41 FABRICATION AND ERECTION OF STRUCTURAL STEELWORK

1.0 INTRODUCTION

The steel-framed building derives most of its competitive advantage from the virtues of prefabricated components, which can be assembled speedily at site. Unlike concreting, which is usually a wet process conducted at site, steel is produced and subsequently fabricated within a controlled environment. This ensures high quality, manufacture offsite with improved precision and enhanced speed of construction at site.

The efficiency of fabrication and erection in structural steelwork dictates the success of any project involving steel-intensive construction. Current practices of fabrication and erection of steel structures in India are generally antiquated and inefficient. Perhaps, this inadequate infrastructure for fabrication is unable to support a large growth of steel construction. In India, the fabrication and erection of structural steelwork has been out of the purview of the structural designer. Nevertheless, in the future emerging situation, the entire steel chain, i.e. the producer, client, designer, fabricator and contractor should be able to interact with each other and improve their efficiency and productivity for the success of the project involving structural steelwork. Hence it becomes imperative that structural designers also must acquaint themselves with all the aspects of the structural steel work including the "fabrication and erection," and that is the subject matter of the present chapter to briefly introduce good fabrication and erection practices.

2.0 FABRICATION PROCEDURE

Structural steel fabrication can be carried out in shop or at the construction site. Fabrication of steelwork carried out in shops is precise and of assured quality, whereas field fabrication is comparatively of inferior in quality. In India construction site fabrication is most common even in large projects due to inexpensive field labour, high cost of transportation, difficulty in the transportation of large members, higher excise duty on products from shop. Beneficial taxation for site work is a major financial incentive for site fabrication. The methods followed in site fabrication are similar but the level of sophistication of equipment at site and environmental control would be usually less. The skill of personnel at site also tends to be inferior and hence the quality of finished product tends to be relatively inferior. However, shop fabrication is efficient in terms of cost, time and quality.

Structural steel passes through various operations during the course of its fabrication. Generally, the sequence of activities in fabricating shops is as shown in Table1. The sequence and importance of shop operations will vary depending on the type of fabrication required. All these activities are explained briefly in the subsequent parts of the section.

Table 1: Sequence of activities in fabricating shops

S.No.	Sequence of Operation
1.	Surface cleaning
2.	Cutting and machining
3.	Punching and drilling
4.	Straightening, bending and rolling
5.	Fitting and reaming
6.	Fastening (bolting, riveting and welding)
7.	Finishing
8.	Quality control
9.	Surface treatment
10.	Transportation

2.1 Surface cleaning

Structural sections from the rolling mills may require surface cleaning to remove mill scale prior to fabrication and painting.

Hand preparation, such as wire brushing, does not normally conform to the requirements of modern paint or surface protection system. However in some applications manual cleaning is used and depending on the quality of the cleaned surface they are categorised into Grade St-2 and Grade St-3.

Blast cleaning is the accepted way of carrying out surface preparation in a well-run fabrication shop. Abrasive particles are projected on to the surface of the steel at high speed by either compressed air or centrifugal impeller to remove rust and roughen the surface before applying the coating. By using shot or slag grits, both of which have an angular profile, surface oxides are removed and a rougher surface is obtained to provide an adequate key for metal spraying or special paint. Depending upon the increase in the quality of the cleaned surface, the blast cleaning is categorised into Grade – Sa2, Grade – Sa2½ and Grade Sa- 3.

Flame cleaning is another method of surface cleaning. In this method the surface is cleaned using an oxy-acetylene torch which works on the principle of differential thermal expansion between steel and mill scale. In another method called ‘ the steel piece is immersed in a suitable acid and the scale and rust are removed.

2.2 Cutting and Machining

Following surface preparation, cutting to length is always the first process to be carried out, and this is done by any of the following methods.

2.2.1 Shearing and cropping

Sections can be cut to length or width by cropping or shearing using hydraulic shears. Heavy sections or long plates can be shaped and cut to length by specialist plate shears. For smaller plates and sections, machines featuring a range of shearing knives, which can accept the differing section shapes, are available.

2.2.2 Flame Cutting or Burning

In this method, the steel is heated locally by a pressurised mixture of oxygen and a combustible gas such as propane, which passes through a ring of small holes in a cutting nozzle. The heat is focussed on to a very narrow band and the steel melts at 1500^0 C when a jet of high-pressure oxygen is released through a separate hole in the centre of the nozzle to blast away the molten metal in globules. The desired cuts are obtained quickly by this process. However due to a rapid thermal cycle of heating and cooling, residual stresses and distortion are induced and hence structural sections that are fabricated using flame cutting are treated specially in the design of structural steelwork.

2.2.3 Arc Plasma Cutting

In this method, the cutting energy is produced electrically by heating a gas in an electric arc produced between a tungsten electrode and the workpiece. This ionises the gas, enabling it to conduct an electric current. The high-velocity plasma jet melts the metal of the work piece. The cut produced by plasma jet is very clean and its quality can be improved by using a water injection arc plasma torch. Plasma cutting can be used on thicknesses upto about *150 mm* but the process is very slow.

2.2.4 Cold Sawing

When a section cannot be cut to length by cropping or shearing, then it is normally sawn. All saws for structural applications are mechanical and feature some degree of computer control. There are three forms of mechanical saw - circular, band and hack. The circular saw has a blade rotating in a vertical plane, which can cut either downwards or upwards, though the former is more common. Band saws have less capacity. Sections greater than *600 mm X 600 mm* cannot be sawn using band saws. The saw blade is a continuous metal edged, with cutting teeth, which is driven by an electric motor. Hack saws are mechanically driven reciprocating saws. They have normal format blades carried in a heavy duty hack saw frame. They have more productivity than band saws.

2.3 Punching and Drilling

Most fabrication shops have a range of machines, which can form holes for connections in structural steelwork. The traditional drilling machine is the radial drill, a manually operated machine, which drills individual holes in structural steelwork. But this method has become too slow for primary line production. Therefore, larger fabricators have installed NC (Numerically Controlled) tooling, which registers and drills in response to keyed in data. These can drill many holes in flanges and webs of rolled steel sections simultaneously. It is also possible to punch holes, and this is particularly useful where square holes are specified such as anchor plates for foundation bolts. While this method is faster compared to drilling, punching creates distortion and material strain hardening around the holes, which increase with material thickness. Its use is currently restricted to smaller thickness plates. In order to reduce the effect of strain hardening and the consequent reduction in ductility of material around punched holes, smaller size (*2 mm* to *4 mm* lesser than final size) holes are punched and subsequently reamed to the desired size.

