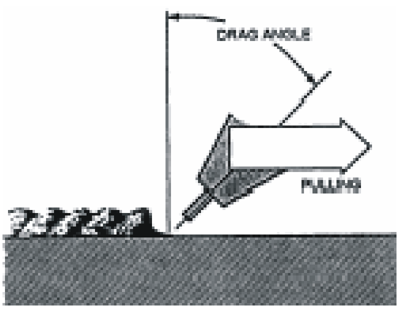
Electrodes are classified as AC or DC but some electrodes are AC & DC. Selection of right kind of electrode for particular application is very important for sound and economical desired weld joint.

Diameter of electrode	Steel Plate thickness
2.0 mm	2.5 mm
3.0 mm	3 to 6 mm
4.0 mm	6 to 10 mm
5.0 mm	10 to 18 mm
6.0 mm	18 to 22 mm

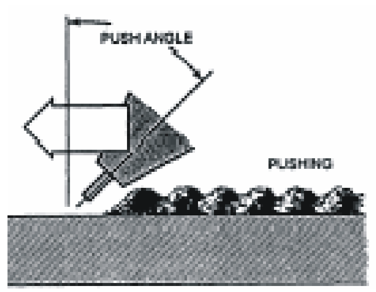
For railway structures, electrodes for MMAW are classified as per IRS – M- 28-2003 over and above IS specification based on steel used for fabrication and type of loading. Utmost care is required in handling and storage of electrode. Electrode coating should neither be damp nor be damaged. Electrode shall not be bent or broken. Each package has details of electrode and setting of voltage and current for guidance of welder hence package shall be intact and loss of identity may cause problem to welder. Damp coating of electrodes produces violent arc, porosity and sometimes cracking of weld also. Damaged coating will produce weld with poor mechanical strength. Electrodes shall be stored in dry and well ventilated store room. It is good to use dried electrode at 150° C for an hour or as per manufacturer's recommendation.

a2.3 Position of welding

During welding once welder establishes arc and adjusts arc length. There after he has to manipulate motion to make weld bead as well as lowering to maintain arc length for sound weld. Of all the positions in welding, the flat position welding is the best and the horizontal welding position is next best. Therefore, the steel article to be welded shall be manipulated such that most of the welds come in the flat or horizontal positions of welding. Even in flat position welding, the pulling of electrode is preferable as compared to pushing of electrode and the job may be handled accordingly. (Fig. a2.2)



Pulling Method



Pushing Method

Fig. a2.2

a2.4 Choice of welders: Quality of welding in MMAW is totally dependent upon skill and experience of welder. Therefore, only qualified and experienced welders shall be deployed for carrying out the welding work to get good quality. At each site, even if the detailed procedure of WPSS/ WPQR is not being followed (as in case of fabrication of platform shelter etc.), before the work is started the welder shall be asked to weld a few test pieces with steel comparable to the one which will be used for final fabrication and the welds made shall be closely inspected and NDT tested to check the capability of the welder to execute the welding work satisfactorily.

a2.5 Surface Preparation: Proper surface preparation is a must to ensure good quality weld without any impurities and defects. The steel edges being welded (fusion faces) shall be prepared by machining or by gas cutting and grinding. The area adjoining the weld, about 50 to 75 mm, shall be cleaned thoroughly by wire brushing or grinding to ensure that the same is free from dust, mill scale, rust, paint oil etc. Further it shall be ensured that the steel is dry and moisture free.

a2.6 Various defects commonly seen in welds

A defective weld fails under service conditions and cause damage to structure affecting the safety; hence it is necessary to understand defects and precautions to be taken to avoid defect. All precautions shall be taken to avoid defects as it is very difficult to repair a cracked/ defective weld and it is preferable to make a proper weld in the first instance. Various factors concerning welding parameters, base metal and welding procedure induce defects in weld as well as Heat Affected Zone such as:

a) **Cracks** may appear in base metal, weld metal and its boundary or in the crater due to poor ductility of base metal. To avoid this, steel as per specifications given in IRS – B1 shall be used. Concave weld bead & faster travel speed by welder due to lack of experience and qualification can cause cracks. Hydrogen inclusion in weld is a major cause for brittle cracks in weld. To avoid these cracks, the electrode shall not have high hydrogen content and, especially the electrode shall not be damp. Further, welding shall not be carried out when humidity in atmosphere is high. i.e. welding shall not be carried out during foggy weather or in rainy/stormy weather.

b) **Distortion:** Due to difference in temperature ahead of weld and behind weld, the steel plates get differentially heated up and cool differentially. This can lead to distortion of steel articles being welded. Thinner steel members and those having too much welding are more liable to distortion during welding. For each pass, the steel has to be molten locally and heat input has to be given and therefore distortion is more if more numbers of weld passes are made at one location with slow travel. To avoid/minimize the distortion, welding shall be done in proper sequence, balancing the distortion forces about the neutral axis and proper speed of welding shall be followed. For members with heavy weld concentration, use of jigs and fixture with clamps can reduce the distortion. Some of the methods for controlling/ correcting distortion have been discussed in chapter V.

c) **Incomplete penetration**: Due to improper preparation of fusion face, less arc current, faster arc travel, longer arc length, the distance of top of base metal to maximum depth of weld can vary and there can be incomplete penetration (and hence the strength of the welded joint). Properly trained welder following proper welding procedure can easily eliminate this type of defects.

d) **Inclusion**: If surface is not properly cleaned when taking up the further pass of weld over an older pass or if welder does not move the electrode properly, it may cause slag inclusion in weld, which will reduce the strength of weld joint.

e) **Porosity and blow holes**: Porosity means small voids in weld, whereas blow hole is a bigger cavity. These occur due to entrapment of gases (which are bye-product of welding and oxidation of flux) in the molten metal, which then escape, leaving voids behind. These occur due to defective coating on electrode, damp electrode, steel surface containing smears of oil, rust and grease at weld joint or improper welding techniques.

f) **Spatter**: Small metal particles getting thrown out of arc around weld bead during welding is called splatter. This occurs primarily on account of excessive arc current, damp electrodes or incorrect coating of flux.

h) **Under cutting:** A grove formed in the parent metal along the sides of weld bead, leading to notch in base metal is called undercutting. (Fig. a2.3) This causes stress concentration and can lead to early failure of structures. This defect comes from improper manipulation by welder (long arc length), higher current. This is a serious defect and must be avoided.

Fig. a2.3: UNDER CUT

i) Overlapping: It is just reverse of under cutting. Weld metal side deposit over metal by the side of joint without fusion with base metal. This is caused due to too low current, too slow arc movement and use of incorrect electrode diameter. (Fig. a2.4)

Fig. a2.4: OVERLAPPING

j) **Improper leg size:** The weld may be formed eccentrically with different leg lengths due to improper manipulation of electrode by welder. (Fig. a2.5)

Fig. a2.5: Size of fillet welds

a2.7 Some codal provisions regarding welding

a) The size of normal fillet weld shall be minimum leg length.(Clause 6.2 of WBC)

Minimum size of fillet weld is as per thickness of plate as follows:

Thickness of plate	Fillet Size (mm)
Upto 6 mm	3
6 to 12 mm	4
12 to 18 mm	6
18 to 36 mm	8
36 to 56 mm	10
56 to 150 mm	12
Over 150 mm	16

If plates are unequal thickness, the minimum size shall be equal to thickness of thinner part or as above whichever is less. As a precaution if thicker plate is more than 20mm preheating should be done of thicker part to prevent cracking. If plate is more than 50mm special precautions of preheating as per IS 9595 for sound weld should be taken.

b) The effective throat thickness for calculation of strength of weld for 90° fusion face is 0.7 x L. (Clause 6.3 of WBC)

c) Chain intermittent weld shall be preferred to stagger welding. (Clause 6.8.4 of WBC). In intermittent fillet weld there shall be weld at both ends. (Clause 6.8.5 of WBC)(Fig. a2.6)

STAGGERED WELDING **CHAIN INTERMITTENT WELDING**

Fig. a2.6

d) The size of fillet weld shall at least be 1.5mm less than thickness of plate. For rolled edge, the size shall not exceed ¾ times of thickness. (Clause 6.9.1 of WBC) (Fig. a2.7)

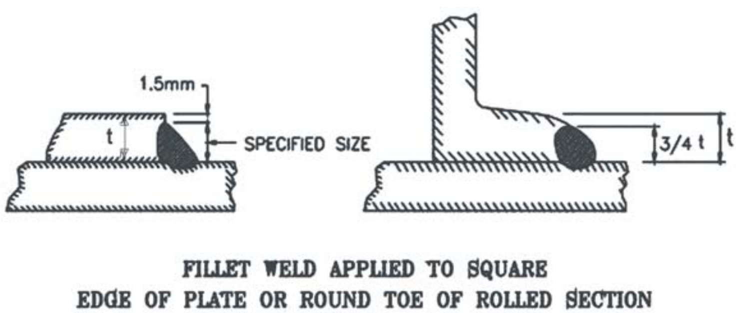


Fig. a2.7: SIZE OF WELD

e) When end fillet welds are used alone each fillet shall be returned by minimum length equal to size of fillet. (Clause 6.10 of WBC) (Fig. a2.8)

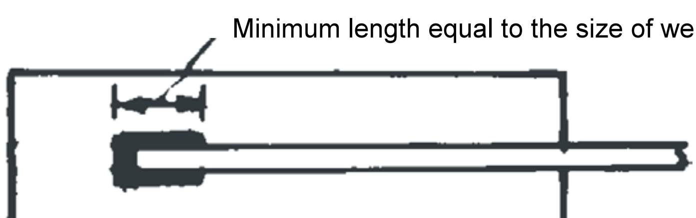


Fig. a2.8: END FILLET WELD

f) Preparation of fusion face shall be as specifies in IS9595 or IS4353 as per drawing.(Clause 11.1 of WBC)

g) MMAW is normally used for tack welding of girder components. These welds shall be not less than throat thickness or leg length of root run. Length shall not be less than four times thickness of thicker part or 50mm whichever is smaller. (Clause 24.1 of WBC).

h) The tack welds shall not be made at the extremity of the joint (Clause 24.3 of WBC).

i) Stray arcing on structure shall be avoided as this can leave hard spot. (Clause 26.1 of WBC**)**

a2.8 Inspection of Welds:

a) Proper cleaning of slag shall be checked.

b) Dye Penetration Test (DPT) is conducted to find cracks, undercuts, overlaps etc.

c) The finished welds shall be visually inspected and shall conform to the size and counter by profile gauge. Each size of fillet weld will have one profile gauge i.e. for fillet weld size of5, 6, 8, 10, 12, 14, 16, 18, 20, 22, 25 mm.

d) **Details of Profile Gauge**: All size Fillet weld profile gauges details are mentioned in table below.

