Indian Standard

CODE OF PRACTICE FOR DESIGN OF TUNNELS CONVEYING WATER

PART II GEOMETRIC DESIGN

(First Revision)

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BUREAU OF INDIAN STANDARDS
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NEW DELHI 110002

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PART II GEOMETRIC DESIGN

(First Revision)

0. FOREWORD

0.1 This Indian Standard (Part II) (First Revision) was adopted by the Indian Standards Institution on 24 July 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 1968. Its revision was taken up with a view to keeping abreast with the technological developments that have taken place in the field of tunnel design and construction. This revision incorporates modified Fig. 1 which more clearly illustrates *A*-line and *B*-line. A new geometric shape, egglipse, has also been added to the list of sections recommended for adoption for tunnels. The details for drawing the egglipse curve have been included as Appendix A.

0.3 Tunnels are generally used for conducting water through high ground or mountains, in rugged terrain where the cost of a surface line is excessive and elsewhere as convenience and economy dictate.

0.4 This standard has been published in parts. Other parts of the standard are as follows:

(Part I)-1975	General design
(Part III)-1976	Hydraulic design (*first revision*)
(Part IV)-1971	Structural design of concrete lining in rock
(Part V)-1972	Structural design of concrete lining in soft strata and soils
(Part VI)-1971	Tunnel supports
(Part VII)-1975	Structural design of steel lining

0.4.1 This part (Part II) lays down only general guidance in regard to the shape of various sections generally used for tunnels. However, for particular project the judgement of the designer is required for making a final choice of a section considering the prevailing site conditions, since no general recommendations can be made to fit in each and every individual case.

0.5 This code of practice represents a standard of good practice and therefore, takes the form of recommendations.

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1. SCOPE

1.1 This standard (Part II) lays down general requirements and criteria for geometric design of tunnels conveying water under pressure or under free-flow conditions. This standard does not, however, cover the geometric design of other tunnel structures.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definitions shall apply.

2.1 Minimum Excavation Line (*A*-Line) — It is the line within which no unexcavated material of any kind and no supports other than permanent structural steel supports shall be permitted to remain (*see* Fig. 1).

