# *Indian Standard*

# CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS

## PART VI STEEL LINING

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

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# *Indian Standard*

# CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS

## PART VI STEEL LINING

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# *Indian Standard*

# CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS

## PART VI STEEL LINING

## 0. FOREWORD

**0.1** This Indian Standard was adopted by the Indian Standards Institution on 29 January 1975, after the draft finalized by the Water Conductor Systems Sectional Committee had been approved by the Civil Engineering Division Council.

**0.2** The construction of tunnels involves a large number of problems. Because of the great longitudinal extent of the work many different kinds of conditions are encountered which for maximum economy should be treated differently. This standard covers recommendations which would be generally applicable to construction of tunnels for the assistance of the engineers engaged in the project. This standard should, however, be used with caution since due to the very nature of the subject it is not possible to lay down detailed specifications to cover each and every possible case. The specifications laid down by designers shall be followed and the discretion of the engineer-in-charge would be required in some cases.

**0.3** Lining of tunnels generally contributes to the total cost of the tunnel to an extent of 30 to 40 percent, and therefore, lining operation requires considerable study and careful planning.

**0.3.1** The type of lining chosen for tunnels depends upon the quality of the rock and the type of tunnel. Tunnels forming part of a water conductor system have to be invariably lined with cement concrete from structural and hydraulic considerations. If the tunnel has to withstand very high internal pressures, it will have to be steel lined.

**0.4** This standard is being published in parts. Other parts of this standard are as follows:

Part I Precision survey and setting out

Part II Underground excavation in rock

Section 1 Drilling and blasting

Section 2 Ventilation, lighting, mucking and dewatering

Section 3 Tunnelling method for steeply inclined tunnels, shafts and underground power houses

Part III Underground excavation in soft strata

Part IV Tunnel supports

Part V Concrete lining

Part VII Grouting

**0.5** Other related standards are given below:

IS : 2825-1969 Code for unfired pressure vessels

IS : 4081-1967 Safety code for blasting and related drilling operations

IS : 4137-1967 Safety code for working in compressed air

IS : 4756-1968 Safety code for tunnelling work

IS : 4880( Part II )-1968 Code of practice for design of tunnels conveying water: Part II Geometric design

IS : 4880( Part III )-1968 Code of practice for design of tunnels conveying water: Part III Hydraulic design

IS : 4880( Part IV )-1971 Code of practice for design of tunnels conveying water: Part IV Structural design of concrete lining in rock

IS : 4880( Part V )-1972 Code of practice for design of tunnels conveying water: Part V Structural design of concrete lining in soft strata and soils

IS : 4880( Part VI )-1971 Code of practice for design of tunnels conveying water: Part VI Tunnel supports

**0.6** This standard does not cover the design of steel lining for tunnels. The design aspects are covered in IS : 4880 ( Part VII )-1975*.

**0.7** For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS : 2-1960†. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

## 1. SCOPE

**1.1** This code of practice covers fabrication, testing and erection of steel lining of tunnels conveying water from reservoirs to hydraulic turbines in hydro-power plants or *vice-versa* in case of reversible pump turbines in pumped storage schemes or for other similar installations.

*Code of practice for design of tunnels conveying water: Part VII Steel lining.

†Rules for rounding off numerical values ( *revised* ).

**1.2** This code of practice does not cover fabrication, testing and erection of specials like bends, bifurcations, etc.

## 2. MATERIALS

**2.1** The material to be used for different components shall be as given in **2.1.1** to **2.1.4**.

**2.1.1** Steel plates for liners, nozzle attachments and all pressure parts shall be of weldable boiler quality plates conforming to Grade I or Grade 2A of IS : 2002-1962*. These plates shall come under carbon steels of minimum tensile strength of 28 to 53 kg/mm$^2$. High tensile steel, low alloy steel, etc, may be used provided proper welding procedure is established for the use of such steel. Where high heads are involved, the use of high tensile steel conforming to IS : 2041-1962† is recommended.

**2.1.2** The stiffeners may be cut from plates or structurals bent to the required shape. The material shall conform to the requirements of IS : 226-1969‡.

**2.1.3** Gaskets for manholes or other flanged nozzles shall be of compressed asbestos fibre suitable for the purpose and temperature of the working conditions. If rubber ring is used, the hardness of the rubber ring shall be Durometer 75 $\pm$ 5.

**2.1.4** Welding consumables such as electrodes, filler rods and wires shall conform to IS : 814 ( Part II )-1974§, IS : 1395-1971‖, IS : 3613-1966¶, IS : 6419-1970**, IS : 6560-1972†† and IS : 7280-1974‡‡.