2.4 Straightening, Bending and Rolling

Rolled steel may get distorted after rolling due to cooling process. Further during transportation and handling operations, materials may bend or may even undergo distortion. This may also occur during punching operation. Therefore before attempting further fabrication the material should be straightened. In current practice, either rolls or gag presses are used to straighten structural shapes.

Gag press is generally used for straightening beams, channels, angles, and heavy bars. This machine has a horizontal plunger or ram that applies pressure at points along the bend to bring it into alignment. Long plates, which are cambered out of alignment longitudinally, are frequently straightened by rollers. They are passed through a series of rollers that bend them back and forth with progressively diminishing deformation.

Misalignments in structural shapes are sometimes corrected by spot or pattern heating. When heat is applied to a small area of steel, the larger unheated portion of the surrounding material prevents expansion. Upon cooling, the subsequent shrinkage produces a shortening of the member, thus pulling it back into alignment. This method is commonly employed to remove buckles in girder webs between stiffeners and to straighten members. It is frequently used to produce camber in rolled beams. A press brake is used to form angular bends in wide sheets and plates to produce cold formed steel members.

2.5 Fitting and Reaming

Before final assembly, the component parts of a member are fitted-up temporarily with rivets, bolts or small amount of welds. The fitting-up operation includes attachment of previously omitted splice plates and other fittings and the correction of minor defects found by the inspector.

In riveted or bolted work, especially when done manually, some holes in the connecting material may not always be in perfect alignment and small amount of reaming may be required to permit insertion of fasteners. In this operation, the holes are punched, *4 to 6 mm* smaller than final size, then after the pieces are assembled, the holes are reamed by electric or pneumatic reamers to the correct diameter, to produce well matched holes.

2.6 Fastening Methods

The strength of the entire structure depends upon the proper use of fastening methods. There are three methods of fastening namely bolting, riveting and welding. A few decades back, it was a common practice to assemble components in the workshop using bolts or rivets. Nowadays welding is the most common method of shop fabrication of steel structures. In addition to being simple to fabricate, welded connection considerably reduce the size of the joint and the additional fixtures and plates. However, there is still a demand for structural members to be bolted arising from a requirement to avoid welding because of the service conditions of the member under consideration. These may be low temperature performance criteria, the need to avoid welding stresses and distortion or the requirement for the component to be taken apart during service e.g. bolts in crane rails or bolted crane rails.

2.7 Finishing

Structural members whose ends must transmit loads by bearing against one another are usually finished to a smooth even surface. Finishing is performed by sawing, milling or other suitable means. Several types of sawing machines are available, which produce very satisfactory finished cuts. One type of milling machine employs a movable head fitted with one or more high-speed carbide tipped rotary cutters. The head moves over a bed, which securely holds the work piece in proper alignment during finishing operation.

Bridge specifications require that sheared edges of plates over a certain thickness be edge planed. This is done to remove jagged flame cut edges and the residual stresses at the edges. In this operation, the plate is clamped to the bed of milling machine or a planer. The cutting head moves along the edge of the plate, planing it to a neat and smooth finish.

The term finish or mill is used on detail drawings to describe any operation that requires steel to be finished to a smooth even surface by milling, planing, sawing or other machines.

2.8 Surface Treatment

Structural steelwork is protected against corrosion by applying metal or paint coating in the shop or at site.

2.8.1 Metal Coatings

The corrosion protection afforded by metallic coating largely depends upon the surface preparation, the choice of coating and its thickness. It is not greatly influenced by the method of application. Commonly used methods of applying metal coating to steel surfaces are hot-dip galvanising, metal spraying, and electroplating. Electroplating is generally used for fittings and other small items.

Galvanising is the most common method of applying a metal coating to structural steelwork. In this method, the cleaned and fluxed steel is dipped in molten zinc at a temperature of about 450^0C. The steel reacts with molten zinc to form a series of zinc or iron alloys on its surface. As the steel workpiece is removed, a layer of relatively pure zinc is deposited on top of the alloy layers. For most applications galvanised steel does not require painting.

An alternative method of applying metallic coating to structural steelwork is by metal spraying of either zinc or aluminium. The metal, in powder or wire form, is fed through a special spray gun containing a heat source, which can be either an oxy-gas flame or an electric arc. Molten globules of the metal are blown by a compressive jet on to the previously blast cleaned steel surface. No alloying occurs and the coating, which is produced, consists of porous overlapping platelets of metal. The pores are subsequently sealed, either by applying a thin organic coating which soaks into the surface, or by allowing the metal coating to weather, when corrosion products block the pores.

2.8.2 Paint Coatings

Painting is the principal method of protecting structural steelwork from corrosion. Paints are usually applied one coat on top of another, each coat having a specific function or use.

The primer is applied directly on to the cleaned steel surface. Its purpose is to wet the surface and to provide good adhesion for subsequently applied coats. Primers for steel surfaces are also usually required to provide corrosion inhibition. They are usually classified according to the main corrosion-inhibitive pigments used in their formulation, e.g. zinc phosphate, zinc chromate, red lead, and metallic-zinc. Each of these inhibitive pigments can be incorporated into a range of binder resins e.g. zinc phosphate alkyd primers, zinc phosphate epoxy primers, zinc phosphate chlorinated-rubber primers.

The intermediate coats (or undercoats) are applied to build the total film thickness of the system. This may involve application of several coats. The finishing coats provide the first-line defence against the environment and also determine the final appearance in terms of gloss, colour etc. They also provide UV protection in exposed condition. Intermediate coats and finishing coats are usually classified according to their binders, e.g. vinyl finishes, urethane finishes.

The various superimposed coats within a painting system have, of course, to be compatible with one another. They may be all of the same generic type or may be different, e.g. chlor-rubber base intermediate coats that form a film by solvent evaporation and no oxidative process, may be applied on to an epoxy primer that forms a film by an oxidative process which involves absorption of oxygen from the atmosphere. However, as a first precaution, all paints within a system should normally be obtained from the same manufacturer. The reader may refer to *IS:487(1985)* to know more about the surface treatment using paints.