Dimension (in mm)	Weld size										
	5	6	8	10	12	14	16	18	20	22	25
A	3.5	4.2	5.7	7.1	8.5	9.9	11.3	13.9	14.2	15.6	17.5
S	5	6	8	10	12	14	16	18	20	22	25
C	6	7	9	11	13	15	17	19	21	24	26
D	6.7	7.8	10.3	12.4	14.8	17.2	19.3	21.6	23.7	26.3	30.3
E	40	40	40	50	50	50	50	50	65	65	65

The profile gauge has been shown in fig. a2.9. Length of plate shall be 105mm and its width shall be 40 / 50 / 65 mm (E)

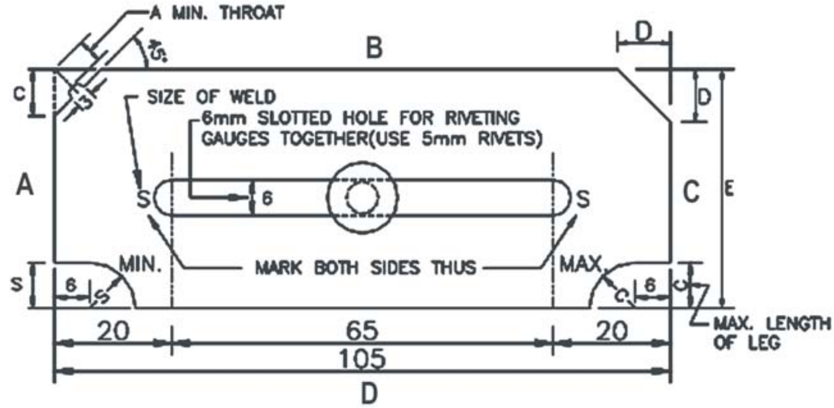


Fig. a2.9: DETAILS OF PROFILE GAUGE

e) **Use of profile gauge:** Details of profile gauge for 5mm fillet weld and its application methodology is explained below. Same principle shall be applicable to all sizes.

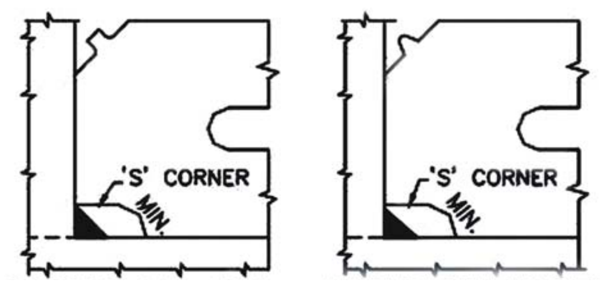
- Computations:

1. Minimum size 5mm (S) 2. Throat thickness,3.5 mm (=0.7 x 5mm) (A)

3. Maximum size 6 mm (C) 4. Required convexity 6.7 mm (D)

- **Minimum size** i.e Length of leg of 5mm Fillet weld is 5 mm (marked as "S" on side 'A' of profile gauge at bottom corner). Corner of sides 'A' & 'D' is used to check for Minimum Size. (Fig. a2.10)

Correct Minimum Size

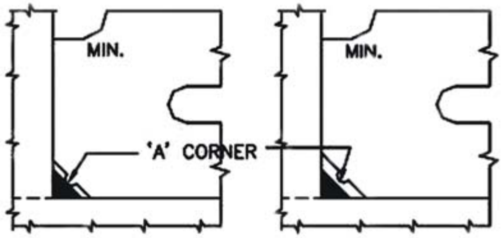


Incorrect Minimum Size

Fig. a2.10: DETAILS OF PROFILE GAUGE

- **Minimum Throat thickness** i.e 0.7 x 5 = 3.5 mm for 5 mm fillet. (marked as "C" on side 'A' of profile gauge at top corner). Corner of sides 'A' & 'B' is used to check for throat thickness (Fig. a2.11)

Correct
Throat Size (A)

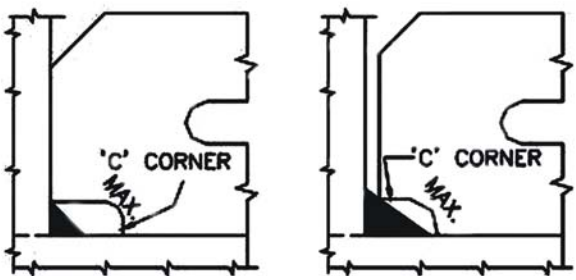


Incorrect
Throat Size

Fig. a2.11

- **Maximum size** i.e Leg length shall not exceed 6 mm for 5 mm fillet weld. (marked as "C" on side 'C' of profile gauge at bottom corner). Corner of sides 'C' & 'D' is used to check for Maximum Size. (Fig. a2.12)

Correct
Maximum Size
(C)

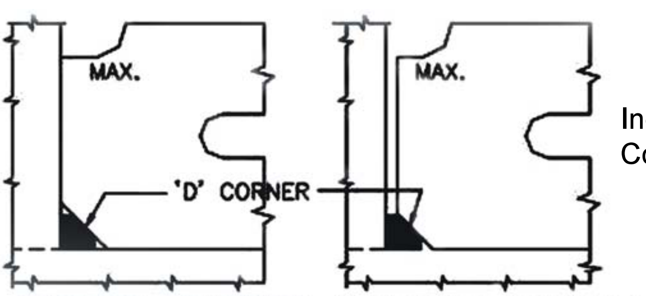


Incorrect
Maximum Size

Fig. a2.12

- Required **Convexity** of 5 mm weld is 6.7 mm. (marked as "D" on side 'C' of profile gauge at top corner). Corner of sides 'B' & 'C' is used to check for required Convexity. (Fig. a2.13)

Correct
Convexity
(D)



Incorrect
Convexity

Fig. a2.13

In this manner, all four corner of gauge are used to check one fillet weld. Central slot shown in the profile gauge in fig. a2.9 is used to make a bunch of profile gauges using a 5mm dia rivet.

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ANNEXURE - III

SCHEDULE OF TECHNICAL REQUIREMENTS

Sr. No. FORM NO. BS/REG/GIRDER

Issued to:………………………
…………………………………..
…………………………………..

SCHEDULE OF TECHNICAL REQUIREMENTS FOR FABRICATION OF STEEL GIRDERS

a3.1. **Scope**

This schedule covers the norms for evaluation of both the capability and the capacity of any firm to manufacture and supply Steel Bridge Girders. Intended fabricators will be required to fabricate riveted/welded plate girders and riveted/welded open web girders.

a3.2. **Procedure for registration of firms for fabrication of girders**

a3.2.1 The firm will ensure availability of

i) The required infrastructure, machinery & Plant.

ii) Testing and measuring equipments duly calibrated.

iii) Trained technical manpower and Quality Assurance Programme

iv) Equipments meeting the requirements of relevant specifications.

v) Space required for manufacturing, testing and storage viz. manufacturing floor, godown, store, office and test lab etc.

a3.2.2 In case fabricator is satisfied that the infrastructure available commensurate with the above stated requirements then Form duly filled in duplicate along with all relevant self attested documents, Bank Draft of Rs. 15,000-/ (non-refundable) drawn in favour of Executive Director (Finance), RDSO, Lucknow, shall be submitted to Director General/B&S, RDSO/ Lucknow.

a3.2.3 After scrutinizing the details given in application form, nominated inspection team may inspect the firms premises for capability and capacity assessment. The deficiencies noticed, if any, would be advised to the firm for rectification.

a3.2.4 As soon as deficiencies are removed, the same may be advised to Director General/B&S/RDSO, Lucknow, who in turn may organize the visit to firm for re-verification.

a2.5 In case of delay of more than 6 months in removing the deficiencies, the case will be closed. The firm will be permitted to reapply afresh after expiry of one year from the date on which firm was advised the deficiencies. The fresh application shall contain certificate that all the deficiencies have been removed.

a2.6 In case of firm having been considered prima facie suitable after capability and capacity assessment, the firm will be advised in this regard within 60 days (approx.) after completion of assessment by Inspection team.

a3. **Norms for Acceptance**

a3.1 To qualify for riveted steel bridge girders production, the firm must satisfy the infrastructural requirement as laid down in para 4 to 6.

a3.2 To qualify for welded steel girders production, firm must satisfy the requirement laid down in para 7 in addition to requirement of other para 4 to 6.

a3.3 Fabricators who do not have established the workshop for fabrication but do have required facilities at site as given in para 3.1 & 3.2 above as applicable will also be considered.