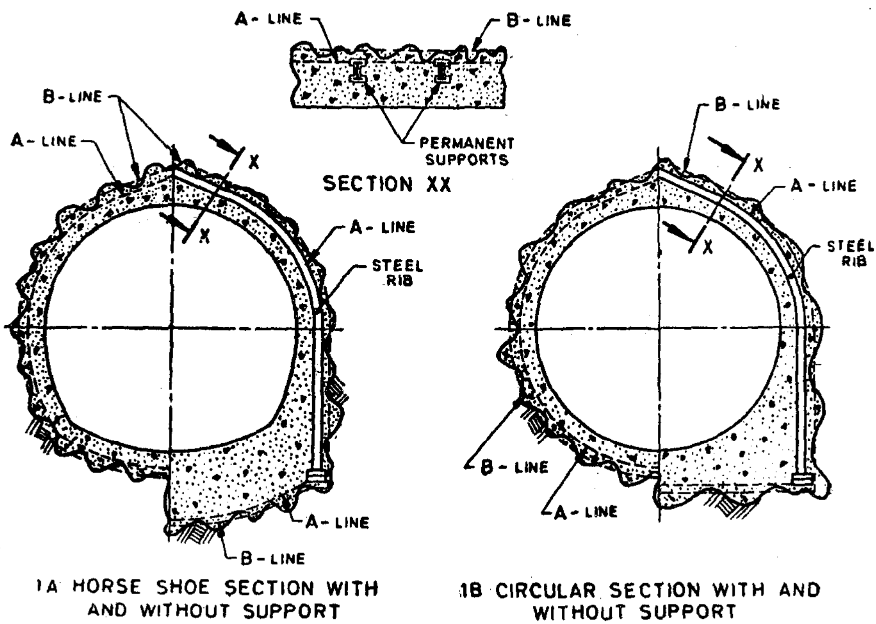


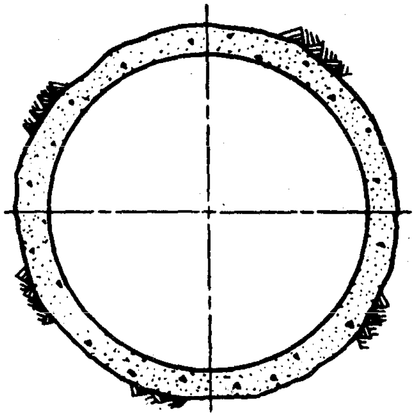
Fig. 1 Typical Section of Concrete-Lined Tunnels Showing *A*- and *B*-Lines

2.2 Pay Line (*B*-Line) — It is an assumed line (beyond *A*-line) to which payment of excavation is made whether the actual excavation falls inside or outside it (*see* Fig. 1). Sometimes *B*-line may merge with *A*-line. It is a common practice to adopt *B*-line for payment for concrete lining.

3. SHAPES

3.1 The following shapes are generally used for tunnel cross sections:

a) Circular section (*see* Fig. 2),
b) D Section (*see* Fig. 3),
c) Horse-shoe section (*see* Fig. 4),
d) Modified horse-shoe section (*see* Fig. 5),
e) Egg shaped section (*see* Fig. 6), and
f) Egglipse section (*see* Fig. 7).



NOTE — For tunnels excavated to horse-shoe section and concreted to circular section, *see* Fig. 1.

FIG. 2 CIRCULAR SECTION

4. GEOMETRIC DESIGN

4.1 Cross section of a tunnel depends on the following factors:

a) Geological,
b) Hydraulic,
c) Structural, and
d) Functional.

NOTE — It is not uncommon that the sections get modified during the course of construction.

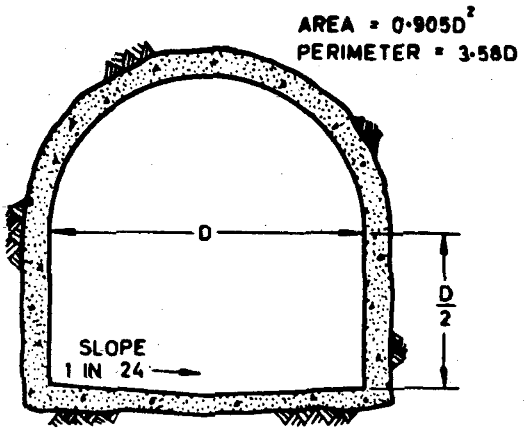


Fig. 3 D Section

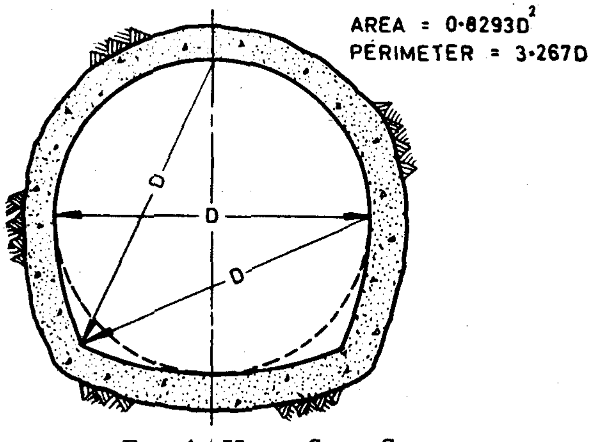
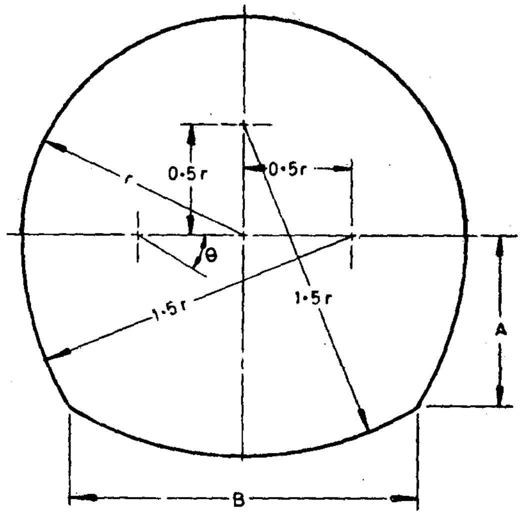


