Productivity in Penstock Fabrication

By AWTAR SINGH*

Introduction

Penstock Fabrication is primarily a welding job right from selection of weldable steels and consumables to design of welding joint, welding procedures, techniques and other processes upto testing stage.

Inspite of being blessed with a good topography and rainfall, India has not so far been able to exploit adequate power potential in keeping with its fast developing economy and needs. In line with recent trend of undertaking development works in a big way, large capacity and high head penstocks are required to be produced for multipurpose Projects at the cheapest rates consistent with good workmanship and quality control. Inadequate availability of funds and higher costs have stood in the way of such works. Therefore higher production at lower rates is the need of the hour. This paper incorporates results of developments and innovation towards this goal.

Selection of Steel

In India, steel has to be imported as the indigenous production capacity is much less than the demand. Most of the weldable penstock steels are not produced in the country as yet. While planning steel whether for indigenous procurement or import, maximum possible width of high strength steel plates in line with capacity of the bending roll should be arranged to minimise number of girth joints and quantity (Tonnage) of steel to be handled at various stages. The length of plates should also be such as to reduce the number of longitudinal joints in accordance with the shop handling facilities. Single plates upto to about 11 metre length (suitable for about 3350 mm dia penstocks) can be conveniently handled. For ASTM A-285 Grade C Steel, a design stress of 18,300 psi is taken while for ASTM A-517 Steel (quenched and tempered), the stress is 38,300 psi. Therefore for a 32 mm thick plate of A-285-C steel, the equivalent thickness in A-517 steel would be 15.2 mm (Say 15 mm). While the cost of A-517 steel would be about 1.6 times, the tonnage to be imported and handled would be only about 0.4 times, thus effecting a saving of 35% in the cost of steel itself. The weld metal requirements will be reduced by 56%. The percentage saving in the weld metal goes on increasing as the thickness goes on increasing. There is saving in almost every operation in higher tensile steel except rate of consumables, the total cost of which is also less as the saving in requirements is more than the higher rate.

Weld Joint Details and Procedures

There is a general practice to adopt 60° V groove with a joint gap of 3-4 mm and a shoulder of 3-4 mm. The joint gap can be conveniently reduced to 1.5 mm or even nil in carbon steels like A-285-C while using automatic welding process, since higher current is possible to be used in this steel. The angle of V groove is reduced to 45°. This results in a saving of 30% in welding consumables for plate thickness of 15 mm. This saving will increase as plate thickness increases.

There is not much scope for reduction in the V-groove angle for manual welding. We have however successfully reduced the angle to 45° in lesser thickness (say upto 20 mm) and obtained good results of radiographic quality. Instead of bevelling both

* Mr. Singh is Executive Engineer, Beas Sutlej Link Project. This paper was presented at the Institute's Seminar held in Calcutta in July 1973,

edges, only one edge was bevelled to 45° and other edge was kept straight thus effecting saving in the cost of edge preparation also. Use of two torches mounted on the Oxy-acetylene cutting machine reduces time and cost of edge preparation.

As far as practicable, maximum possible welding is done in the down hand position thus making it possible to use thicker electrodes which are also available at cheaper rates per ton than thinner electrodes. This reduces the cost of overheads and labour upto 25-30% while using 5 mm electrodes as compared to 4 mm electrodes.

It is always economical to use low hydrogen, iron powder electrodes. Though the price of these electrodes is more, the ultimate weld deposit is definitely cheaper because of higher deposition efficiency higher rate of welding, reduced over-heads and less completion time. Low hydrogen electrodes almost eliminate underbead cracking. Where preheating is required, iron powder low hydrogen electrodes also save in preheating costs because of higher heat input in the joint which gives higher temperature of weld and base metal near the joint provided cleaning is done quickly and no undue time is lost.

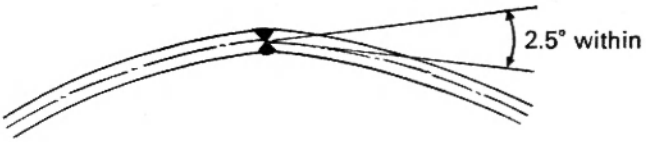
Maximum possible welding in penstock fabrication should be done by automatic welding processes. It requires some experience and skill to control the curvature at the longitudinal joints when butt welding with the automatic or semi-automatic process. For girth or circumferential seams, all welding should be done by automatic process to save completion time and reduce welding costs. The chances of distortion are almost negligible in girth joints. All the necessary equipment and cousumables for automatic welding are now indigenously available for most applications except wire for automatic welding of quenched and tempered steels.