a4. **General and Infrastructural Requirements for Steel Girders**

a4.1 The fabricator must have adequate organization including supervisors, skilled workers and adequate manpower to execute the fabrication work in competent manner.

a4.2 A proper organization must exist to perform the functions of purchasing of various raw materials and consumables etc. and maintaining related inspection certificates, test certificates etc.

a4.3 Previous experience of fabricating steel structures capable of withstanding dynamic loads such as bridge girders, microwave towers, pressure vessels, heavy industrial steel structures etc. is essential.

a4.4 A proper procedure for maintenance of records for receipt and consumption of raw material should be in vogue or developed so as to permit verification by railway's representative.

a4.5 Adequate power supply should be available through distribution agencies and adequate backup shall be available through captive generation.

a4.6 Covered bay area served by EOT cranes or by mechanically operated machines should be provided to handle day today fabrication of girder components.

a4.7 Enough area to store raw material, sub assemblies and finished product should be available. The area provided should be enough to store raw material to execute the work order for requirement of steel. Suitable material handling facilities in form of EOT/mobile cranes should be available.

a4.8 A separate line for inspection and testing of girders should be provided for final inspection and testing of bridge girders by railway's inspecting engineers.

a4.9 Covered shed area protected from rain, dust etc. should be provided for surface preparation/painting/metallising of steel girders. As no part of the work shall be painted unless it has been finally passed and cleared by inspecting officer, adequate space for storing fabricated component awaiting painting shall be available.

a4.10 For full scale layout of drawings to which girders are to be manufactured, template shop with steel/concrete floor should be available. For symmetrical girders, central half of the layout may be done and for non-symmetrical girders full-length layout shall be required. Further, for development of jigs and fixtures this shop should have in-house jigs manufacturing facilities.

a4.11 Sufficient space for trial erection of the girder after manufacture shall be available. For this purpose, proper handling equipment, stacking space and other facility shall be available.

a4.12 An adequately equipped and staffed drawing office is required for preparation of fabrication drawings.

a4.13. Digital Signatures:

It is mandatory for all the vendors to obtain Digital Signature Certificate & get registered with IREPS at http://www.ireps.gov.in

a5. **Machinery & Plants**

Following machinery and plants shall be available with the fabricator:

a5.1 EOT/Portal/mobile crane of min. 10t capacity or suitable material handling facility to serve the handling of material for fabrication of girders, unloading of raw material and loading of finished product.

a5.2 Compressors of adequate capacity suitable for riveting and for other simultaneous applications.

a5.3 Oxy-Acetylene gas cutting equipment

a) Profile cutting equipment of adequate size.

b) Self propelled straight cutting equipment preferably consisting of multiple torches.

a5.4 Radial drilling machines of adequate capacity to drill holes of 12 to 50 mm diameter.

a5.5 End milling machine /Edge planing.

a5.6 Plate & structural sections straightening machine.

a5.7 Pneumatic/hydraulic yoke riveting machine.

a5.8 Adequate number of portable pneumatic tools such as grinders, drilling machines, chipping machines, wrenches etc.

a5.9 Dumpy level or theodolite instrument for recording of camber/ deflection of trial erected girder.

a5.10 Facilities for surface preparation/painting/metallising as per IRS B-1 specification.

a5.11 A) To test the raw material and girders to conform it for relevant specification, testing facilities for the following must be provided:-

(a) Elcometer for measuring thickness of paint.

(b) Steel measuring tape duly calibrated

a5.11 B) Following facilities for testing of material can be in house or may be arranged from external agencies:

(a) Equipments required for testing of mechanical properties, chemical composition and microstructure etc.

(b) Ultrasonic flaw detection testing facilities for checking internal flaws and thickness of section.

5.12 System of periodical maintenance of M&P must be in vogue and proper records maintained.

a6. **Quality Infrastructure**

a6.1 Fabricator shall have proper quality infrastructure to ensure the quality product as required under latest issue of IRS B1 Specification and IRS Welded Bridge Code as applicable. ISO certified firms would be preferred.

a6.2 A system should be in force for analysis of defects noticed during internal and external inspections of the final product and sub-assemblies. A dynamic arrangement for a feed back to the source of defects and for rectification should be in vogue.

a6.3 The fabricator should have adequate infrastructure and facilities like checking gauges, templates etc. during fabrication required from time to time so as to ensure that the finished product is as per requirement of IRS: B1 and Welded Bridge Code

a6.4 Following specifications/codes commonly referred in connection with fabrication of riveted steel girders must be available with fabricator.

IRS B-1	Fabrication and erection of steel Girder Bridges
IRS	Steel Bridge Code
IS: 1148	Hot rolled steel rivet bars (upto 40mm dia) for structural purpose.
IS: 1149	High tensile steel rivet bars for structural purpose
IS: 1852	Rolling and cutting tolerance for Hot Rolled Steel Products.
IS: 2062	Hot rolled low, medium and high tensile structural steel.

The latest version of BIS Code/Specifications referred herein including their amendments issued from time to time are to be followed.

a6.5 All equipments must meet the requirements of corresponding BIS or other international Specifications.

a7. **Additional general and infrastructural requirements for fabrication of welded girders**

a7.1 The following facilities should be available for fabrication of welded girders.

a) Welding transformers/rectifier for Manual Metal Arc Welding (MMAW)

b) Inert gas (Carbon Dioxide) welding equipment sets.

c) Automatic sub-merged arc welding equipment.

d) Suitable welding manipulators

e) Macroetching /Dye Penetrant or Magnetic Particle testing facilities

f) Arrangement for radiographic test either in house or from external agency.

g) Tongue tester for measuring current and voltage

h) Gauges for checking weld size, throat thickness and edge preparation etc.

a7.2 Machine for edge preparation before welding.

a7.3 Fabricators must ensure that welding and gas cutting equipment/ accessories meet BIS or other international standard requirements. It will be fabricators responsibility to satisfy the inspecting engineer that all the welding equipment/accessories conform to the BIS standard or any other standard in the absence of proper marking on such equipment/accessories.

a7.4 Only trained and qualified Welders shall be deployed for welding. The welders must be trained in accordance with the provisions of IS: 817. They must be trained either from recognized welding institutes or by in-house training, if proper facilities exist. The welders must be tested as per requirements of IS: 7310 and proper records maintained.

a7.5 All welding shall be carried out under the overall supervision of a qualified welding supervisor who has been trained in Welding Technology from any recognized welding institute

a7.6 Welding instructions shall be prominently displayed on the shop floor. Requirement of the job in hand must be clearly explained to the welder before he is permitted to work.

a7.7 Following specifications/codes commonly referred in connection with fabrication of welded steel girders must be available with fabricator.

IRS WBC	IRS Welded Bridge Code
IS:817	Code of practice for training and testing of metal arc welders.
IS:818	Code of Practice for Safety and health requirements in electric and gas welding operations
IS: 822	Code of Procedure for inspection of welds.
IS: 4353	Recommendations for sub-merged arc welding of mild steel and low alloy steels.
IS:7307 (Pt1)	Approval tests for welding procedure
IS:7310(Pt.1)	Approval tests for welders working to approved welding procedure-fusion welding of steel.
IS:9595	Recommendations for metal arc welding of carbon and carbon manganese steel.

The latest version of BIS Code/Specifications referred herein including their amendments issued from time to time are to be followed. Wherever to the standards mentioned above appears in the specification it shall be taken as a reference to the latest version of the standard.

a7.8 Firm will be initially registered for a period of two years in the approved list. **For renewal** of the registration, which will be done for three years, following are the requirements:

(a) The firm should continue to maintain the facilities as required at the time of initial approval.

(b) The firm should have participated in at least one of the tender of Railway Bridge Girder Fabrication during last three years.

(c) The firm should not have any adverse report from any of the Railways.

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ANNEXURE - IV

GUIDELINES FOR RIVETING WORKS

a4.1 What is Riveting?: Riveting, in girder fabrication, means joining two steel members using a steel bar with heads at either end. A rivet as purchased from the market has head formed on one side and has a cylindrical shaft as shown in fig a4.4 below. The riveting is done in hot condition and the head on the other side is formed during the riveting operation.

a4.2 Action of Rivets: Mostly, the rivets act in either shearing (fig a4.1) or bearing (fig a4.2). Occasionally the rivets act in axial tension (fig a4.3) also.