## 3. FABRICATION

### 3.1 General

**3.1.1** Each manufacturer or contractor shall be responsible for the quality of the welding done by his organization and shall conduct tests not only of the welding procedure to determine its suitability to ensure welds which will meet the required tests, but also of the welders and welding operators to determine their ability to apply the procedure properly. For this purpose

*Specification for steel plates for boilers.

†Specification for steel plates for pressure vessels.

‡Specification for structural steel ( standard quality ) ( *fourth revision* ).

§Covered electrodes for metal arc welding of structural steels: Part II For welding sheets ( *fourth revision* ).

‖Specification for molybdenum and chromium molybdenum vanadium low alloy steel electrodes for metal-arc welding ( *second revision* ).

¶Acceptance tests for wire flux combinations for submerged arc welding.

**Welding rods and bare electrodes for gas shielded arc welding of structural steels.

††Molybdenum and chromium molybdenum low alloy steel welding rods and bare electrodes for gas shielded arc welding.

‡‡Bare wire electrodes for submerged arc welding of structural steels.

reference may be made to IS : 7307 ( Part I )-1974* and IS : 7310 (Part I)-1974†.

**3.1.2** No production work shall be undertaken until both the welding procedure and the welders or welding operations have been approved.

**3.1.3** *Forming Shell Sections and Tolerance* — All plates for shell sections shall be formed to the required shape by any process that will not unduly impair the physical properties of the material. The formed shell section shall conform to the tolerances given in **3.1.3.1** to **3.1.3.3**.

**3.1.3.1** The formed section shall be substantially circular in cross-section. The measured circumference at any cross-section shall not be less than the calculated circumference and shall not exceed the calculated circumference by more than 10 mm.

**3.1.3.2** The difference between the maximum and minimum diameter at any cross-section shall not exceed one percent of the nominal diameter at the cross-section under consideration subject to a maximum of 10 mm.

**3.1.3.3** The ends of each shop fabricated shell section (pipe) shall be in a plane normal to the longitudinal axis of the section with a maximum deviation of 2 mm on either side of the plane.

**3.2 Welding Process** — The welding process to be adopted in the construction of liners shall be restricted to the following:

a) Manual metal arc,

b) Submerged arc, and

c) Metal inert gas arc.

**3.2.1** The welding procedure adopted shall conform to IS : 823-1964‡ and IS : 4353-1967§.

**3.2.2** Where the weld metal is deposited in successive layers, each layer shall be thoroughly cleaned bofore the subsequent layer is deposited. Whenever possible, joints shall be welded in the flat position. Welded joints shall be reasonably free from craters, depressions and other irregularities. After welding is completed, all weld spatters shall be removed. Welded beads on the interior surfaces of the liner shall be corrected by grinding so as not to project more than 1·5 mm.

**3.2.3** Field girth joints may be accomplished using back up bars if both side welding is not possible due to non-accessibility.

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*Approval tests for welding procedures: Part I Fusion welding of steel.

†Approval tests for welders working to approved welding procedures: Part I Fusion welding of steel.

‡Code of procedure for manual metal arc welding of mild steel.

§Recommendations for submerged arc welding of mild steel and low alloy steel.

**3.2.4** *Lowest Permissible Temperature for Welding* — It is recommended that no welding of any joint be done when the temperature of the base metal is lower than −18°C. At temperature between −18°C and 0°C the surface of all areas within 75 mm of the point where a weld is to be started should be heated to a temperature 15°C ( that is, warm to hand ) before welding is started. It is also recommended that no welding be done when surfaces are wet or covered with ice or during periods of high wind, unless the welders or welding operators and the work are properly protected.

**3.2.5** All welds shall have complete penetration and shall be free from imperfections and all defective welds shall be repaired. Defects in the welds shall be chipped or flame gauged until sound metal is reached on all sides and the resulting cavity shall be filled by the same procedure as when the original grooves were filled. The test shall be repeated.

**3.2.6** *Cutting, Fitting and Alignment*

**3.2.6.1** Plates and other parts may be cut to shape and size by mechanical means or by oxy-acetylene cutting. When plates are shaped by oxygen or arc cutting, the edges to be welded shall be uniform and smooth and shall be free from all loose scale and slag accumulations before welding.