Detailed treatment of corrosion protection systems will be found in the Chapter on 'Corrosion, fire protection and fatigue considerations of steel

2.9 Welded connections

Welding is used extensively for joining metals together and there is no doubt that it has been a most significant factor in the phenomenal growth of many industries. The different terminology used in welds are explained in *IS:812(1957)*.
A welded joint is made by fusing (melting) the steel plates or sections along the line of joint. The metal melted from each member of the joint unites in a pool of molten metal, which bridges the interface. As the pool cools, molten metal at the fusion boundary solidifies, forming a solid bond with the parent metal. When solidification completes, there is a continuity of metal through the joint.

There are five welding process regularly employed namely:

(i) Shielded Metal Arc Welding (SMAW)
(ii) Submerged-Arc Welding (SAW)
(iii) Manual Metal-Arc welding (MMA)
(iv) Metal-Active Gas welding (MAG)
(v) Stud welding

All these methods of welding has been described with illustrations, in the chapter on 'Welds - Static and Fatigue Strength - I'. Nevertheless, for the sake of completeness, these methods are briefly enumerated below.

2.9.1 Methods of welding

(1) Shielded Metal Arc Welding (SMAW)

This is basically a semi-automated or fully automated welding procedure. The type of welding electrode used would decide the weld properties. Since this welding is carried out under controlled condition, the weld quality is normally good.

(2) Submerged-Arc welding (SAW)

This is fully mechanised process in which the welding head is moved along the joint by a gantry, boom or tractor. The electrode is a bare wire, which is advanced by a motor. Here again, since the welding is carried out in controlled conditions, better quality welds are obtained.

(3) Manual Metal-Arc welding (MMA)

This is the most widely used arc welding process and appears to be advantageous for labour intensive Indian construction practices. As it is manually operated it requires considerable skill to produce good quality welds. Hence in the case of MMA, stringent quality control and quality assurance procedures are needed. In India, the Welding Research Institute, BHEL, Trichy, Tamil Nadu, conducts periodical courses for welders and weld inspection personnel. Welders who are employed in actual fabrication are, infact, graded according to their training and skills acquired.

(4) Metal-Active Gas welding (MAG)

This process is sometimes referred to as Metal-Inert Gas (MIG) welding. It is also manually operated. A gas that does not react with molten steel shields the arc and the weld pool. This protection ensures that a sound weld is produced free from contamination-induced cracks and porosity. Nevertheless, this procedure also depends on the skills of the welder.

(5) Stud welding

This is an arc welding process and is extensively used for fixing stud shear connectors to beam in the composite construction. The equipment consists of gun hand tool (Fig.1(a) and 1(b)), D.C. power source, auxiliary contractor and controller. The stud is mounted into the chuck of the hand tool and conical tip of the stud is held in contact with the work piece by the pressure of a spring on the chuck. As soon as the current is switched on, the stud is moved away automatically to establish an arc. When a weld pool has been formed and the end of the stud is melted the latter is automatically forced into the steel plate and the current is switched off. The molten metal, which is expelled from the interface, is formed into a fillet by a ceramic collar or ferrule, which is placed around the stud at the beginning of the operation. The ferrule also provides sufficient protection against atmospheric contamination (Figs. 1(a) and 1(b)).

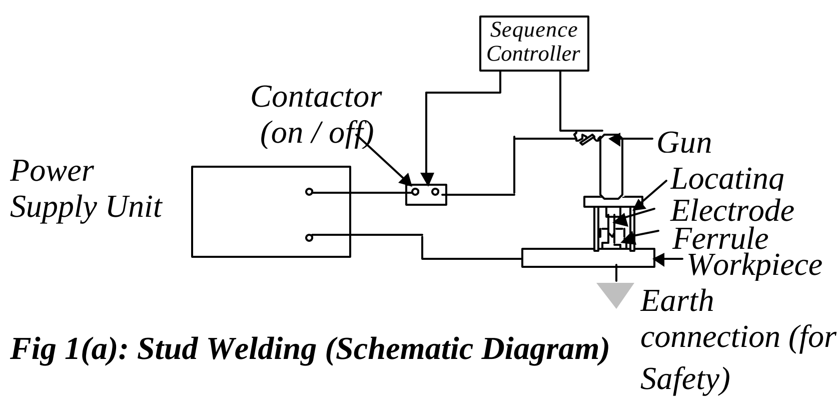
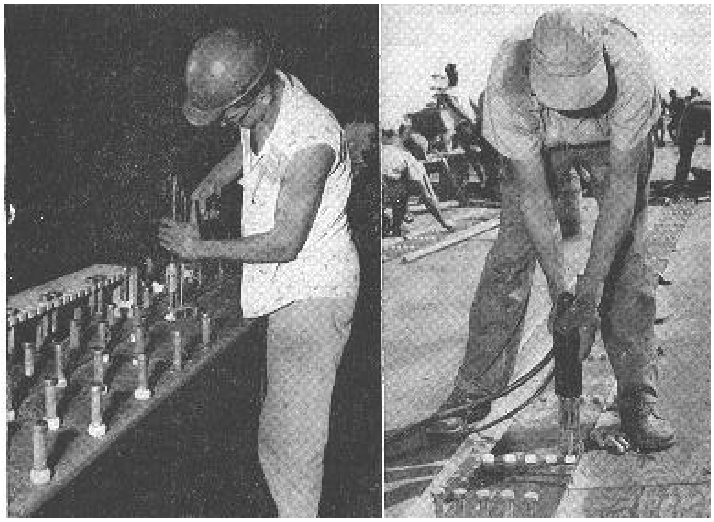


Fig 1(a): Stud Welding (Schematic Diagram)

This process offers an accurate and fast method for attaching shear connectors, etc with the minimum distortion. While it requires some skill to set up the weld parameters (voltage, current, arc time and force), the operation of equipment is relatively straight forward.



(a) Shop welding *(b) Site welding*

Fig.1 (b) Stud Welding on composite beam

3.0 RESIDUAL WELDING STRESSES AND DISTORTION

3.1 Residual welding stresses

When a weld such as a butt weld is completed and begins to cool the hot weld and parent metal contracts longitudinally. The surrounding cold parent metal resists this contraction so that the weld is subjected to a tensile stress. This is balanced by the compressive stresses induced in the cold regions of the parent plate. These self-equilibrating forces introduce residual stresses both in the longitudinal and transverse direction. These stresses can even reach yield stress. Hence, the fabricator should adopt good fabrication practices that reduce the detrimental effect of residual stresses.