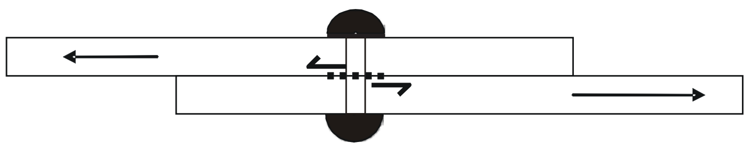


Fig a4.1: Shearing action of rivets(trying to cut the rivet across its diameter)

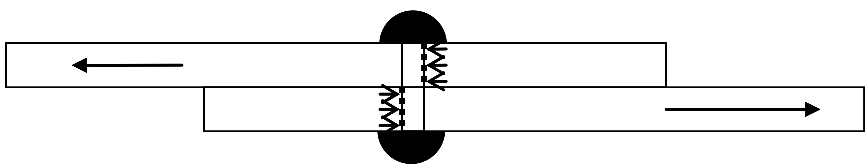


Fig a4.2: Bearing action of rivets (trying to press the rivet against the plate walls)

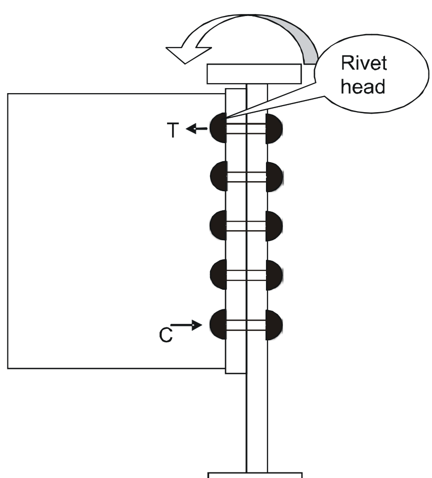


Fig a4.3: Tension on rivets (Axial load trying to open out the head of rivets near top of connection)

As can be seen from the action, **the riveting must completely fill up the hole so that the shearing/bearing action can take place properly as designed**. **In case the rivets are in axial tension, proper head formation is very important.**

a4.3 Types of Rivets: The rivets are of different types but the most common types used in steel fabrication are:

a4.3.1 Button head rivets: These are the normal rivets with elliptical heads. These rivets are also known as **snap head rivets**. The snap head rivet has a head 0.7d high and 1.6 d dia at the base where d is the dia of the shank of the rivet as shown in fig a4.4 below:

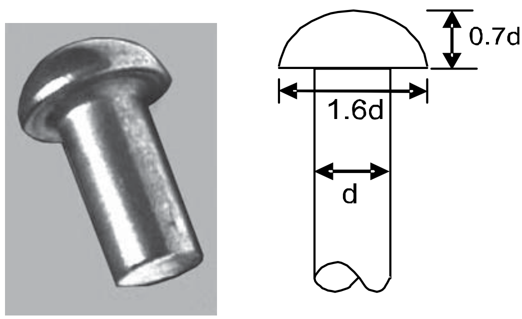


Fig a4.4: Snap head rivet

a4.3.2 Countersunk rivets: These are rivets with no projection due to head. These rivets are used in structures where flat surface after riveting is desired e.g. these rivets are used to connect the bearing to the girder so that the sliding surface obtained does not have any obstruction, and also for connecting location strips to the bed plate. The "head" in the case of counter sunk rivets is "sunk" in the steel member itself. The top portion of the steel plate is drilled to form an internal head for the rivet. These rivets are also known as **CSK rivets** in short. The countersunk head has a height of 0.5d and top dia of 1.5 d as shown in fig a4.5. The CSK head can be on one side or both the side:

i) **One side CSK:** In this case, the factory made head is standard button head and the site head is made CSK.

ii) **Both sides CSK:** In this case, the factory made head is ordered in CSK shape and the site head is also made CSK.

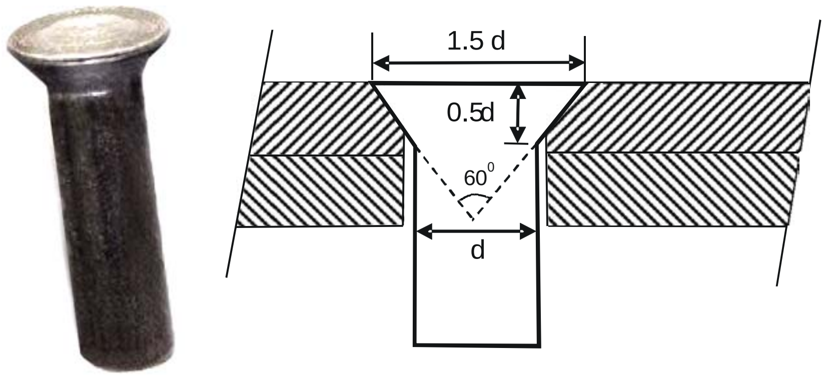


Fig a4.5: Countersunk rivet

a4.3.3 Methods of Riveting: The riveting can be done by various methods: **Electric or pneumatic.**

- **The electric riveting** is done using electricity driven equipment. The equipment in this case is not handy and it is difficult to carry out riveting by this method in field. This method, however, is very good for formation of first head of rivets in factory and also for certain workshop riveting applications.
- **The pneumatic riveting** is done using air under pressure coming from compressor. The equipment in this case is very handy and portable. This riveting method is quite suitable for making the rivets in structural members like girders. This method has been described in detail hereinunder.

a4.4 Riveting Procedure[1] : The riveting may be done in the workshop or in field. The steps in riveting are as follows:

a4.4.1 Ordering Rivets: The rivet steel shall conform to IS:1148 for steels conforming to IS:2062 rivets and IS: 1149 for high strength rivets for steels conforming to IS:961/8500. Ordering of rivets has to be done giving the following details:

i) **Diameter of rivets:** The rivets shall have diameter as per drawing. The diameter mentioned in the drawing is the actual diameter of the rivet shank. **The holes in plates are made 1.5 mm larger than the nominal diameter for rivets upto 25 mm diameter and 2 mm larger for larger than 25 mm diameter rivets. Normally, 16/18mm dia rivets are used for bracing, 20mm dia rivets for workshop connections and 22mm dia rivets for field connections.**

[1] Pneumatic riveting procedure is explained. If electric riveting is being done, basic principles are same and only modification in equipment is there.

ii) **Number of rivets** required as per the drawing. 10% extra rivets may be ordered to take care of the loose rivets and defective rivets etc.

iii) **Lengths of rivets ordered:**[2] The rivet length is worked out as follows:

- Length of rivet shanks **for Button Head Rivets** shall be = G+1.5D+1mm for every 4mm grip:

  G = Grip or joint thickness

  D= Diameter of rivet (1.5 D length is to form other head and 1mm for every 4mm grip is to fill the cavity between shank and holes)

- Length of rivet shanks **for Countersunk Rivets** shall be = G+0.5D+1mm for every 4mm grip:

  G = Grip or joint thickness

  D= Diameter of rivet (0.5 D length is to form CSK head)

- **Trial for length:** A few rivets may be driven as a trial to check if the length of rivets worked out is OK or not. Sometimes minor adjustment of lengths (upto 5 mm) may have to be made after the trial.

a4.4.2 Quality Checks for Rivet Material: The rivet material shall be checked for the following:

i) **Material:** The rivets shall be accompanied with Material Test Certificate (MTC) indicating that the material conforms to the relevant IS code. If there is doubt about the rivet material quality, the samples may be sent for independent material testing also.

As per IS 1148, the **chemical composition** of steel shall be as follows:

Constituent	% max	variation
Carbon	0.23	0.02
Sulphur	0.055	0.005
Phosphorus	0.055	0.005

The **tensile strength** shall be between 410 N/mm^2 and 530 N/mm^2. The **minimum elongation** shall be 23% and rivets shall be subjected to **dump test and bend test.**

ii) **Visual Examination:** The rivets received shall be checked visually for:

– Uniform texture of steel surface,

[2] The formulae given are valid only for rivets with grip length less than 8 times the rivet diameter.

- Cracks/blemishes/other surface defects,
- Proper formation of head to the requisite dimensions,
- Head concentric to the shank, etc.

a4.4.3 Equipment for Riveting: The riveting requires the following

- **Compressor**: The compressor may be a stationary large reservoir type used in the workshops or portable type compressor used in field. The compressor shall be capable of supplying air for riveting at minimum 7.6 Kg/cm^2. The compressor capacities are expressed in cft/s (cubic feet per second). A compressor with 70cft capacity can support one riveting team at short distance (Each team requires 3 air feeds, one each for riveting machine, dolly and forge). A 300 cft compressor can support 4 riveting teams at shorter distances. At longer distances, the air availability reduces, so the number of teams which can be supported also reduces. A compressor commonly used in field is shown in fig a4.6.

Fig a4.6: Diesel operated portable compressor

- **Pipe line:** The air from the compressor is taken to the job through pipelines. The pipeline from the compressor to the approximate location of the job shall be through GI pipes with non-leaking joints. The GI pipeline shall be provided with sockets at regular intervals so that any socket can be opened or closed as desired for connecting riveting equipment. The last stretch of connection of the riveting equipment has to be with rubber hoses so that there is flexibility in operations. In workshop, normally there is no requirement for alterations in the GI pipeline but in field, the compressor location and the pipeline layout may have to be shifted as the work progresses. Diameter of pipeline is to be decided looking at the volume of compressed air and distance. Normally 4" dia pipes for mains and 2"near the ends are good enough. Hose pipes are usually ¾" or ½" diameter. The length of pipeline which can be connected to a compressor is limited as the pressure keeps dropping along the length and minimum 5.6 kg/cm^2 pressure shall be available at the end for satisfactory riveting.

– **Riveting Hammer:** Different type of riveting hammers are there such as pneumatic/hydraulic squeezer, yoke hammer, jam riveter etc. However, many of these are no longer available and the riveting hammer most commonly used in field as well as workshop, known as **hand pneumatic hammer**, is shown in fig a4.7. The hand pneumatic hammer top is connected with a rubber hose pipe through steel nipple

Fig a4.7: Pneumatic riveting hammer

which supplies compressed air from compressor. The other end of the hammer is provided with required **snap** depending on the shape of the rivet head desired. The snap is attached with a clip for easy attachment/detachment and to facilitate the movement of the snap. When riveting is done, the riveter operates a lever near head which allows compressed air to enter the machine cylinder. The compressed air presses the snap head. If the riveter releases the air, the piston rebounds. The riveter can repeatedly open/close the lever to put percussion load on the rivet. While riveting, the riveter first applies squeezing pressure so as to fill up the annular space between the hole and rivet and then applies quick percussion blows to form the head. The riveting hammer is manipulated along the periphery of the head to from proper head. To put adequate force, the riveter transfers his body weight on the riveting hammer. The procedure for riveting means that the quality of the rivets formed depends to a great extent on the skills and experience of the riveter.

