Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER

PART V CONCRETE LINING

(First Revision)

Third Reprint SEPTEMBER 1994

UDC 624.191.2:69.034.92

BUREAU OF INDIAN STANDARDS
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NEW DELHI 110002

Gr 3

November 1976

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(*Continued on page* 2)

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PART V CONCRETE LINING

(First Revision)

0. FOREWORD

0.1 This Indian Standard (Part V) was adopted by the Indian Standards Institution on 31 August 1976, after the draft finalized by the Water Conductor Systems Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 This Indian Standard was first published in 1971 and is being revised with a view to keeping abreast with the technological developments that have taken place in the field of tunnel design and construction.

0.3 The construction of tunnels involves a large number of problems. Because of the great extent of variations in the nature of the work many different kinds of conditions are encountered which for maximum economy, consistent with technical requirements should be treated differently. This standard covers recommendations which would be generally applicable to construction of tunnels for the assistance of engineers engaged on such projects. 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 and the discretion of the engineer-in-charge would be required in some cases.

0.4 Lining in tunnels is technically an important component and generally constitutes 30 to 40 percent of the total cost of the tunnel. Therefore lining operation requires considerable study and careful planning. Tunnels forming part of water conductor system have to be invariably lined with cement concrete from structural and hydraulic considerations with some exceptions when the rock is extremely hard, sound and massive like granite and/or where the tunnel may be in operation for short periods in a year.

0.5 This standard has been 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 VI Steel linings
Part VII Grouting

1. SCOPE

1.1 This standard (Part V) lays down specifications and procedures for placing concrete lining for tunnels conveying water.

2. REQUIREMENTS

2.1 The requirements for concrete lining of tunnels shall be carefully drafted as the conditions for lining tunnels are quite different from those of other cement concrete works. Requirements of lining of tunnels are special on account of curvature, thin sections and difficulties in placement and compaction in restricted spaces.

2.1.1 All the requirements for coarse and fine aggregates, cement, water, and concrete grading and corresponding strength in accordance with IS : 456-1964* shall apply. On account of curvature, irregularities in rock profile, thin sections and placing of concrete generally required to be done either through a concrete pump or pneumatic placer, the concrete necessarily requires to be flowy to avoid seggregation and to ensure proper filling in. The slump of concrete should not be less than 10 cm and the sand content shall be more than that specified in IS : 456-1964*. The cement content shall also be more than what is indicated by laboratory tests alone (*see* Note below). Where concrete is placed directly, as in inverts and kerbs, the slump should be reduced to 5 cm. Use of natural aggregates, especially sand, either wholly or partly, improves the pumpability of concrete and is recommended commensurate with practicability and economy. The maximum size of aggregate shall not exceed 40 mm. This should, however, be reduced suitably for specific locations and conditions.

NOTE — The cement content in concrete may vary from 350 to 400 kg/m^3. However, in particular locations where experience indicates, the minimum cement content may be reduced to 325 kg/m^3 where natural aggregates are used and there

*Code of practice for plain and reinforced concrete (*second revision*).

is no hindrance of supports or reinforcement. Where crushed aggregates are used and where supports or reinforcement come in the way, the minimum cement content may be suitably increased to ensure adequate workability. All the above mentioned cement contents are applicable to concrete placed through a concrete pump or by pneumatic placer.

2.1.2 It is advisable to use air entraining agent, to entrain up to 4 percent of air for improving workability of concrete.

3. CONTROL OF SEEPAGE WATER

3.1 Seepage water shall be suitably controlled and prevented from getting mixed with green concrete in the lining.

4. APPROPRIATE TIME FOR PLACING CONCRETE LINING

4.1 The appropriate time for placing concrete lining will be governed by the conditions of rock tunnelled through. In cases where due to tectonic forces rock dilates, it is advisable to allow sufficient time for such dilations to reduce to reasonable limits to ensure that concrete lining will not fail by cracking due to heavy and unequal external forces. In cases where rock may not dilate much but may deteriorate in structure causing spalling, placing of a thin layer of concrete between steel ribs to support full surface of the rock and transfer the forces to the steel supports would be desirable (in certain conditions, shot-crete may be resorted to in place of such blocking concrete, taking care to ensure that the gap between external flange of the support and rock is fully filled up). Blocking concrete or shot-crete has to be placed with minimum possible time lag after excavation. Shot-crete can be applied more quickly than blocking concrete. In cases where rock is of better type than referred to above, concrete lining may come at any time convenient to suit the construction programme and practical considerations.