Fig. 4 Horse-Shoe Section

4.1.1 *Circular Section* — The circular section is most suitable from structural considerations. However, it is difficult for excavation, particularly where cross-sectional area is small. For tunnels which are likely to have to resist heavy inward or outward radial pressures, it is desirable to adopt a circular section. In case where the tunnel is subjected to high internal pressure, but does not have good quality of rock and/or adequate rock cover around it, circular section is considered to be the most suitable.



$r = 0{\cdot}987\ 580\ R$

where

R = Radius of Hydraulically Equivalent Circle

Area of Section	$= 3{\cdot}253\ 572\ r^2$
Perimeter of Section	$= 6{\cdot}426\ 334\ r$
Hydraulic Radius	$= 0{\cdot}506\ 287\ r$
A	$= 0{\cdot}780\ 776\ r$
B	$= 1{\cdot}561\ 553\ r$
θ	$= 31°\ 22'\ 01''$

FIG. 5 MODIFIED HORSE-SHOE SECTION

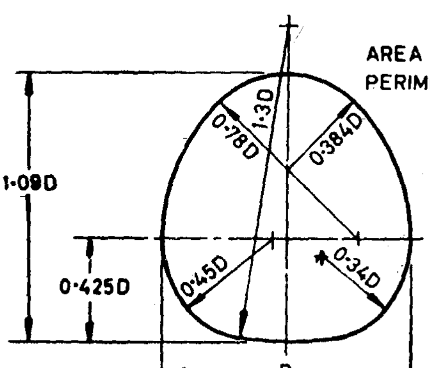


FIG. 6 EGG SHAPED SECTION

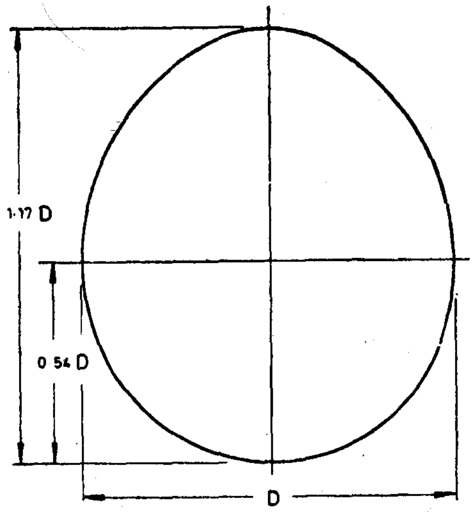


FIG. 7 TYPICAL EGGLIPSE SECTION

4.1.2 *D Section* — *D* section would be found suitable in tunnels located in massive igneous, hard, compacted, metamorphic and good quality sedimentary rocks where the external pressures due to water or unsound strata upon the lining is slight and also where the lining is not required to be designed against internal pressure. The principal advantages of this section over horse-shoe section (*see* **4.1.3**) are the added width of the invert which gives more working floor space in the heading during driving and the flatter invert which helps to eliminate the tendency of wet concrete to slump and draw away from the tunnel sides after it has been screeded.

4.1.3 *Horse-Shoe and Modified Horse-Shoe Sections* — These sections are a compromise between circular and *D* sections. These sections are strong in their resistance to external pressures. Quality of rock and adequate rock cover in terms of the internal pressure to which the tunnel is subjected govern the use of these sections. Modified horse-shoe section offers the advantage of flat base for constructional ease and change over to circular section with minimum additional expenditure in reaches of inadequate rock cover and poor rock formations.