– **Dolly:** The rivet being driven by hammer from one side has to be held from the other side otherwise the rivet will not deform as required. This task is performed by the dolly. **The dolly can be pneumatic** in which case the air from compressor tightens the dolly between the factory made head of rivet and some component of the girder. The length of the dolly arm to be used will depend upon the distance between the rivet being made and the available support to dolly. If space is not available for fixing of pneumatic dolly, **hand held dolly** may be provided. Fig a4.8 shows a pneumatic dolly and the fig a4.14 and a4.15 show hand held dolly being used for riveting.[3]

Fig a4.8: Pneumatic dolly fixed against other flange of member for riveting

– **Rivet Heating forge:** This is a forge fed with hard coke and fired with clean air supply from the compressor. A forge is shown in fig a4.9 below.

[3] If there is no support available on other side for supporting the rivet, two hammers may be used, one for supporting the rivet and the other for driving the rivet in a process called 'double gunning'. Alternately the riveting may not be done at this location and turned bolt may be left permanently.

Fig a4.9: Forge for heating rivets

- **Scaffolds** to keep the equipment and help workers make rivets. The rivetter must have his staging at a height which enables him to put the whole weight of his body behind the hammer. This ensures proper riveting and prevents the hammer from bouncing.
- **Miscellaneous tools** like long handle tongs, black bolts, turned bolts, spanners, drifts, hammers etc.

a4.4.4 Manpower for Riveting: The following minimum staff are required to carry out riveting work:

- **Rivet heater**: 1 no
- **Rivetor**: 2 nos
- **Dolly Man**: 2 nos
- **Khalasis**: As per site conditions and scaffold requirements.

a4.5 Bolts and Drifts for riveting work:

- **Black or service bolts**: Bolts which can be easily installed and removed from a hole due to their lesser diameter than the hole are called black or service bolts. These bolts for steel fabrication work have 1.5 mm lesser diameter than the hole diameter. These bolts are used to provide clamping force to keep the steel members in dead close contact (without gap) during fabrication before riveting. Fig a4.13 shows service or black bolts inserted in holes during assembly of the members. The heads of the bolts shall be forged to a hexagonal shape. The bolts shall be to IS: 6639 and nuts shall conform to IS:1363.
- **Turned bolts:** Turned bolts or Close fitting bolts are bolts with very less clearance between the bolt shank and the hole. The turned bolts shall conform to IS: 1364 and manufactured to IS:1367. The nominal

diameter of the turned bolts shall be same as the diameter of the hole with a tolerance of +0 and -0.125 mm. The turned bolts must have parallel shank and shall have a barrel length at least 3 mm more than the grip of joint. The diameter of the threaded portion shall be 1.5 mm less than the shank diameter and it shall have 45^0 chamfer. The turned bolts shall be provided with minimum one plain washer to IS:2016 and IS:5369. The washer under nut shall have diameter 1.5 mm more than the shank of bolt and thickness of the washer shall be 6 mm. These are sometimes used as a substitute for the rivets.[4] During in situ work, if trains have to be passed before all rivets have been driven, these bolts have to be provided and trains allowed at speed restriction of 20KMPH. Fig a4.10 shows a typical turned bolt.

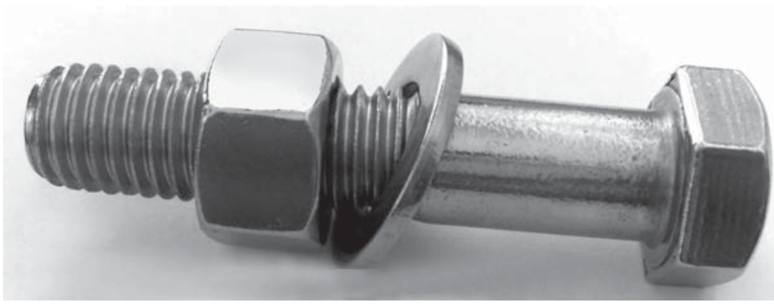
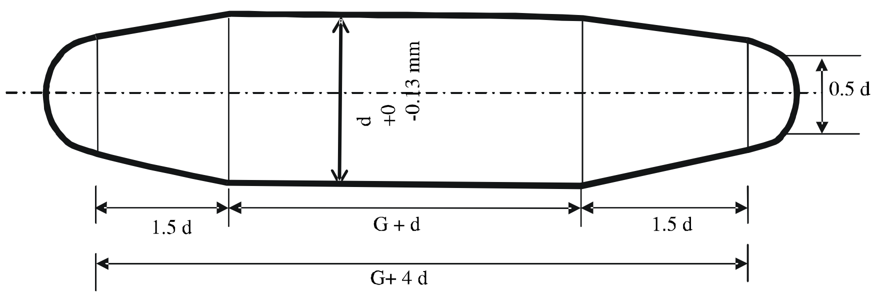


Fig a4.10

- **Drifts:** As per fig 2 in IRS B1, parallel shank drifts shall be used for fabrication/assembly, the dimensions of a typical drift are as shown in fig a4.11 below.



where d is the nominal diameter of the hole (21.5 mm for 20 mm dia rivet and 23.5 mm for 22 mm dia rivet)
G is the combined thickness of metal (joint) through which the drift has to pass

Fig a4.11: Parallel barrel drift

[4] These shall not be confused with another type of bolts called High Strength Friction Grip (HSFG) or High Tensile Friction Grip (HTFG) bolts which are a totally different category of bolts which act through the friction between the mating surfaces of joined plates rather than the shearing/ bearing action as in case of rivets.

The steel for drifts shall be as per IS:1875 for forged quality steel or IS:7283 for hot rolled bars.

a4.6 Drifting: Before the riveting is started, the holes have to be matched. The holes made by same template/jig shall match, but if the plates/members are not aligned properly, all or few holes will not match. The problem increases as the number of plates/ members through which the rivet has to pass increases. To ensure proper alignment of all plates/ members, the procedure of drifting is used. **Drifting means driving of drifts by force in holes during initial assembly of steel girders.** The lesser dia of the drift ends can go in the hole even if the plates/members are not properly matching and the loose plates/ members are slowly pulled/pushed as the parallel barrel of drift enters the hole. When a number of drifts are in position, the members get in proper alignment and the riveting work can start. Before riveting is started, in order to ensure that the plates/members do not slide/ open out, the clampin force through service bolts is applied. As per clause 20.3 of IRS B1, **for workshop assembly, joints shall normally be made by filling not less than 50% of the holes with service bolts and barrel drifts in the ratio of four to one.** The service bolts are to be fully tightened up as soon as the joint is assembled. **For field assembly of girders, use of 40% drifts and rest black bolts has been specified in clause 616 of IRBM.** Fig a4.12 shows the drifting operation and fig a4.13 shows the member drifted/ bolted and the holes matched.

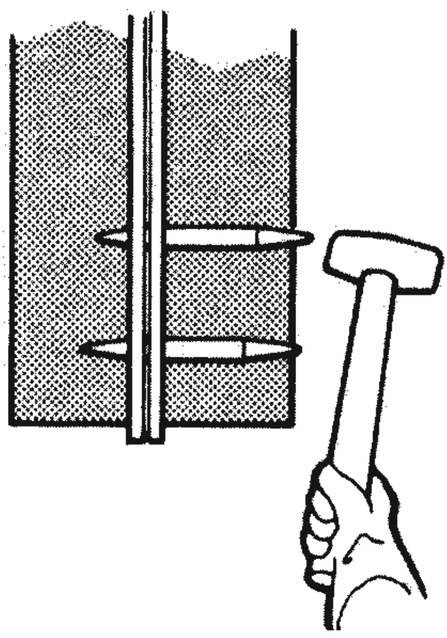


Fig a4.12: Drifting with hammer for hole matching

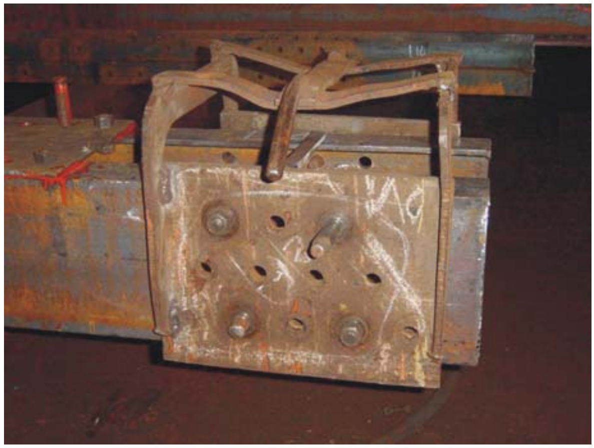


Fig a4.13: Assembled member after drifting and bolting with holes matching

The drifting shall be done carefully with light hammering taking care not to damage the edge of hole. In no case, shall drifting be allowed to such an extent that holes are distorted. As per clause 19.3 of IRS B1, drifting to enlarge unfaired (non matching) holes is prohibited. The holes that will have to be enlarged to admit rivets should be reamed provided the Engineer permits such reaming after satisfying himself about the extent of inaccuracy and the effect of reaming on the soundness of the structure.

a4.7 Carrying out Riveting: Before riveting is started, the holes are matched by drifting procedure explained above. If there are any bolts or drifts in the holes, these are opened out one by one just ahead of riveting (Large number of bolts/drifts cannot be opened out as the members might slip/move and holes will not match). The steps in riveting are as follows:

i) Rivets are put in the forge and heated uniformly (from tip to toe) to white heat and to a point when sparks are just beginning to fly off, so that they attain temperature between 550^0C and 1000^0C without burning/oxidising the outer surface of rivets. The heater keeps an eye on the rivets and keeps adjusting the fire, gives the properly heated rivets for riveting and feeds more rivets to fire as these are consumed. The heater may be assisted by one khallasi. This is a very important task in riveting.

ii) The heated rivet is handed over to one of the dollymen using a pair of tongs. Before inserting rivet in hole, the dollyman shall give a smart jerk to the rivet to remove any scale or ash etc on the heated rivet.

iii) The dollyman inserts the rivet in the hole to be riveted. Since holes are already matched and there is 1.5/2 mm difference between the dia of the rivet and the hole, the rivet can be easily inserted.

iv) The second dollyman inserts the dolly below the factory made rivet head and either manually or pneumatically holds the hot rivet in proper position.

v) One of the riveters brings the hammer and drives the rivet as well as forms the head. The head shall be formed by applying force by leaning on with the body weight on the rivet. The riveter's body gets too much jerks in the process and gets fatigued very soon. So, the two riveters take turns doing riveting.

vi) The operations ii) to v) above shall be completed before the rivet gets cold i.e. within about 20 seconds of rivets leaving fire. If the operation gets delayed due to any reason, the rivet can not be driven and has to be removed.

vii) 100% checking of rivets for geometry and tightness shall be done after the rivets have cooled to room temperature.