5. SEQUENCES OF LINING

5.1 The sequence of concrete placement for tunnel lining depends on the shape of the tunnel, its size, the nature of the rock strata and the type of form work and other plant and equipment used and has to be selected taking into account the construction schedule and progress scheduled to be achieved for the particular work. The sequences generally adopted for lining in tunnels are:

a) placing concrete to form the kerbs first, followed by side walls and arch and finally the invert;

b) placing concrete to form the invert first followed by sides and arch; and

c) placing concrete for the invert, side walls and arch all at one time.

5.1.1 The sequence given at **5.1** (a) is suited for horse-shoe, D-shaped and other flat bottomed and wide tunnels. The kerb shall be built up to a section of sufficient width to serve as a base for the errection of forms for sides and shall be properly anchored and made stable to withstand the loads of concrete lining and form work. After the kerb is constructed, the lining of the sides and arch follows. The sides of the kerb against which the sides and the invert concrete will be laid later should preferably be radial to their respective curvatures. This sequence has the advantage that all operations of concreting kerb, placing of shutters and forms and lining of sides and arches can be done with minimum disturbance to the track lines on the floor and for movement of other traffic. Then the track lines and other service lines are removed and invert concreting is done last. By this method the bottom concrete surface does not get damaged. An additional advantage in this is that it permits of concreting the sides and arch simultaneously with excavation with a suitable gap.

5.1.2 The sequence described at **5.1** (b) is suitable when the bottom of the tunnel is narrow or when the section is circular. The invert concreting is done first and a regular base for the erection of the form work for sides and arches is obtained making further work easier. But this procedure entails the removal of trolley tracks and other service lines laid on the floor and again laying them over the concreted invert for lining of sides and arch. It has also the disadvantage that the concrete surface of the invert is likely to get damaged during the operations for laying the overt. These practical difficulties increase if transport is by trucks.

5.1.2.1 In tunnels through weak strata, where the tunnel floor tends to wear out fast or heave up, the above sequence is required to be adopted. In cases where large horizontal thrusts are encountered, the placing of invert concrete in advance of lining of sides, serves as strutting between the sides. The concrete surface can be protected suitably.

5.1.3 The sequence described at **5.1** (c) is possible only in small and circular tunnels. It is difficult to be adopted in ordinary course and may be resorted to only where concrete pumping facilities are available and construction programme demands it. It has some advantages in steeply inclined tunnels. These present problems in proper alignment along the tunnel axes.

5.1.4 In case of tunnels through soft rock, when it is found that the rock strata is likely to collapse, it may become necessary to provide a primary lining over and between the steel supports (if provided) at the time of driving the tunnel, or by shot-creting immediately. (*see* **4**).

NOTE — Different types and methods of primary and main lining are described in IS : 5878 (Part III)-1972*.

*Code of practice for construction of tunnels conveying water; Part III Underground excavation in soft strata.

6. FORM WORK

6.1 General — Generally for tunnel lining steel forms are used in the interest of speed and economy due to their multiple use. There are various types of form work used for tunnel lining, such as rib and plates, rib and laggings, travelling shutters with or without telescoping. Timber formwork has to be resorted to in sharp bends, transitions and junctions. The use of a particular type for a job depends on the size, shape and the length of tunnel.

6.1.1 In a rock tunnel where the concrete is placed mechanically, forms may be removed after 16 to 24 hours from the placing of last batch of concrete. The form surface shall be oiled before concreting to avoid concrete sticking to it.

6.2 Rib and Plate or Rib and Lagging — This type of form work may be used for tunnels of medium size, that is, up to 5 m diameter. When concrete is to be hand placed on short tunnels, this type of form work is convenient.