3.2 Residual distortions due to welding

3.2.1 Butt welds

Fig. 2 shows a typical angular rotation of the plates due to a single V butt weld. This occurs because the major part of the weld is to one side of the neutral axis of the plate. This induces greater contractile stresses on that side. A double V or double U butt weld preparation reduces this distortion.

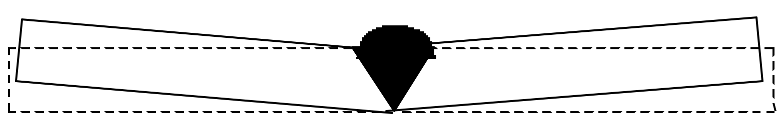


Fig 2: Angular distortion of butt weld

The welding sequence for double preparation has an important influence on the resultant distortion. If a few weld runs are first made on one side, and the plate turned over and then the same number of runs are made on the second side (i.e., sequential welding), a 'balanced' weld will be produced with little distortion. This will not, of course, be possible in situations where rotation of the plate is impracticable such as a plate, which is part of a large fabrication.

One aspect of butt-welding that should be noted is where back gouging is necessary to produce a full penetration weld. This can lead to distortion because the back gouging will produce bigger weld on the second side about the neutral axis of the plate. Such distortion can be reduced using an unsymmetrical weld section. Single V butt welds may produce cusping as shown in Fig.3 if the overall plate is restrained. This can be reduced by using a double V butt weld.

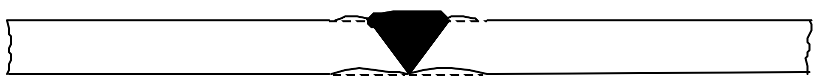


Fig 3: Cusping due to transverse butt weld

3.2.2 Fillet welds

In single and double fillets, shrinkage across the throat area can lead to distortion as shown in Fig.4. The distortion caused by a double fillet weld is important in box or plate girder webs where stiffeners are attached to only one side of the web. The use of a thicker plate can reduce the fillet weld angular distortion due to increased stiffness.

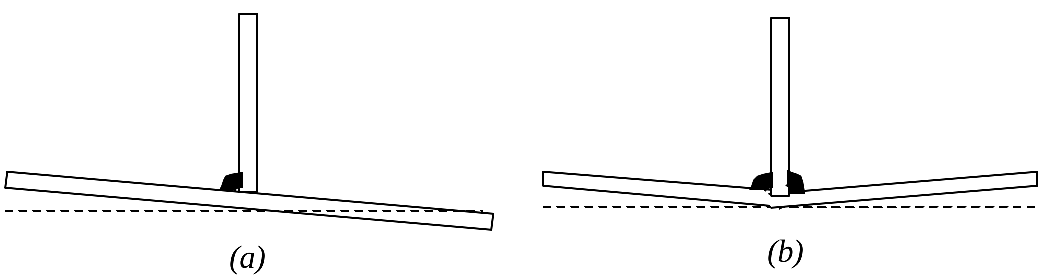
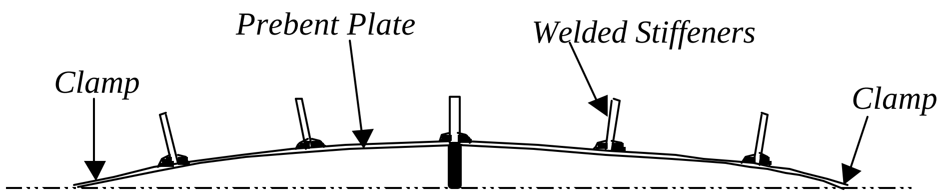


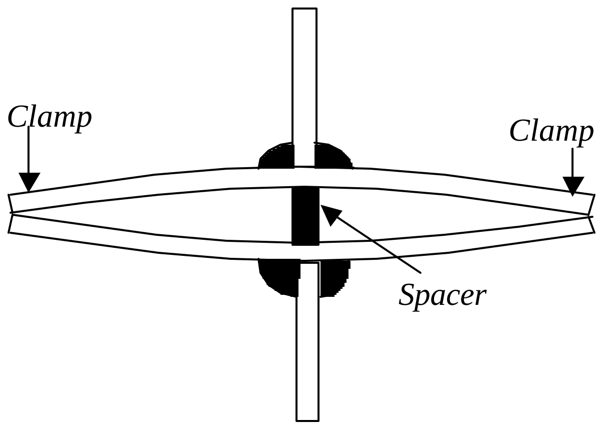
Fig 4: Angular distortion of fillet welds

3.3 Control of distortion

Some distortion from welding is due to transverse and longitudinal contraction of weldments. Adopting suitable methods that can resist contraction can control the distortion. Weld distortion of a flat plate with a series of stiffeners on one side can be countered by elastically prebending the plates. In a similar manner two T sections can be welded, prebent back to back, to prevent final curvature in the web plate. Presetting the flange plate at an angle initially as shown in Fig.5 and Fig.6 may reduce the angular rotation due to a single fillet.



(a) Prebent Plate



(b) Prebent T's

Fig 5: Prebending

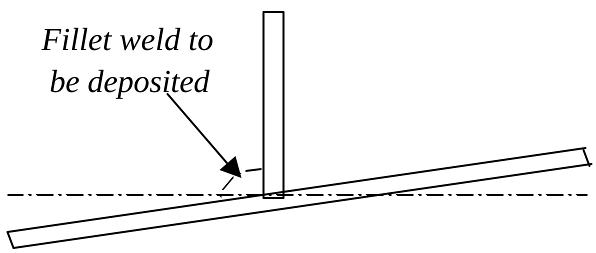


Fig 6: Preset for fillet weld

Sometimes both presetting and prebending may be required, e.g. in plate girder fabrication where the web to flange welds are made automatically. When the welds are made manually, it is customary to put the stiffeners into the girder before the web/flange welds are made; in this way the square profile of the web to flange is maintained. Where automatic welding is employed the stiffeners cannot be put first since they would impede the progress of the automatic machine; in this presetting of the flange plates may be required. Welding should preferably be started at the centre of the fabrication and all succeeding welds from the centre outwards. This allows contraction to occur in the free condition. If the welding sequence is not chosen correctly, locked up stresses at either end of a welded portion can lead to uncorrectable distortions.