The use of turning rolls-rotators greatly facilitates the work and increases arc time by bringing the work piece quickly in the most convenient position and dispenses with the need of helpers to a great extent. It also permits use of large sizes of electrodes by presenting the joint in the down hand position.

Accurate dimensioning, correct edge preparation, close fit-up and proper alignment contribute to saving in requirements of weld materials and permit use of proper size electrodes by eliminating the necessity of use of smaller size electrodes to prevent burn-throughs. Badly cut joints mean wider V-groove requiring more weld metal than necessary, necessitate building up of edge, more cost in back cleaning of the joint, longer time of execution and increased distortion. Overwelding and throwing away of long stub ends can increase cost of welding by about 50% or even more.

Besides butt welding, fillet welding for stiffener rings has been done by the submerged arc process cutting down the welding time by 50-60%. Automatic welding has given as much progress as 8-10 manual welders.

The so-called equal grooves in double bevel are in fact unequal as after back gouging the second side (back side) becomes deeper by 4-5 mm. This occasionally presents problems in the control of curvature at the longitudinal joints. This problem has been successfully overcome by adopting unequal V grooves having a difference of 4-5 mm and welding the deeper side first. It will be advisable not to complete the first side fully and leave about 2 to 3 layers and lay these depending upon the behaviour of the joint. This deformation or bend at the joint is undesirable especially in high strength steels exceeding 60 Kg class as the joint is liable to crack even under low loading. According to data of last experiments, the limit of this bend has been determined at 2.5°.

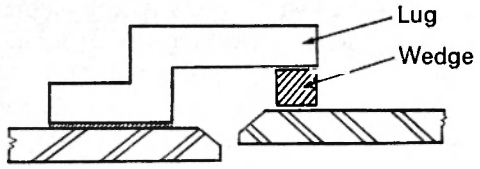


Control of this bend is very important as re-rolling involves avoidable cost and there have occurred cracks in weld as a result or re-rolling in case of excessive bend correction.

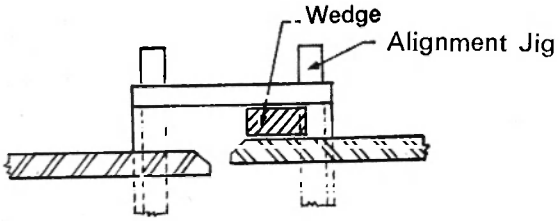
Alignment Jigs

For matching the abutting edges, the usual practice of welding the L shaped lug on the lower surface and driving a wedge between the over-hanging arm of the lug and the higher surface involves welding and wastage of lug steel. The welding some times causes damage to the base metal which has to be repaired before the job can be accepted. Besides, this operation involves cost of fabricating the lugs and removing them by cutting or gouging afterwards.

A considerable saving has been adopted in this operation by using a jig which goes round the circumferential joint and matching the edges by simply driving the wedges at the required points. The jig is made in



two semi circles and is easily put on the joint. This has saved upto Rs. 100/- per joint and speeded up the time. Such a jig is also suitable for alignment of longitudinal joints.



Cleaning of Weld

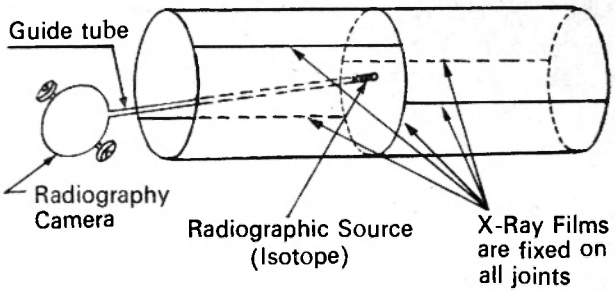
Chipping and cleaning of the weld seams after every layer is an essential part of the welding job. Proper tools and more joints in hand (about twice the number of welders in a shift) give optimum out-turn by keeping the welders busy for most of the time. Cleaning, chipping and welding should go on alternate joints thus providing job for all workmen at all times for maximum utilisation of labour. Treatment of back side of welding groove can be greatly expedited by the combined use of arc air gouging and high speed grinding wheels.

Weld Reinforcement

Reinforcement in welded joints is required to some extent to ensure that no point on the weld seam is below the plate surfaces. Excessive reinforcement say above 1.5 mm for 12 mm plates, 2.5 mm for 13-25 mm plates and 3.0 mm for plates more than 25 mm thickness is not permissible. This can cause head losses on the inside surface of penstocks and also result in wastage of weld metal. Besides, extra reinforcement has to be removed and thus involves avoidable labour and materials for grinding off. The ideal joint would be just flush with plate surfaces and can save weld metal upto 10 percent and avoid labour and over heads upto Rs. 20-25 per Ton of fabrication.