6.2.1 Ribs made of either channels or T-sections placed at intervals of about 1 m according to the thickness of the concrete lining shall be erected firmly over the invert and either adequately stiffened steel plates or timber lagging shall be fixed from the bottom upwards as the concrete rises.

6.3 Travelling Non-telescoping Form Work — In this case the whole form work is preassembled and mounted on a travelling frame fixed with wheels running on a track and screw jacks are provided for collapsing the form work, when required. In all types or travelling forms the sections are hinged to permit collapsing. Jacks are required for bracing and aligning the forms.

6.3.1 This type is easy and economical to move. For this type of forms concrete for the sides and arch may be placed in one continuous operation. The traveller which carries the form structurally forms a part of the form work. The forms are made in units 6 to 12 m long and can be struck and reassembled quickly depending on the requirements of construction traffic and matching concreting equipment.

6.4 Travelling Telescoping Form Work — This is so designed that the back unit can be collapsed and moved forward through the front unit without disturbing it. The side plates are hinged to the arch plate so that it is possible to collapse them. The traveller is equipped with jacks and other accessories for this purpose. The form work shall be self-supporting while travelling in the collapsed condition also.

6.5 Monolithic Form Work — This is practically a slip form work for continuous use. This type of form work is only suitable for a circular or near circular tunnel when the lining of full section is done in one operation. This type of form work may be suitable in steeply inclined tunnels/shafts.

6.6 General Requirement of Forms — All form work should have inspection windows about 50 × 30 cm in size and not more than 3 m apart. Horizontal and vertical intervals of spacings will depend on the size and shape of tunnel, thickness of lining, method of placement and workability of concrete. The aim shall be to ensure dense compact concrete. These windows are used to place and vibrate the concrete. The shutters to these should be strong and easily operable and fitting well as not to permit cement slurry to flow out or to leave projections in the finished concrete surface. Flexible shaft internal type vibrators may be used through these windows.

6.6.1 All forms, except where continuous non-stop concreting is adopted, require provision of a bulk head shuttering at the other end where use of timber is generally convenient. The bulk head is necessary to make a neat construction joint.

7. BATCHING AND MIXING PLANT

7.1 In large tunnel lining jobs, it is necessary to use batching and mixing plants to manufacture concrete for lining. Depending on the size of tunnel and equipment available, the concrete may be mixed in a standard batching and mixing plant outside the tunnel and the mixed concrete taken to site of placement or the aggregates batched and mixed dry outside and taken to site of placement inside the tunnel and mixed with water inside the tunnel. It is advisible to add cement also inside to avoid its setting as the aggregates are often wet or moist. Except in small or very short tunnels, the concrete placer or concrete pump shall be inside the tunnel, near the site of lining. In large tunnels especially long ones, wherever it is possible and convenient, taking the mixing and batching plants also inside the tunnel is advisable.

8. TRANSPORTING CONCRETE OR DRY MIXED AGGREGATES

8.1 For tunnels of short length and where comparatively large volumes of concrete are required, concrete is generally mixed in a batching plant located at a suitable site outside the tunnel, and the mixed concrete conveyed as quickly as possible to the site of placement by means of short belt conveyors, agitator cars, truck mounted mixers, etc, and poured into the hopper of the concrete pump or placer kept close to the location of concreting. This has a disadvantage that as the time of transportation increases, the quality of concrete tends to get affected through over-mixing in the case of agitator cars and truck mounted mixers and a certain amount of initial set may take place before actual placement.

8.2 For tunnels of comparatively longer lengths, it is advantageous to batch and mix the concrete in dry condition outside the tunnel and then convey the same inside the tunnels to locations of placement by means of tipping wagons or dumpers. The dry mixed aggregates are then remixed at site adding the required quantity of cement and water to obtain the specified slump and water cement ratio. The aggregates should be as dry as possible when mixed outside. The mixer for mixing at site of placement has to be so located that the dry mixed aggregates can be easily dumped into the hopper of the mixer and the mixed concrete pouring out of it can fall into the hopper of the placer or pump. Suitable retarders may be used where ready mixed concrete is transported in transit cars. In case of vertical shafts used as construction adit, mixed concrete can be conveyed through 'elephant trunks'. These 'trunks' should be made up of short tapered pieces linked to each other. The drop from the bottom of the 'trunk' to the concrete heap below shall not be more than 1 m.