**3.2.6.2** Plates that are being welded shall be fitted, aligned and retained in position during the welding operation.

**3.2.6.3** Bars, jacks, clamps, tack-welds or other appropriate means may be used to hole the edges to be welded in line. Tack welds may be used provided those in plates over 6 mm thick are removed by suitable means before welding the joints, so that these tack welds do not become part of the final joint.

**3.2.6.4** The edges of butt joints shall be held during welding so that the tolerances are not exceeded in the completed joint. When fitted girth joints have deviations exceeding the permitted tolerance, the shells ring shall be finished until the errors are within the limits specified.

**3.2.7** *Cleaning of Surfaces to be Welded* — The surfaces to be welded shall be clean and free from foreign materials, such as grease, oil, lubricants and marking paints for a distance of at least 15 mm from the welding edge. When weld metal is to be deposited over a previously welded surface, all slag shall be removed by a roughing tool, chisel or air chipping hammers or other suitable means so as to prevent inclusion of impurities on the weld metal.

**3.2.8** Cast surfaces to be welded shall be machined, chipped or ground to remove foundry scale and to expose sound metal.

**3.3 Alignment Tolerance** — Alignment of sections at edges to be butt welded shall be such that the maximum offset is not greater than the values given in Table 1.

**TABLE 1 ALLOWABLE VALUES FOR MAXIMUM OFFSETS IN BUTT WELDING**

( *Clause* 3.3 )

| Thickness $t$ | Longitudinal Joints | Girth Joints |
|---|---|---|
| (1) | (2) | (3) |
| mm | mm | mm |
| Up to 12 | 1/4 $t$ | 1/4 $t$ |
| Over 12 and up to 20 | 3 mm | 1/4 $t$ |
| Over 20 and up to 40 | 3 mm | 5 mm |
| Over 40 and up to 50 | 3 mm | 1/8 $t$ |
| Over 50 | Lesser of 1/16 $t$ or 10 mm | Lesser of 1/8 $t$ or 20 mm |

**3.4 Staggering of Joints** — The longitudinal seams of adjoining course of liner section shall be staggered by at least five times the thickness of thicker plate. If, however, this is not possible 100 mm on either side of each welded inter-section shall be radiographed.

**3.5 Bends** — Bends shall be mitred with minimum radius of curvature three to five times the internal diameter of the pipe and included angle of maximum 10° between segments. The radius of curvature shall be referred to the centreline of the bend.

**3.6 Stress Relieving** — No stress relieving is required for joints in steel liners made up of plates of 32 mm or lesser thickness. Where thickness of the plates exceeds 32 mm but not 38 mm, the joints shall be preheated before welding. If thickness of steel plates exceeds 38 mm, stress relieving of joints shall be done in a furnace. Where this is not possible then stress relieving may be done by induction coil heating method.

**3.7 Painting**

**3.7.1** All the surfaces requiring painting shall be sand/shot blasted according to accepted practices.

**3.7.2** The inside surface of liner shall be protected against corrosion by painting with suitable paints selected to meet working and operating conditions of the pipes. The recommended paints are coal tar enamel/coal tar epoxy.

**3.7.3** Surfaces in contact with concrete, after cleaning in accordance with **3.7.1** shall be coated with a thin film of cement slurry to protect against corrosion and for proper bondage with concrete.

## 4. TESTS AFTER FABRICATION

**4.1** The tests given in **4.1.1** to **4.1.3** shall be conducted after fabrication.

**4.1.1** *Radiography* — All butt welded longitudinal joints shall be 100 percent X-rayed. Use of Gamma rays is recommended for thicker plates,

**4.1.2** *Ultrasonic Tests* — All butt welded girth joints shall be 100 percent ultrasonically tested.

**4.1.3** *Shop Hydraulic Tests* — All pipes of standard lengths shall be subjected to shop hydraulic test. Non-standard pipe and elbows can be tested as standard pipe before being cut to size. Hydraulic testing of longitudinal joints is mandatory.

**4.1.3.1** The test pressure shall be calculated from the following formula:

$$P = \frac{2 f_t \cdot t}{D}$$

where

$P$ = hydrostatic test pressure in kg/cm$^2$,

$f_t$ = 0·8 yield stress in steel,

$t$ = minimum thickness in centimetre of plate in liner length tested, and

$D$ = maximum internal diameter in centimetre of section being tested.

**4.1.3.2** In general, the shop test pressure shall ensure that the plate material is stressed to 80 percent of minimum yield strength and at least equal to one and half times the allowable working pressure.