4.1.4 *Egg Shaped and Egglipse Sections* — Where the rock is stratified, soft and very closely laminated (as laminated sand stones, slates, micaceous schists, etc) and where the external pressures and tensile forces in the crown are likely to be high so as to cause serious rock falls, egg shaped and egglipse sections should be considered. In the case of these sections there is not much velocity reduction with reduction in discharge. Therefore, these sections afford advantage in cases of sewage tunnels and tunnels carrying sediments. Egglipse has advantage over egg shaped section as it has a smoother curvature and is hydraulically more efficient. Details for drawing egglipse curve are given in Appendix A.

4.1.5 *Other Sections* — In addition to the sections mentioned in **4.1.1** to **4.1.4** there may be other composite geometrical sections which may be adopted particularly for tunnels which are free flowing and often only partly lined. If characteristics of a rock formation are fairly well known it may be possible to evolve a section which is likely to fit the shape in which the rock will break naturally. Thus, while a horse-shoe or *D* section is fairly easy to obtain in some formations there are others where the tunnel crown tends to break into a form more nearly square, and if there is no risk of heavy external pressure upon the lining or if the tunnel is to be unlined there is no reason why the designed cross section should not be made to suit the characteristics of the rock.

4.1.6 The typical geometry of both *A*- and *B*-lines for some sections are shown in Fig. 1 and the distance between *A*- and *B*-lines depends on the nature and geology of rock and method of tunnelling.

APPENDIX A

(*Clauses* 0.2 *and* 4.1.4)

DETAILS FOR DRAWING EGGLIPSE CURVE

A-1. GOVERNING RULE

A-1.1 F_1, F_2 and F_3 are the focal points (*see* Fig. 8) of the egglipse. The radii $F_1 P$, $F_2 P$ and $F_3 P$ are designated as r_1, r_2 and r_3 respectively. The governing rule for any point P on the egglipse is

$$r_1 + r_2 + r_3 = K \qquad \text{..............(1)}$$

where

K is a constant.

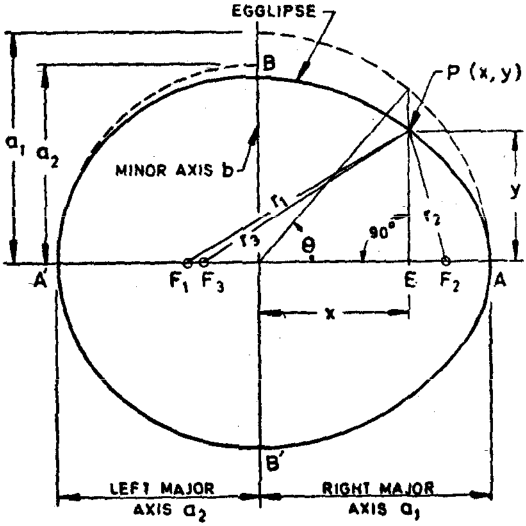


FIG. 8 DETAIL OF EGGLIPSE CURVE

A-2. BASIC EQUATIONS

A-2.1 The basic equations for the egglipse are

$$x = a \operatorname{Cos} \theta \qquad \ldots\ldots\ldots\ldots\ldots (2)$$

$$y = a \operatorname{Sin} \theta - \frac{a - \dfrac{a\,b}{(a^2 \operatorname{Sin}^2 \theta + b^2 \operatorname{Cos}^2 \theta)^{1/2}}}{\operatorname{Sin} \theta} \qquad \ldots\ldots\ldots\ldots\ldots (3)$$

where

a is the major axis, and

b is the minor axis.

NOTE — In equations (2) and (3), use *a* for a_1 for right side curve and use *a* for a_2 for left side curve, a_1 and a_2 are the right major axis and left major axis respectively.

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