9. PLACING CONCRETE

9.1 If the invert concreting or kerb concreting is done first, the surface of old concrete shall be covered by 25 mm thick layer of mortar (of the same mix as the concrete, without coarse aggregate) to get a proper bond with the new concrete. During concreting by a pump or a placer behind form work for sides and arch, if the placing is interrupted for a period of more than one hour, a batch (sufficient to cover the area by a 15 mm layer) of mortar as above shall be pumped to cover the cold joints.

9.1.1 Care shall be taken while pouring through side doors in forms so that no hollow pockets remain. In the case of monolithic forms, as the concrete will fill the invert first, there may be a tendency for the form to float, and therefore the form shall be strutted down rigidly from the sides and the roof of the tunnel as well.

9.1.2 The concrete may be placed either by a concrete pump or pneumatic placer. Concrete in the invert may be placed direct. The discharge end of the concrete delivery pipe may be kept buried a few centimetres inside the freshly placed concrete, as far as practicable, to avoid segregation. Pumps and especially placers are sensitive to the pressure of the compressed air supply. In case of long compressed air supply lines, air chambers of adequate capacity shall be provided on the pipe line near the discharge end to reduce pressure drop.

10. REINFORCEMENT

10.1 It is generally not necessary to provide any reinforcement in the lining in good rock [*see* IS : 4880 (Part IV) - 1971*]. Whenever it becomes

*Code of practice for design of tunnels conveying water: Part IV Structural design of concrete lining in rock.

necessary to provide reinforcement, sufficient cover shall be provided. The spacing of reinforcement shall be adequate to permit flow of concrete around it without any hollows anywhere.

11. CONSTRUCTION JOINT

11.1 Two types of construction joints generally become necessary namely, (a) bulk head and (b) longitudinal.

11.1.1 Bulk head joints are required to be provided at the end of each shutter.

11.1.2 Longitudinal joints become necessary at the junction of the sides and the invert where the kerb becomes an integral part of either the invert or the sides. Where the kerbs are laid separately, there will be two such joints at each kerb. When the sides and arch are laid separately similar joints become necessary at sides and arch. No special treatment is necessary for such construction joints except general cleaning and, where applicable, a layer of cement sand mortar as specified in **9.1** may be laid on the joint.

12. CONSOLIDATION

12.1 As far as possible, flexible shaft immersion type vibrators having a vibrating needle of 50 mm dia and 8 000 vibrations/min frequency should be used for vibration of concrete (*see* IS : 2505-1968*). In addition the concrete shall be vibrated by external form vibrators of minimum 0·5 kW capacity. The spacing of form vibrators depends on the size of vibrator, mass of form work, thickness of concrete, etc. The spacing shall be adequate to ensure satisfactory compaction. The vibrator spacing shall be closer at the crown portion.

13. CURING

13.1 Curing may be generally done by spraying water at short intervals to maintain a wet surface. Strong draft of wind shall be avoided through the tunnel to reduce chances of sudden drying and consequent cracking.

14. GROUTING

14.1 Concrete lining of underground works shall be grouted to pack the hollow space (gaps) between rock and concrete lining. Grouting shall be done under flow pressure not exceeding 5 kg/cm^2 or as required depending on the circumstances. The pattern and spacing of the holes shall be decided in accordance with IS : 5878 (Part VII)-1972†. Where grout intake indicates gap of more than 10 mm, very fine sand or rock dust should be added to the grout to fill the gap. In certain locations addition of bentonite may be helpful to hold cement in suspension for satisfactory grouting. The grout pressure should be reduced adequately when contact grouting in crown portion is done before invert is laid.

*Specification for concrete vibrators, immersion type (*first revision*).
†Code of practice for construction of tunnels conveying water: Part VII Grouting.

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