IS 4090 (1967): Criteria for design of reinforced concrete arches [CED 38: Special Structures]

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Indian Standard
CRITERIA FOR THE DESIGN OF REINFORCED CONCRETE ARCHES

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

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Indian Standard
CRITERIA FOR THE DESIGN OF REINFORCED CONCRETE ARCHES

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0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 30 March 1967, after the draft finalized by the Criteria for Design of Structures Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 Reinforced concrete arches, because of their aesthetic appearance and ability to carry heavy loads over large spans, are advantageously used in bridges, monumental buildings, assembly or exhibition halls and similar other structures. The use of reinforced concrete allows much greater freedom in the choice of arch curve and very large spans are possible even with heavy loads without the necessity of fitting the arch curve to the pressure curve. However, the design of an economical arch has always been a rather lengthy process involving several sets of calculations and in this standard an attempt has been made to give general recommendations for guidance in the design of reinforced concrete arches. Certain essential features of construction which have a bearing on the design have also been briefly covered.

0.2.1 The provisions laid down in the standard are for the general guidance for designers and are applicable to reinforced concrete arches of spans up to 120 m and with rise to span ratio between 1/8 and 1/3. The designers may adopt other suitable methods of design and construction provided there is sufficient evidence by analysis or tests or both to prove the adequacy and safety of the method adopted. It has also been assumed that the design of reinforced concrete arches is entrusted to a qualified engineer and the execution of the work is carried under the directions of an experienced supervisor.

0.3 This criteria is complementary to IS : 456-1964* and the recommendations for usual reinforced concrete construction apply to reinforced concrete arches also.

0.4 Various formulae in **8** and **9** are a few of the formulae commonly adopted for the purpose and have been given in this standard as an aid for ready reference but the designer is free to use any other suitable formulae.

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

0.5 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 standard lays down recommendations for the classification, dimensional proportioning, analysis and design of reinforced concrete arches. The criteria for design is intended to apply only to arches which are primarily loaded (with dead and live loads) in their own plane and where curve lies in one plane. Portals are not covered by this criteria.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definitions shall apply (*see* Fig. 1).

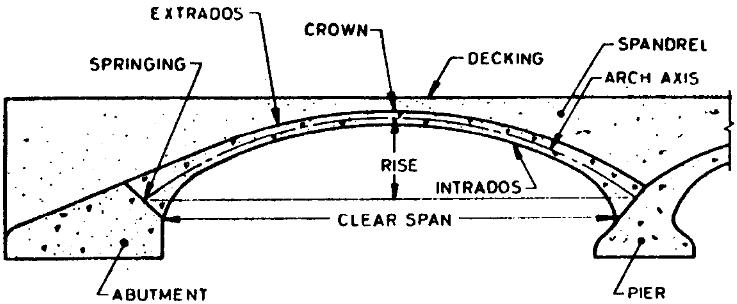

FIG. 1 TERMINOLOGY RELATING TO AN ARCH

2.1 Arch — Beam curved in one plane which is also the plane of loading with respect to dead load and live loads, and in which the displacement of the ends are restricted.

2.2 Back — The top surface of the arch.

2.3 Clear Span — The horizontal distance between the springing lines on a plane parallel to the axis of the arch.

2.4 Crown — The highest point on the arch axis.

2.5 Extrados — The line of intersection of the back of the arch with the plane parallel to the axis of the arch.

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

2.6 Hinge — Unless otherwise defined, a hinge is an artifice which is so designed and constructed as to provide no resistance to rotation (flexural resistance) so that the bending moment at the section of hinge can be assumed in the analysis to be zero. Hinges may be temporary or permanent.

2.7 Intrados — The line of intersection of the soffit with the plane parallel to the axis of the arch.

2.8 Right Arch — An arch in which the angle made by the springing line with the plane of axis of the arch is 90°.

2.9 Rise — The height of the arch axis at the crown above the level of the springing point. Unsymmetrical arches have different rises with respect to each springing point.