**4.1.3.3** Each liner length shall be filled with water and the pressure slowly and uniformally increased until the required test pressure is reached and held at that pressure until all welded joints are examined. Any defects in welds or plate disclosed by the hydrostatic test shall be repaired and all repaired sections shall be retested.

## 5. ERECTION OF STEEL LINERS

**5.1 General** — Installation of steel liners is an extension of fabrication procedure at site in conjunction with the construction of underground works like tunnels, powerhouse, surge tower, etc.

**5.2 Construction of Rail Track** — To facilitate erection of steel liners in position, a rail track should be laid inside the tunnel and also winch of suitable capacity installed. In case of vertical penstocks, instead of the track a platform is constructed with bridge arrangements to handle the pipes during erection.

**5.2.1** The rail track is not considered as a permanent part of the work unless agreed between the parties in the contract since this is only an item to facilitate erection of the liners.

**5.3** Installation of steel liners is taken up from the anchor blocks at the lowest or tail ends progressing upwards to surge tank. Steel liners could be installed over the tunnel lengths separately and both joined together at the junction.

**5.4** Excavation of tunnels, surge, junction and other places where steel liners are to be installed should be done according to the relevant code of practice ( *see* **0.4** ). Loose scales have to be removed completely and there shall be no stretch with tightness which will infringe on the steel liners. In case of loose soft rock, adequate temporary supporting should be ensured with steel girders and backfill concrete and/or shot-creting which could be embedded in the final concrete. If temporary lining is done with material that cannot be burried in final concrete, the same has to be removed without fail. Major excavation being thus completed to full section, only spot tightness may be required to be removed during the actual installation of steel liners in position which could be done without much inconvenience.

**5.5 Anchor Bolts** — Anchor bolts shall be installed at the levels established as working bases for the installation of liners. The liners sections shall be located or placed in position in accordance with erection diagram and shall be completely aligned to grade before the joints are welded and the sections are embedded in concrete. Necessary permanent structural steel supports, blocking cables, anchors or expansion spiders required to hold the liners in position or prevent distortion while the liners are being welded or being embedded in concrete, shall be provided in respective locations. When assembled and ready for welding the distance between ends of adjoining sections which are to be connected together with butt-welds shall not go greater than 6 mm and not less than 3 mm. Care shall be taken to avoid excessive increase or shrinkage in length. All welding and repairing of defective welds shall be performed according to the provisions detailed under fabrication. In case of penstock or other liners where the clearance all around is not adequate to accommodate welders to perform proper welding, welding is done from inside. The size of back up bar is minimum 75 × 12 mm. Double welded butt joints can be accomplished if space around is 0·6 m or more. After the given joints are welded and repaired where required according to the specification the sections are cleaned and are ready for being encased in concrete.

**5.6 Concreting** — Liners are encased in concrete — concreting being done generally by pneumatic placement. Concreting is done generally over lengths at a stretch up to 6 to 7·5 m for smoother and economical operations to minimize interruptions in the installation of pipes and welding them which is the major work in the whole procedure.

**5.7 Grouting** — Grouting should be done behind the concrete lining to fill up the shrinkage gap between the rock and concrete and concrete and steel liner if any to make the whole mass monolith with the parent rock. Grouting has also to be done in the rock all around to fill up the pores, fissures in

rock mass to prevent building up of hydrostatic pressure and to strengthen the rock all around in general. Grouting shall be done in accordance with IS : 5878 (Part VII)-1972*.

**5.7.1** For grouting, holes are provided in the liner generally 3 numbers on periphery or at every 3 m arc length whichever is more staggered in alternate ferrules. The holes drilled in plate steel liners shall be plugged; alternatively holes may be closed by plug welding after completion of grouting. The plug weld shall be ground flush with the liner surface.

**5.7.2** While drilling such holes utmost care shall be taken to ensure that the anchor rods or stiffeners behind the plate steel liner or reinforcement, if any, in case of concrete lining shall not be cut through.

## 6. BASIS OF MEASUREMENT

**6.1** All items which form permanent part of the steel lining work including supports, struts between rocks and steel liner, grout plugs, backup bars, stiffeners, etc, shall be measured for payment.

**6.2** The basis shall be theoretical weight plus half of maximum provided tolerance in accordance with IS : 2002-1962†.

*Code of practice for construction of tunnels : Part VII Grouting.
†Specification for steel plates for boilers.

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TO

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## PART VI STEEL LINING

### Alteration

*(First cover page, pages 1 and 3, title)* - Substitute the following for the existing title:

'*Indian Standard*
CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER

PART VI STEEL LINING'

(BDC 58)

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