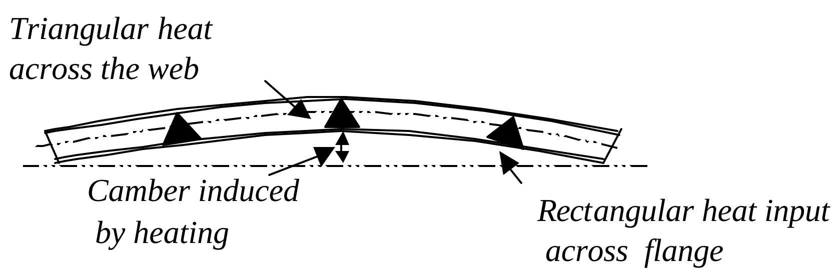
Restraint procedure to reduce the effect of weld distortion should be carefully planned otherwise it can lead to solidification cracking.

3.4 Methods of correcting distortion

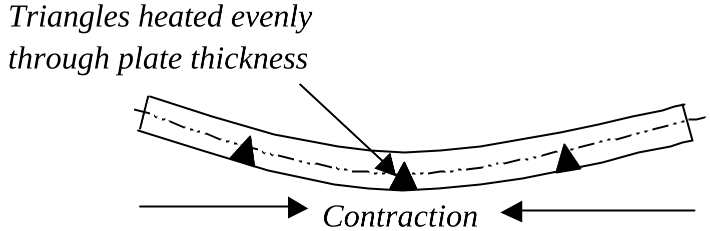
In general, there are two methods available to correct distortion namely:

(a) applying force and (b) heating

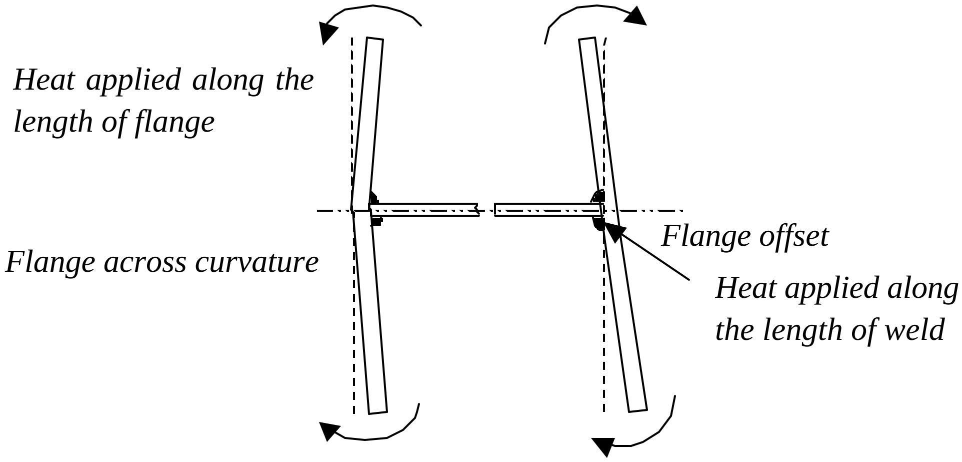
Light sections can be corrected by applying force such as by hydraulic presses and local jacking or wedging. While heavier structures will require heating to apply stresses to reduce or eliminate the distortion. The effect of heating is similar to that of welding in which distortion results from the induced stresses. An area of steelwork will expand when heated but this expansion will be constrained by the surrounding cold unheated area, causing a plastic upset. On cooling, the area contracts and the element then becomes shorter, this principle can be used to correct or induce any curvature. The heat must be evenly applied right through the material, if not, unwanted curvature may occur in the plan of the section. Fig.*7* shows some of the methods to induce and correct distortion. Fig.*7(c)* shows how it can be applied to a H section in which a camber is required. Rectangular heating across the bottom flange will shorten it compared with the top flange and hence induce camber. Since the shortening of the flange in the heated areas may tend to buckle the web adjacent to the flange, the heat is also applied to the web in a triangular manner such that the most affected part of the web contracts with the flange. In a similar manner a cambered plate may be straightened by applying triangular heating with the bases of the triangles parallel to the plate edges to be shortened. When the plate cools the heated edge will shorten and so reduce the camber. For panels in box girder webs, spot heating as shown in Fig.*7(d)* may be employed to reduce the concavity produced by the welding around the panel perimeter. Each spot contracts on cooling and induces a local plate shrinkage within the panel boundary and so reduces the dish. If the heat applied and the web panel thickness are such that there is a large temperature difference between the surfaces of the plate at each spot heat, then the resultant contraction on the hotter surface will produce a greater correction of the dish.