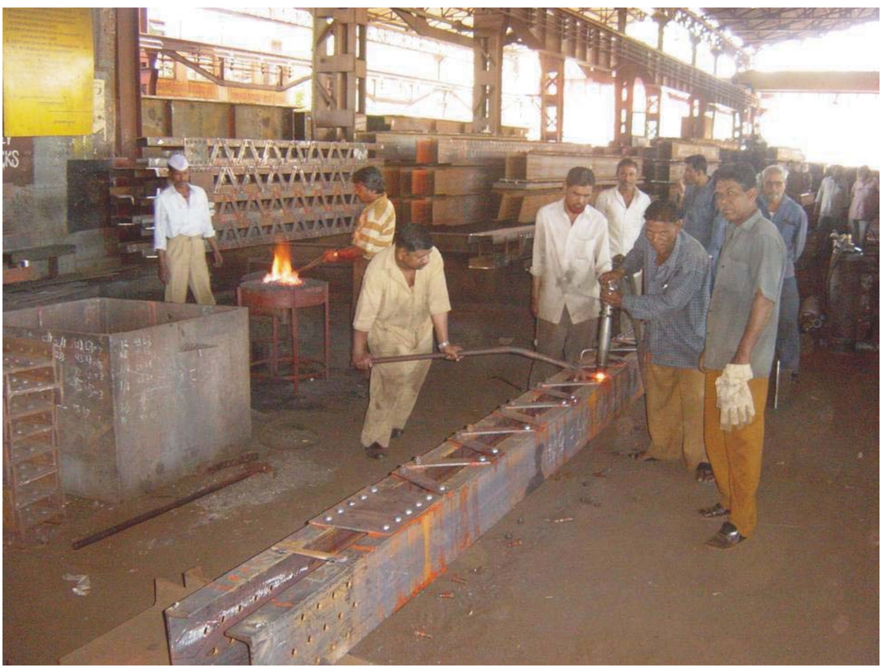


Fig a4.14: Riveting: Heating, hand held dolly, rivet driving operations are seen

Fig a4.15: Forming rivet head after driving the rivet

a4.8 Quality Control for Riveting work:

a4.8.1 Visual inspection: The rivet head is a good indication of the workmanship and whether the hole has been filled up properly. The length of rivet is pre-decided and if the hole is not filled up properly, the rivet head will also not be so good. The defects come due to inadequate space availability for the hammer, improper workmanship, improper rivet material, improper length of rivets etc. An improperly formed rivet head due to space constraints is shown in fig. a4.16.

Fig a4.16 Improper head due to space constraints

The defects in the head which are to be seen include:

- Improper shape of head
- Eccentric head
- Notching in the steel due to impact on member by the hammer
- Unevenness on rivet head etc.

The Annexure IV of IRS B1 gives the defects in the rivet heads, which is given in fig a4.17 below.

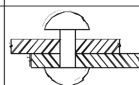
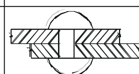
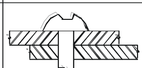
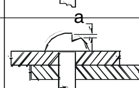
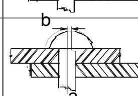
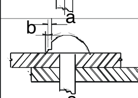
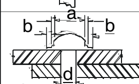
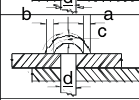
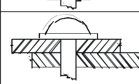
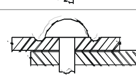
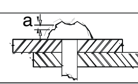
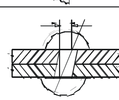
S.NO.	DESCRIPTION OF DEVIATIONS	SKETCH	TOLERANCE
1.	SHANKING OR SHIFTING OF THE HEAD UNDER THE KNOCKS OF HAMMER.		NOT ALLOWED
2.	CAULKING OF THE HEAD		NOT ALLOWED
3.	IMPROPER BEARING OF THE HEAD ON THE ELEMENT WHILE RIVETTING ALONG THE ENTIRE CONTOUR OF HEAD.		NOT ALLOWED
4.	IMPROPER BEARING OF THE HEAD ON THE ELEMENT WHILE RIVETTING ALONG THE ENTIRE PART OF CONTOUR OR RIVET.		NOT ALLOWED
5.	PRESENCE OF CRACKS IN THE HEAD.		NOT ALLOWED
6.	NOTCH IN THE HEAD.		2 mm
7.	SHIFTING OF HEAD FROM THE AXIS OF RIVET.		b ≤ 0.1d
8.	BAD SHAPE OF HEAD ALONG THE PART OF CONTOUR OF RIVET.		a + b ≤ 0.1d
9.	BAD SHAPE OF HEAD ALONG THE ENTIRE CONTOUR OF RIVET.		a + b ≤ 0.1d
10.	HEAD OF REDUCED DIMENSION.		a + b ≤ 0.1d c ≤ 0.5d
11.	CROWN NEAR THE HEAD.		NOT ALLOWED
12.	NOTCHING OF STEEL BY SNAP.		NOT ALLOWED
13.	UVEVENNESS OF THE SURFACE OF THE HEAD.		a ≤ 0.3 mm
14.	OBLIQUE RIVETTING.		DEVIATION UP TO 3% OF THICKNESS. THICKNESS OF JOINT ELEMENTS BUT NOT MORE THAN 3mm.

Fig a4.17: Annexure IV of IRS B1 giving the defects in the Rivets

a4.8.2 Check for Geometry: For proper dimension, gauges for checking rivet dimensions and contours shall be used. The head formed in factory shall also be checked before the rivets are used.

a4.8.3 Check for Looseness: A hammer 110 gms weight and 310 mm long shall be used for rivet testing. The rivets shall be tested on dolly side and for testing, index finger of one hand shall be put on one side of the rivet head and the other side of the head shall be tapped smartly using the hammer. If vibrations are felt in the index finger, it means that rivet is loose, else the rivet is tight. Dull sound during striking also indicates loose rivets.

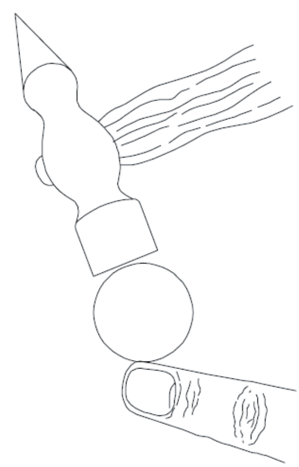


Fig a4.16 Checking for loose rivets using rivet testing hammer

a4.9 Do's and Don'ts During Riveting:

– **Do's**

i) Before riveting work is commenced, proper matching of holes must be ensured. The drifts and service bolts may be used to match the holes.

ii) Proper length of rivets shall be chosen otherwise the rivet will not have proper head and might be loose. Too short rivet length used can lead to damage to the parent steel by forming notch around the head.

iii) Riveting work shall be done systematically from one side to the other or from inside to the outside.

iv) Proper heating of the rivet to the desired temperature uniformly over the entire length of the rivet must be ensured.

v) The rivet head shall be formed in proper shape by manipulating the rivet hammer all round.

– **Don'ts**

i) Heavy drifting so as to damage the holes shall not be done. The plastic flow of material can damage the steel around the holes and can lead to cracks in service.

ii) Overburnt rivets shall not be used as these have undergone permanent metallurgical change.

iii) Rivet heads shall be checked for dimensions as well as cracks before being fed in the forge else the rivet will be rejected later on.

iv) Caulking of head to fill gap between the head and the plate shall not be done.

v) Rivets shall not be cooled suddenly by pouring water (or falling rain).

a4.10 Replacing loose/bad Rivets: All rivets found loose after testing with hammer or rejected due to the dimension defects and poor/eccentric head formation etc have to be cut and made again. Cutting of the rivets shall be done by attaching rivet cutting chisel to the riveting hammer in place of the snap. The head is cut by same percussion action which forms the rivet heads. The shank of the rivet left is then driven out by punching the same. Punching can be done by using a punching tool in the riveting hammer in place of cutting chisel. The new rivet shall then be made by the procedure already explained. A few issues in this respect are:

- The rivet testing shall be done as soon as the rivet becomes cold. The loose rivets shall be marked and the contractor shall be advised for replacing these. There are sometimes dispute regarding whether the marked rivet is actually loose or not. This dispute shall be resolved and it shall be ensured that the loose rivets are replaced before the scaffold and compressor are shifted. Otherwise, the replacement of loose rivets will become very costly and time consuming.
- The heavy force required to cut rivet head using the chisel leads to excess force on the member and can render otherwise good rivets adjoining the earlier loose rivet also loose. Sometimes, this can lead to a chain of loose rivets i.e. one loose rivet replacement leads to next rivet getting loose and so on. In this situation, the cutting of loose rivet may be done by first drilling a hole through the rivet and reducing the force required to cut it[5], or the loose rivet may be left as it is[6].