Radiography of Welds

In high pressure fabrication like penstocks, radiography of welded joints is essential to ensure quality



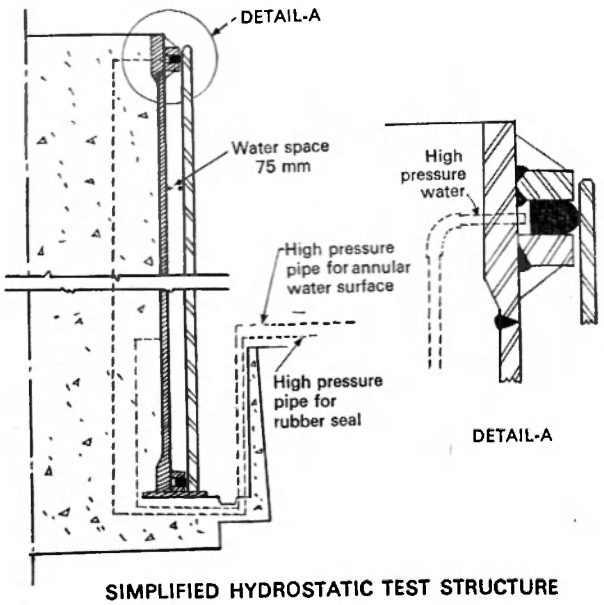
especially for longitudinal joints which are subjected to maximum stress. Weld surface irregularities especially low points are built up before hand and some grinding on the interior surface is also done so that resulting radiograph contrast due to any irregularities does not mask or is confused with that of any objectionable defect. X-Ray machines are imported in our country while Gamma Radiography sources and cameras of various capacities and types are indigenously available from Atomic Energy Commission (Isotope Division) Trombay, Bombay. The usual procedure is to radiograph the longitudinal joints separately covering about 3 to 4 films (about 38 cm length each) in one exposure thus requiring about 8 exposures for four longitudinal joints of two shells or 2 metres length each. This exposes radiography operator to more hazards of radiation absorption. We have successfully radiographed one-girth joint (after joining 2 shells) and four longitudinal joints each of 2 metre length of a 4880 mm dia and 50 mm thick penstock in one exposure thus cutting down the radiography time and labour by 40 percent. This also reduced the cordoning off period in the neighbourhood and caused least disturbance to other works.

The stress in the girth joint is about 50 percent of the stress in the longitudinal joint when there are no expansion joints or couplings. When expansion joints are provided, this stress considerably reduces in the direction of the flow. Ultrasonic testing which does not involve use of X-Ray films and does not keep a record of the defects, has been effectively substituted for radiography for girth joints. This method is not only cheaper but has other advantages. This operation can go on in the shop along side other jobs at all times as there are no fears of radiation hazards to workers working in the neighbourhood. At erection sites when concreting outside the penstock is provided, the concreting does not have to wait for radiography and repair as the ultrasonic testing can be done even with concrete on the outside. For radiography, the other side has to be approachable for affixing the films while the radiation source is on the inside.

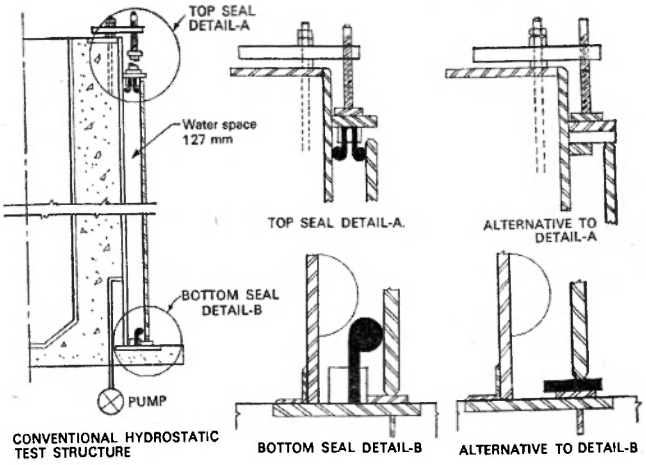
Hydrostatic Testing

All specifications provide for hydrostatic testing of penstocks with a view to check any hidden defects. This incidently also effects mechanical stress relieving to a certain degree. While all straight sections can be tested on a hydrostatic test structure, this is not possible for bends and conical sections which will require welding of bulk heads and holding of bends from opening out. It is permissible to test straight sections individually or in assemblies depending upon the design of test structure and then cut the sections to the required profile and weld to make bends. The girth welds shall be radiographed or ultrasonically tested and this procedure has been accepted as satisfactory. While making assemblies for hydrostatic test (if it is a must, depending upon structure design which may be suitable only for a fixed length), it is not at all essential to fully weld such temporary girth joints. About 20-25% welding on circumferential joints has proved more than satisfactory and we have done it about 25 times. This results in considerable savings.