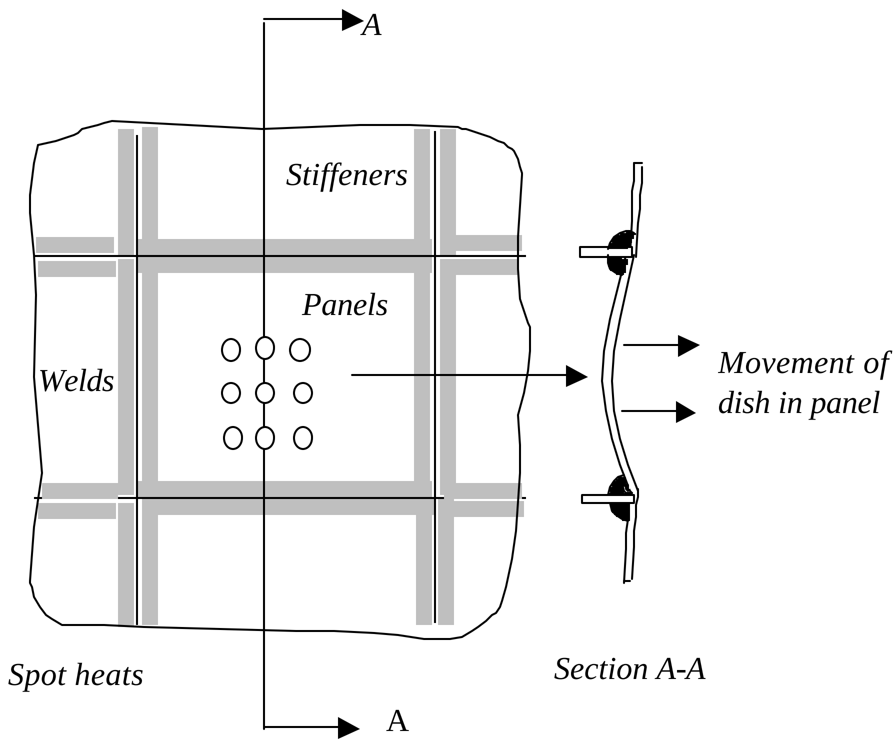
7(a) Camber of beam by heating



7(b) Cambered Plate



7(c) Distorted flanges



7(d) Spot Heating of dished Panel

Fig 7. Methods of correction of distortion

3.5 Defects in welds

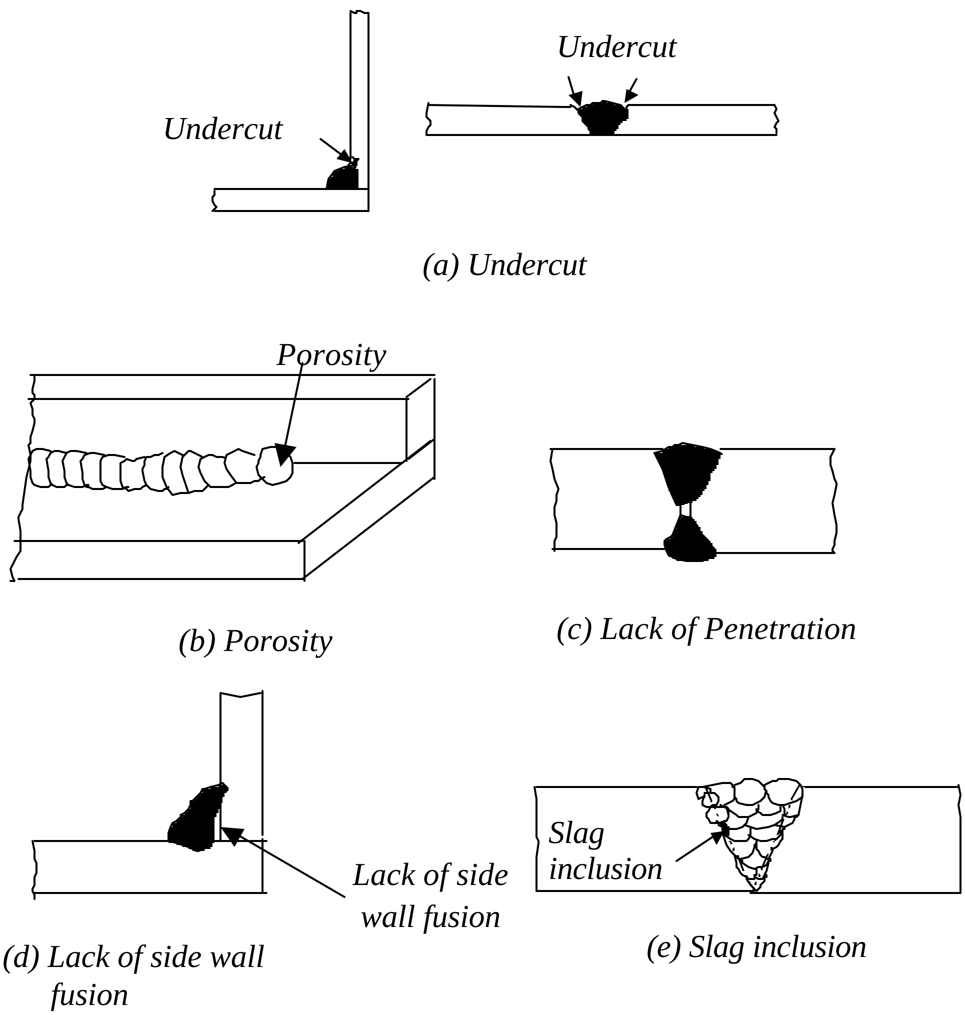
Faulty welding procedure can lead to defects in the welds, thereby reducing the strength of the weld.
Fig.*8* shows some of the common defects in welds. Some of these are:

(i) Undercut

(ii) Porosity
(iii) Incomplete Penetration
(iv) Lack of side wall fusion
(v) Slag inclusions
(vi) cracks

All these weld defects are discussed in the chapter on 'Weld – Static and Fatigue strength – I'. It should be emphasised that a 'theoretical 100% error free' weld is not achievable in practice. While good quality welds are the priority of welders and weld inspectors, minor defects do normally creep in. Hence these defects are assessed during a weld inspection.

If the defects are within acceptable limits, they are accepted. If not, alternative measures of rectification may have to be carried out. Table *2* shows nature of some of the defects and their acceptability limits.



(a) Undercut

(b) Porosity

(c) Lack of Penetration

(d) Lack of side wall fusion

(e) Slag inclusion

Fig8: Defects in welds

Table 2: Nature of defects and their acceptability limits.

Nature of Defect	Acceptance Norms	Disposition
1. Crack, Lack of Fusion	Not accepted	Confirm by Magnetic Particle Inspection, repair and retest.
2. Crater	Not accepted	Fill by weld deposit.
3. Undercut	Upto *0.8 mm* accepted	Fill and grind smooth.
4. Porosity for butt or fillet welds	One pore of dia. < *2.4 mm* every *100 mm* length is permitted. However pores of dia. > *2.4 mm* not accepted	To be repaired.

4.0 QUALITY CONTROL IN FABRICATION

Quality assurance during fabrication assumes utmost importance in ensuring that the completed structure behaves in the manner envisaged during design stage. Any deviation from these design considerations as reflected in detail drawings may introduce additional stresses to the structure and affect its strength and durability. This section discusses the relevant aspects in fabrication and erection, which need to be considered to achieve the desired quality.

4.1 Fabrication

A fabricator's work starts from the point of procurement of raw materials including fasteners and ends with the dispatch of the fabricated items to site for erection.

In order to ensure that the fabrication can be carried out in accordance with the drawings, it is necessary that inspection and checking is carried out in accordance with an agreed Quality Assurance Plan (QAP). The plan should elaborate on checks and inspections of the raw materials and also of the components as they are fabricated, joined etc.