[5] This procedure is given in Annexure 11/12 of IRBM

[6] As per clause 215(1)(i) of IRBM, slight slackness of rivets does not lead to loss of strength and such rivet may be left as it is. This, however, is the option of last resort for the new girder being fabricated and assembled. This is also not allowed for the finger loose rivets or the rivets with badly formed heads and/or other signs of bad workmanship.

a4.11 Painting after riveting: In workshop, the painting of the members may be done after the riveting is done, so no special painting on rivets is required to be done. However, in field, the painted members are being assembled together and in this case, extra corrosion protection to the rivet heads has to be done. The rivet heads shall be covered with one coat of Zinc Chromate primer to IS: 104 followed Red Oxide zinc chrome primer paint to IS: 2074. The top coat of paint which is applied to the entire girder after launching is complete shall be applied on the rivets also.

Fig a4.17 Rivet heads painted after loose rivets replaced

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ANNEXURE - V

CORROSION PROTECTION DURING FABRICATION

a5.1 Introduction: The biggest problem with steel structures is that if exposed to atmosphere, these corrode over time. A number of steps can be taken during fabrication to ensure the good performance of steel structure in service. These are explained hereinafter.

a5.2 Good Fabrication Practices: The steel corrodes wherever water and dust/ dirt accumulates. To prevent corrosion, during fabrication, it shall be ensured that:

a) The flat areas such as horizontal gussets are made with slight slope to drain water away from the steel structure.

b) In complicated layout where providing above mentioned slope is not possible, drainage holes shall be provided in consultation with the designer to drain out any water falling on strucure.

c) Location where vertical plates/members are joined together, such as top lateral bracing in open web through type girders having back-to-back angles, good fit must be ensured so that water is prevented from accumulating between the members. In addition, putty may be filled in the joint to seal the entry of water. Designer can also be requested to modify design to provide a top cover plate which will prevent ingress of water.

a5.3 Corrosion Protection of Hidden or Inaccessible Areas During Fabrication: There are certain steel sections which join together during fabrication. The contact area between the two steel sections cannot be accessed during the life of the structure for painting but these surfaces can corrode due to the ingress of moisture and air. To protect these surfaces from corrosion during service, as per clause 20.1 of IRS B1, "All permanent contact surfaces shall be removed of paint and mill scale, cleaned, dried and immediately a layer of Zinc Chrome Red Oxide Priming to IS:2074 shall be applied". For inaccessibly areas, clause 39.3 of IRS B1 says "The **surfaces which are inaccessible for cleaning and painting after fabrication shall be applied one heavy coat of zinc chrome red oxide priming to IS:2074 before being assembled** for riveting/welding."

a5.4 Corrosion Protection of Fabricated Steelwork Before Dispatch: IRS B1 specifies that if the purchaser has specified, the steel structures shall be painted before dispatch. The painting shall be either ordinary paints or metallising/ epoxy paints shall be applied as per site conditions:

a) For locations where the girders are subjected to salt spray such as in close vicinity of the sea and/or over creeks etc, metallising shall be done. (Clause 39.2.1 of IRS B1)

b) For locations where girders are exposed to corrosive environment i.e. flooring system of open web girders in all cases, girders in industrial, suburban or coastal areas etc, protective coating by metallising or painting using epoxy based may be done. (Clause 39.2.2 of IRS B1)

c) For other locations, protective coating by normal painting shall be applied. (Clause 39.2.3 of IRS B1)

d) As per clause 39.6 of IRS B1, **when doing painting during fabrication, only one layer of the top coat shall be applied in workshop. The second layer of the top coat shall be applied at site after the portions of paint affected by the wear/ abrasion during assembly/ launching of girders have been touched and repaired.** This will ensure sufficient corrosion protection to the surface after launching and also will ensure good uniform look to the newly launched girder. If epoxy painting is to be done, however, the entire painting is done in shop and touching shall be done after erection, if necessary.

a5.5 Procedure for Metallsing: Metallising shall be done as per Annexure VII of IRS B1 and para 218 of IRBM.

a) Surface Preparation:

i) The first step is to clean the dry steel surface of any grease, oil etc by using petroleum hydrocarbon solvent.

ii) The surface shall be thoroughly cleaned and roughened by compressed air blasting or centrifugal blasting with a suitable abrasive material in accordance with Clause 3 of IS:6586. Cleaning is done by abrasives i.e. Chilled iron grit G.24, as defined in BS : 2451 or Washed salt free angular silica sand of mesh size 12 to 30 with a minimum of 40% retained on a 20 mesh screen. The abrasive is fed into hopper which has connection with air from compressor and this abrasive mixed air is used for blast cleaning.

iii) When grit is used, the blasting shall be done in an enclosed chamber so that the grit can be collected and re-used.

iv) The parameters for blasting shall be:

Air Pressure: Not less then 2.109 kg per sq.cm.

Nozzle position: At right angles to and approximately 22.5 cm. from the surface

Nozzle dia: Not exceeding 12 mm

v) The prepared surface shall be comparable in roughness with a reference surface produced in accordance with appendix A of IS:5905 and shall provide an adequate key for the subsequently sprayed metal coating. Blasted steel surface ready for metallising is shown in fig a5.1.

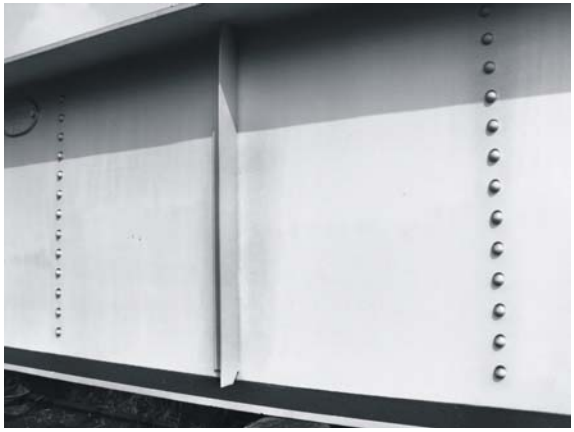


Fig a5.1: Steel Plate girder sand blasted before metallising

b) **Actual Metallising**: The metallising shall be done using a special metallising gun. The metallising gun as seen in fig a5.2 has three pipe feeds. The red pipe carries LPG or acetylene gas, the blue pipe carries oxygen and the third pipe carries air from compressor.

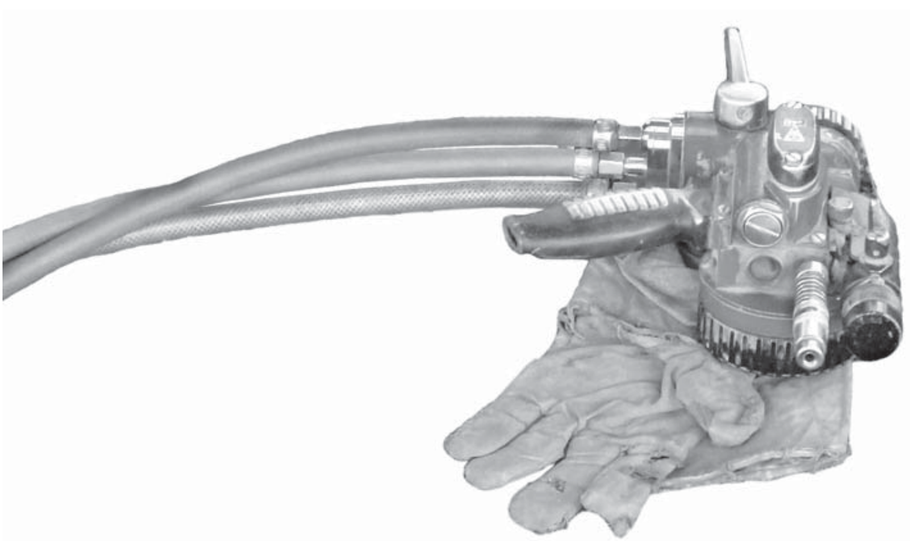


Fig a5.2: Metallising gun

The LPG/acetylene and oxygen create fire which melts the aluminium wire fed to the gun from another side. The globules of molten aluminium are sprayed onto the steel surface by pressure of air coming from compressor by the third feed. The metallising gun synchronizes these activities. The metallising in progress is shown in fig a5.3 below.

Fig a5.3: Metallising in progress

One person holds the gun and carries out the metallising process. The second person holds the aluminium wire coil and keeps uncoiling the wire as it gets consumed in the metallising process. During metallising, following shall be ensured:

i) 3 mm or 5 mm dia aluminium wire shall be used as per BS:1475, material 1-B (99.5%), otherwise as per IS : 739.

ii) The Clean dry air at a pressure of not less than 4.218 kg per sq. cm. shall be used.

iii) The minimum local thickness of metal coating applied shall be 110 microns and nominal thickness 150 microns.[1]

iv) Metallising shall be done in minimum two layers.

v) At least one layer shall be applied within 4 hours of blasting.

vi) Complete metallising thickness shall be obtained within 8 hours of blasting.

c) Quality Control During Metallising:

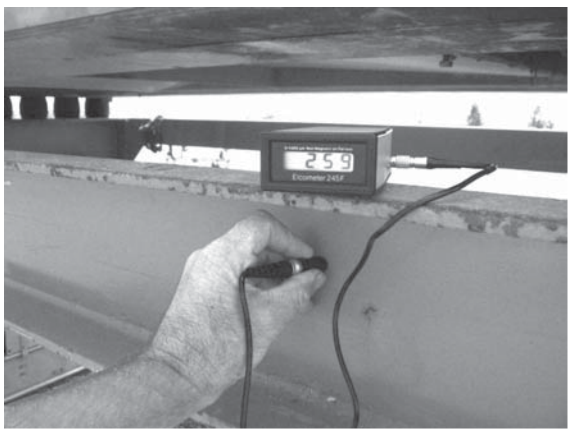
i) The metallising thickness shall be checked using magnetic elcometer

[1] This shall mean that in normal flat surface of steel structure, the thickness obtained shall be 150 microns, whereas at the river heads, edges and corners etc, the thickness can be minimum 110 microns. This gets clear if we read clause 218 (1)(ii)(b) of IRBM which uses the term "Average Thickness" in place of the term "nominal Thickness" used by the IRS B1 for 150 microns thickness.

with an accuracy of 10%. In addition to magnetic elcometer, digital elcometers are also available in market. Few elcometers are shown in fig a5.4.