Conventional hydrostatic test structure involves closing or sealing the ends with bulk heads fitted with rubber seals in which huge holding down bolts and blocks are used to counteract the resulting force on account of test pressure. This also involves a lot of time and labour for fixing blocks and tightening of heavy bolts. A simple and quick test structure can save all this botheration and increase the speed of testing 4-5 times.



SIMPLIFIED HYDROSTATIC TEST STRUCTURE



Size of Assemblies

Longer assemblies in accordance with handling and transportation facilities greatly reduce the cost of work and its completion time. It has been observed that a resulting saving in making an extra circumferential joint in the shop instead of the erection site (or field) can save upto Rs. 200 per metric ton, including the saving in transportation, crane handling, site alignment, site welding and welding consumables. The completion time of the job is also greatly reduced upto 3 days a joint (aggregate of many months for the job), thus not only reducing the cost but greatly increasing the productivity.

Painting

All grades of iron and steel corrode under natural environments unless they are adequately protected. A long life coating in penstocks is necessary because dewatering for maintenance involves loss of revenue from electric power production. "Proper" coating of hot coal tar enamel, which has a service life of 50 years or more as per service records and competent opinion, is the answer.

Shop painting leaving about 250 mm bands at the field joints, not only saves the cost of work by 10-15% as compared to field painting but reduces the completion time by 70-80% as shop painting goes on simultaneously with field erection. In the shop the quality of work is better, the wastage is less and the blasting sand which is hardly reclaimable in field job and constitutes about 15% of the cost of work, can be reclaimed and reused. The usual cold applied paints have a service life of 5-7 years and involve long shut-downs for maintenance painting. The use of hot coal tar enamel practically eliminates shut-down as its life is about equal to usual life of generation equipment which will require some renovation after 50 years.

Care of Consumables

Proper care of electrodes and other consumables not only reduces wastage but minimizes welding defects, thus lowering the cost and increasing the productivity.

Preheating/Stress Relieving

Preheating to 95° to 100° C can be substituted for stress relieving upto 38 mm thickness and may eliminate the necessity of setting up stress relieving furnace for some jobs. No preheating and stress relieving is needed for carbon steels upto 32 mm plate thickness. A good speed to welding and use of thicker electrodes can save preheating costs up to 20-25% as interpass temperature can be maintained with reduced preheating while using the heat of the welding arc which is still in the plate.

Welding at Site and Inside Tunnels

Welding of penstocks at site involves welding in all positions. This situation can be greatly overcome by providing a V-groove in the upper half circle on the outside and on the lower half circumference on the inside with transition at the horizontal centre of the pipe. This will mean provision of single V-groove which becomes uneconomical as thickness goes beyond 25 mm and is not recommended beyond 32 mm plate thickness. This will involve somewhat more weld metal requirements but greater weld metal deposition rate and less costly electrodes in thicker sizes and comparatively less skilled welding operators will easily off set the extra weld metal.

In tunnels excavated in rock, there is usually high humidity because of seeping water. The space between the liner and the tunnel is usually 600 to 750 mm. This restricted space with high humidity and poor ventilation greatly reduces the welding efficiency. Visibility is reduced due to welding fumes and steam formation especially when concreting is following the installation. These problems are minimised by providing ventilation blowers and handling/hauling larger length assemblies. In many cases, the liners are joined and welded near the tunnel face (portal) and pushed in part of the way in the tunnel as each assembly/liner is jointed. This way most of the field welding is done outside the congested and moist atmosphere at a lower cost and with better quality

Out of Roundness

For economical productivity in penstocks, a lathe turned roundness and workmanship should not be demanded and in fact cannot be justified. Out of roundness of 1% between maximum and minimum diameters and minor welding defects (acceptable type) should be accepted as joint efficiency assumed in designs takes care of this situation.

Preventive Maintenance and House Keeping

It has been often observed that preventive maintenance of welding equipment and tools increases their availability for actual job execution and reduces the cost of repairs and even avoids some accidents. Whenever an accident takes place, all labour has a tendency to gather at the site and this can result into many man hours being lost. Good house keeping can and has greatly improved the efficiency of all men and machines.

Labour Relations and Incentives

Healthy management labour relations induce workers to put more into the job and carry out management schemes efficiently. In order to distinguish between a good and a better worker, incentive schemes like advance increments and promotion greatly increase the output. A welding operator who usually consumed about 90 electrodes in a shift of 8 hours (at least half the shift time is spent in rest interval, cleaning of the joint, hooking up the welding accessories and waiting for shifting of job or materials) increased his progress to 150 electrodes in a few days when assured of recognition of his output.