During the last two decades, fabrication activities have increased steadily in yards adjacent to work. In the absence of controlled environment (as in an organised workshop), the quality of workmanship of such fabrication is likely to suffer. It has, therefore, become all the more important to motivate the fabricators to appreciate the usefulness of Quality Assurance Plans and introduce the system in all their works and at site as well.

4.1.1 Imperfections in Fabrication

Structural steelwork cannot be fabricated to exact dimensions and some degree of imperfection is bound to occur during fabrication process. The limits of various imperfections are spelt out in the specifications. In the design, these are accounted by adopting a factor of safety for material. However, in some components an increase of imperfection beyond these limits may lead to reduction in the strength and durability of the structure e.g., imperfections on the straightness of the individual flanges of a rolled beam or a fabricated girder results in the reduction of strength of the girder due to lateral torsional buckling which may cause an overall bow in the girder. This, in turn, may generate twisting moments at the supports.

As a rule all columns and struts should be checked for straightness on completion of fabrication. Also, all rolled and fabricated girders should be checked over a distance in the longitudinal direction equal to the depth of the section in the region and points of concentrated load.

4.1.2 Making holes

Excessive cold working of structural steel can cause reduction in ductility, embrittlement and cracking. Punching holes is a cold-working operation and can, therefore, cause brittle fracture. This becomes critical for the durability of structures subjected to fluctuation of stresses such as railway bridges and crane girders. Under cyclic loading fatigue cracks can initiate from such punched holes. In such cases, holes for bolts may be formed either by drilling or by punching undersize holes followed by reaming to desired size. Drilling is preferable to punching, because it reduces the chances of brittle fracture. Studies show that punching may produce short cracks extending radially from the hole, thereby enhancing the possibility of initiating brittle fracture at the hole when the member is loaded. Even in statically loaded structures the maximum thickness of plates in which holes can be punched is restricted.

4.1.3 Shop assembly and camber check

For important structures particularly for bridges, it is necessary to have the fabricated units temporarily assembled at the place of fabrication before these are dispatched to site for erection. During this operation, the overall dimensions of the structure including alignment, squareness, camber etc. should be confirmed. Inadequate or erroneous camber, in fact, introduces huge secondary stresses in the members instead of eliminating these as originally desired. Shop assembly also ensures that the open holes drilled in various units are within tolerable limits.

4.1.4 Welded joints

As presented in the previous sections, welded joints are very important as far as the quality control of the joints is concerned. It is well known that joints are the last straw of strength in structural steelwork. Any poor quality weld would detrimentally affect the joint and in turn affect the performance of the whole structure itself. Hence welded joints need thorough inspection during and after the fabrication. Different methods of Non-Destructive Testing (NDT) and evaluation of welds are available. The NDT procedures are elaborated in the chapter on 'Welds Static and Fatigue Strength – I'. Depending upon the severity of service loading, the QAP may call for the level of NDT to be used. Guidance could be obtained from *IS:822(1970)* for the inspection of the welded joints.

5.0 ERECTION

5.1 General

Erection of steel structures is the process by which the fabricated structural members are assembled together to form the skeletal structure. The erection is normally carried out by the erection contractor. Generally the steps that are involved in the erection of steel structures are shown in Table 3. The erection process requires considerable planning in terms of material delivery, material handling, member assembly and member connection. Proper planning of material delivery would minimise storage requirement and additional handling from the site storage, particularly heavy items. Erection of structural steel work could be made safe and accurate if temporary support, falsework, staging etc. are erected. Before erection the fabricated materials should be verified at site with respect to mark numbers, key plan and shipping list. The structural components received for erection should be stacked in such a way that erection sequence is not affected due to improper storing. Care also should be taken so that steel structural components should not come in contact with earth or accumulated water. Stacking of the structures should be done in such a way that, erection marks and mark numbers on the components are visible easily and handling do not become difficult. From the earlier discussion it should emphasised that safe transportation of fabricated items to the site, their proper storage and subsequent handling are the pivotal processes for the success of fabrication of structural steel work.

Table 3: Sequence of Activities during Erection

S.No.	Sequence of Operation
1.	Receiving material from the shop and temporarily stacking them, if necessary.
2.	Lifting and placing the member and temporarily holding in place.
3.	Temporarily bracing the system to ensure stability during erection.
4.	Aligning and permanently connecting the members by bolting or welding.
5.	Connecting cladding to the steel structural skeleton.
6.	Application of a final coat of painting.

Guidance for handling and storage for material shall be obtained from *IS: 7969(1975*). The fabrication at shop or site should be so planned that units to be handled weigh nearly the same. The erection drawing should reach the site of construction well in advance to plan the erection sequence and material handling. Erection should be carried out with the help of maximum possible mechanisation. Normally anyone or more of the material handling systems, such as tower crane; crane mounted on rails, crawling crane, pneumatic tire mounted crane, and derrick crane may be used for handling the material. Details of the above said erection equipments can be found in any standard textbooks on construction equipment.

A variety of methods can be employed for the erection of a structure. Normally, the selection of the method is influenced by the type of the structure, site conditions, equipment, quality of skilled labour, etc. available to the erector.

However, regardless of the method adopted the main aim during erection is the safety and preservation of the stability of the structure at all times. Most structures which collapse do so during erection and these failures are very often due to a lack of understanding on someone's part of what another has assumed about the erection procedure. Hence, it is emphasised that as far as strength and stability of the components during erection are concerned, they must satisfy the provision of *IS: 800(1984)*. For the guidance on general fabrication and erection of structural steel work, Chapter 11 of IS:800 (1984) must be followed. As far as safety is concerned guidance could be obtained from Indian safety code for structural steelwork *IS:7205(1974)*. Before the commencement of the erection, all the erection equipment tools, shackles, ropes etc. should be tested for their load carrying capacity. Such tests if needed may be repeated at intermediate stages also.

5.2 Bracings

During the entire erection period, the steelwork should be securely bolted or otherwise fastened and braced to take care of the stresses from erection equipment or the loads carried during erection. In addition to this, adequate provisions to resist lateral forces and wind loads during erection should also be made according to local conditions.

Normally bracings are built into all types of structures to give them a capability to withstand horizontal forces produced by wind, temperature and the movements of crane and other plant in and on the building. Bracings can be permanent or temporary.

Temporary bracings required at some stages of the work must have properly designed connections and should be specifically referred to in the erection method statement.