(a)

(b)



(c)

Fig a5.4: Different type of elcometers a) Roll Back Type Elcometer; b) Pull Off type Elcometer; and c) Digital Elcometer

ii) **Procedure for Checking Thickness using Elcometer:** For each measurement of local thickness, make an appropriate number of determinations, according to the type of instrument used.[2] With instrument measuring the average thickness over an area of not less than 0.645 cm^2, the local thickness shall be the result of the one reading. With instruments having one or more pointed or rounded probes, the local thickness shall be the mean of three readings within

[2] The frequency of testing has not been specified in IRS B1, but clause 217 (3)(d)(i) of IRBM mentions that the checking of thickness shall be done at least 1 per sqm of painted area.
Note: This frequency is much on higher side and it would be prudent to specify some reasonable frequency in contract agreement.

a circle of 0.645 cm^2 area. With meters having two such probes, each reading shall be the average of two determinations with the probes reversed position.

iii) The elcometer shall be calibrated regularly using standard thickness gauges supplied with the equipment. Standard thickness gauges are shown in fig a5.5 below.

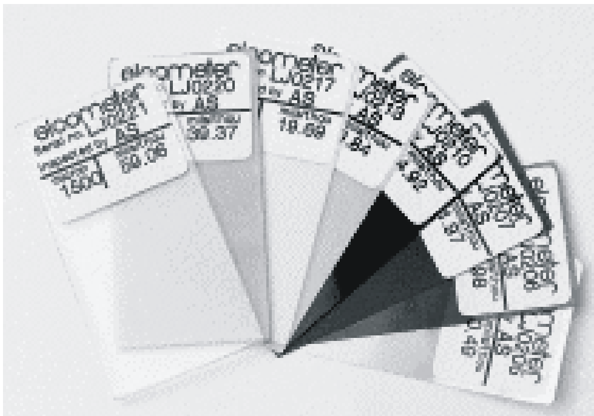


Fig a5.5: Standard thickness gauges

iv) **Adhesion Test:** To check if the metallising layer has good adhesion with the steel surface, i.e. to verify if the cleaning/ blasting has been done properly and the blasted surface has sufficient roughness to ensure the metallising layer to have good adhesion, an adhesion test shall be performed. For this, hardened steel scribe ground to a sharp 30^0 point shall be taken.

Using this scribe, make two parallel lines at a distance apart equal to approximately 10 times the average coating thickness. In scribing the two lines, apply enough pressure on each occasion to cut through the coating to the base metal in a single stroke. If a surface is properly metallised, the metallising layer between the two lines shall not come off. (Fig a5.6)

Fig a5.6: Adhesion test: Metallising between the two lines shall not come of if it has good adhesion

v) **Repair to Metallised Surface:** The metallising may fail either due to inadequate thickness of aluminium or in adhesion test. If the thickness is less, the same may be built up by adding further layer of metallising. If, however, the metallising fails in adhesion test, the complete surface shall be cleaned by blasting and metallising shall be done again.

d) **Painting After Metallising:** The metallised surface has to be protected by ordinary paint layers as follows:

i) One coat of etch primer to IS:5666. The etch primer can be brush applied or sprayed. This primer is applied so that the surface roughness is improved and the subsequent paint layers have good adhesion to the metallised surface.

ii) One coat of zinc chrome primer to IS:104 with the additional proviso that zinc chrome to be used in the manufacture of primer shall conform to type 2 of IS:51.

iii) Two coats of aluminium paint to IS:2339 shall be applied by brushing or spraying as desired. One coat shall be applied before the fabricated steel work leaves the shop. After the steel work is erected at site, the second finishing coat shall be applied after touching up the primer and the finishing coat if damaged in transit.

a5.6 Epoxy Painting:

i) Surface Preparation: Surface preparation for epoxy painting is similar to the one for metallising:

a) Remove oil/grease from the metal surface by using petroleum hydrocarbon solvent to IS:1745.

b) Prepare the surface by sand or grit blasting to Sa 2½ to IS:9954 i.e. near white metallic surface. (Fig. a5.1)

ii) Applying Epoxy Painting: The epoxy coating has three layers:

a) Primer Coats: These coats provide the strong adhesion of the epoxy coating to the cleaned steel surface. This includes brush/airless spray of two coats of Epoxy Zinc Phosphate primer to RDSO Specification No. M&C/PCN/102/86 to 60 microns min dry film thickness (DFT) giving sufficient time gap between two coats to enable the first coat of primer to hard dry.

b) Intermediate Coat: This coat provides the bulk of corrosion protection. This includes brush/airless spray of one coat of Epoxy Micaceous Iron Oxide paint to RDSO Specification No. M&C/PCN/103/06 to 100 microns minimum DFT of 100 and allow it to hard dry.

c) Finishing Coats: These coats provide the toughness to the complete painted surface and protect the complete system from abrasion damage and Ultra-Violet rays from sun. This includes brush/airless spray of two coats of polyurethane aluminium finishing to RDSO Specification No. M&C/PCN-110/06 for coastal locations or polyurethane red oxide (red oxide to ISO 446 as per IS:5) to RDSO Specification M&C/PCN-109/06 for other locations. Thickness of two coats shall be 40 microns minimum DFT and shall be applied with sufficient time gap between two coats to enable the first coat to hard dry. The finishing coats shall be applied in shop itself and touched up after erection, if necessary.

a5.7 Ordinary painting: As per clause 39.2.3 and 39.2.4, the schedule of **ordinary painting for areas not exposed to corrosive environment** shall be:

i) Primer coat: One coat of ready mixed paint zinc chrome priming to IS:104 followed by one coat of ready mixed paint red oxide zinc chrome priming to IS:2074.

or

Two coats of zinc chromate red oxide primer to IRS:P-31.

ii) Finishing coat: Two finishing coats of red oxide paint to IS:123 or of any other approved paint shall be applied over the primer coats. One coat shall be applied before the fabricated steel work leaves the shop. After the steel work is erected at site, the second finishing coat shall be applied after touching up the primer and the finishing coat if damaged in transit.

Where the life of protective coating is required to be longer to avoid frequent paintings, the problem of accessibility of locations and for other locations where metallising or epoxy based painting is recommended vide Clause 39.2.2 but there are no facilities available for the same, protective coating by painting as per following painting schedule may be applied:

iii) **Primer coat:** One coat of ready mixed zinc chrome priming to IS:104 followed by one coat of zinc chrome red oxide priming to IS:2074.

iv) **Finishing Coat:** Two coats of aluminium paint to IS:2339 shall be applied over the primer coats.

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Abbreviations Used and References

References

Abbreviation of Reference	Name of Reference	Remarks
WBC	Indian Railway Standard Code of Practice for Metal Arc Welding in Structural Steel Bridges Carrying Rail, Rail-cum-Road Or Pedestrian Traffic (Welded Bridge Code)	Adopted –1972 Upto Correction slip No 2
SBC	Indian Railway Standard Code of Practice for the Design of Steel or Wrought Iron Bridges Carrying Rail, Road or Pedestrian Traffic (Steel Bridge Code)	Adopted –1941. Upto Correction slip No 17
IRS B1	Indian Railway Standard Specification For Fabrication And Erection Of Steel Girder Bridges And Locomotive Turn-Tables (Fabrication Specification) Serial No. B1-2001	Adopted 1934, latest revision 2001. No Correction Slip.
IRBM	Indian Railways Bridge Manual	Adopted 1998, Upto Correction Slip No 21
IRS M-28	Indian Railway Standard Specification for Classification Testing and Approval of Metal Arc Welding Electrodes for use on Indian Railways	Issued 2002, Amendments 2
IRS M-39	Indian Railway Standard Specification for Classification Testing and Approval of Wire and Flux for Submerged Arc Welding for use on Indian Railways	Issued 2001, Amendments 2
IRS M-46	Indian Railway Standard Specification for Classification Testing and Approval of Filler Wire for MIG/MAG Welding for use on Indian Railways	Issued 2003, Amendments 1
IS 2062	IS 2062:2006 Hot Rolled Low, Medium And High Tensile Structural Steel	Issued 2006, Amendments 1

Abbreviations Used

Abbreviation	Standing for
MMAW	Manual Metal Arc Welding
SAW	Submerged Arc Welding
CO_2 Welding	Carbon Di-Oxide Welding
WPSS	Welding Procedure Specification Sheet
WPQR	Welder Procedure Qualification Record
FOB	Foot Over Bridge
OWG	Open Web Girder
PG	Plate Girder
MTC	Manufacturer Test Certificate
C C Cribs	Christ Church Cribs, Steel modular sections of 1.8 m x 0.6 m x 0.6 m used in railways as staging/ packing

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