The decision on sequence of erection such as which member should be erected first for providing initial stability to the structure or whether temporary bracings should be used for this purpose should be taken at an early stage of planning of the erection process. Fig.*9* illustrates this point. As permanent bracings have been provided in AB, bay erection should logically start from AB bay to give stability and ensure proper alignment of the erected structure. In case, for some reason erection has to start from DE bay, it would be necessary to provide temporary bracings in this bay. The bracing system should be retained till the permanent bracings are fixed in the AB bay. Any mis-alignment at initial stage will impair the performance, of the structure when completed. Early or unauthorised removal of temporary bracings is a common cause of collapse in a partially completed frame.

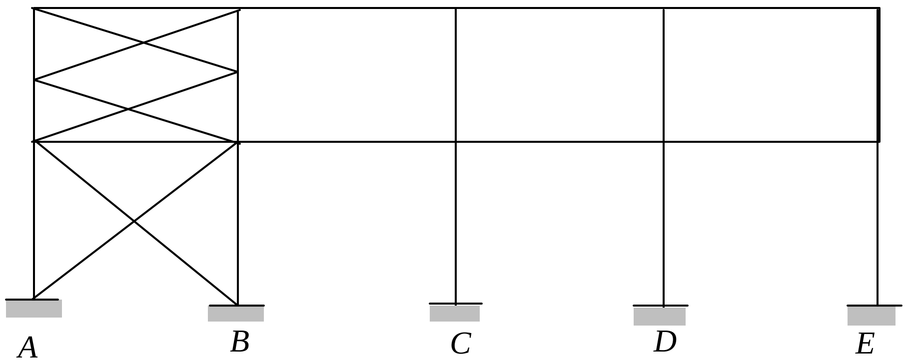


Fig 9. Bracing System

Having considered the need for installing temporary bracings and the need to postpone fixing permanent bracings, consideration should be given to the overall economy of retaining the temporary bracings and perhaps leaving out the permanent bracings. It is a costly and potentially dangerous business to go back into a structure solely in order to take out temporary members, or to insert components that had to be left out temporarily.

5.3 Maintaining tolerances

The best way of erecting a structure within the acceptable tolerance limits is to make sure that accuracy is achieved from the very beginning of the job.

Table 4: Maximum permissible tolerance in erected steel structures

S.No	Description	Tolerance in(mm)
1.	**Columns:** Out of plumbness of column axis from true vertical axis	
(i)	Heights upto *30 m*	$\pm\ell/1000$ or ± 25 whichever is less
(ii)	Heights over *30 m*	$\pm\ell/1200$ or ± 35 whichever is less
2.	**Trusses:** Lateral shift in location of truss from its true vertical position	± 10
3.	**Crane girders and ribs:** Shift in plane of alignment with respect to true axis of crane rail.	± 5
4.	**Chimney and towers:** Out of plumbness (vertically from true vertical axis)	*1/1000* of the height of the chimney or tower

Thus quality control must start from the setting out of the foundations and the holding down bolts. This operation is often done at a stage when site conditions are disorderly and most untidy and the environment appears to be incongruous to accuracy. However, inaccuracies in marking the centrelines and the levels of foundations allowed at this stage are likely to cause misfit in the connections and misalignment of the structure leading to secondary stresses in the members. In such areas corrective measure must be taken by way of locally modifying some of the components so as to eliminate the mismatch. Table 4 shows some typical tolerances that are accepted in structural steel work.

5.4 Joints

Most steel structures are fabricated by either bolting or welding in the shop and bolting or welding in the field. Durability of a structure largely depends on the quality of the joints made at site.

In bolted connections, care should be taken to ensure that all parts intended to be bolted together should be in contact over the whole surface and the surfaces should be thoroughly cleaned and painted with specified primer paint and the two matching plates or sections secured together while the paint is still wet by service bolts. After erection, the joint should be made by filling not less than *50%* of the holes with bolts. The service bolts are to be tightened. The holes that need enlargement to admit bolts or rivets should be reamed only after carefully examining the extent of the inaccuracy and the effect on the soundness of the structure. Such holes must not be formed by gas cutting process. The contact surfaces in HSFG connection if painted will develop lesser friction and this should have been accounted for in design. The fundamentals of HSFG connections are elaborated in the chapter on Bolted connections.

For connections to be done by welding, the components should be securely held in position to ensure alignment, camber etc., before welding is commenced.

In the case of field assembly using bolts the number of washers for the permanent bolts should not be more than two (and not less than one) for the nuts and one for the bolt head. It is desirable to use wooden rams and mallet to force the members in position so as to protect steelwork from injury and shock. It should also be ensured that the bolts project through the nut by atleast one thread. In the case of field assembly by welding almost all the precautions needed for shop welding may be followed. In the case of High Strength Friction Grip (HSFG) bolts the material surfaces should be absolutely free from grease, lubricant, dust, rust etc. and shall be thoroughly cleaned before assembling. The nuts should be pretensioned by a torque–wrench or by the turn of the nut method with the help of pneumatic wrench/lever. After tightening the bolt heads, nuts and edges of the mating, surfaces should be sealed with a coat of paint to obviate entry of moisture. In the case of connections such as base plate they must be aligned and levelled using wedges/ shims and subsequently filled by grouting.

6.0 SUMMARY

In this chapter the importance of fabrication and erection in structural steelwork is underlined. The various tasks involved in fabrication are discussed. The joints, which are important components in structural steelwork are explained, with a special emphasis on welded joints. Some aspects of erection of steel structures are also presented. Thus an overall view of the fabrication and erection of structural steelwork is covered in this chapter.

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3. Ghoshal.A., " Quality Assurance and Training for Fabrication and Erection of Durable Steel Structures", Journal of the Indian National Group of the International Association for Bridge and Structural Engineering, vol.30, n1, Feb. 2000.

4. *IS:812-1957* Glossary of terms relating to welding and cutting of metals.

5. *IS:822-1970* Code of procedure for inspection of welds.

6. *IS:7205-1974* Safety code for erection of structural steelwork.

7. *IS: 7969-1975* Safety code for handling and storage of building materials.

8. *IS:*487-1985 Brush, Paint and Varnish (I) oval ferrule bound (ii) round ferrule bound (Third revision).

9. *IS 800- (1984)* Code of practice for general construction in steel, Chapter 11.