2.10 Skew Arch — An arch in which the angle made by the springing line with the plane of axis of the arch is not 90°.

2.11 Skew Back — The area of the support from which the arch springs.

2.12 Soffit — The under surface of the arch.

2.13 Spandrel — The space between the back of the arch and the decking.

2.14 Springing Line — The line of intersection of the face of the support and the soffit. Unsymmetrical arches have their two springing lines at different levels.

2.15 Springing Point — The point of intersection of arch axis with the face of the support.

2.16 Symmetrical Arch — An arch symmetrical about the crown and having its end supports at the same level.

2.17 Unsymmetrical Arch — An arch which is not symmetrical about the crown and which has its end supports at different levels.

3. NOTATION

3.1 For the purpose of this criteria and unless otherwise defined in the text, the following letter symbols shall have the meaning indicated against each:

- A_{sc} Cross sectional area of steel in compression
- a Depth of the stress block for compression in concrete
- b Width of the arch rib or the unit width of arch slab
- d Depth from the compression face to the tension steel of the arch rib

d_o	Distance between the compression and tension steels in the section
e	Eccentricity of load P on the arch section
E_c	Modulus of elasticity of concrete
E_s	Modulus elasticity of steel
σ_{sy}	Yield strength of steel reinforcement
h	Rise of arch
H	Horizontal dead load thrust in the arch at the crown
I	Moment of inertia of the arch rib at any section
I_c	Moment of inertia of the arch rib at the crown
I_s	Moment of inertia of the arch rib at the springing
L	Span of the arch
U	Ultimate strength of the arch section under direct and bending stresses
t	Thickness or depth of the arch rib
W_s	Average load on arch per unit length of span near springing
W_c	Average load on arch per unit length of span near crown
θ	Angle which the tangent to arch axis makes with the horizontal at the section under consideration
θ_s	Slope of the arch at the springing, that is, the angle which the tangent to the arch axis makes with the horizontal at the springing

4. TYPES OF ARCHES

4.1 Structurally arches may be classified into the following (*see* Fig. 2):

a) Fixed or hingeless arches, and

b) Hinged arches.

4.1.1 *Fixed or Hingeless Arches* — These have their ends built rigidly into the supports which do not allow them to move or rotate. Concrete arches are usually of this type.

4.1.2 *Hinged Arches* — These arches may have only one hinge at the crown, or two hinges; one at each springing, or three hinges; one at each springing and one at the crown. Hinged arches are not commonly employed in concrete. Temporary hinges are, sometimes, introduced during construction.

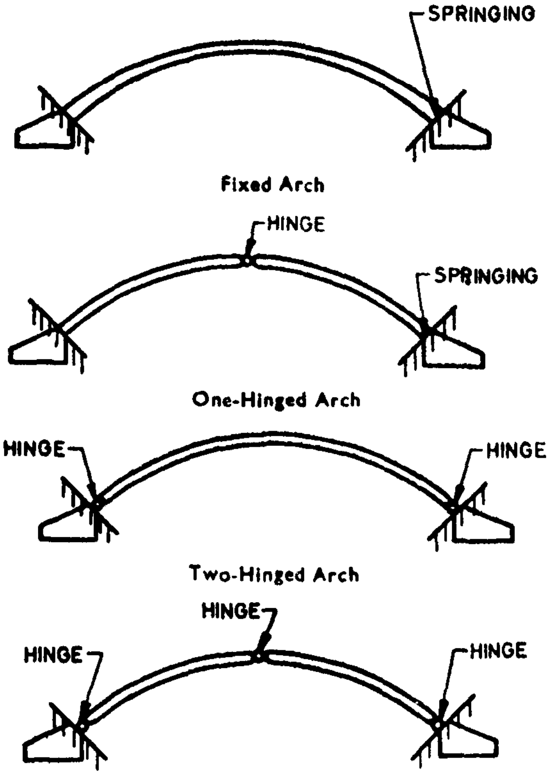

FIG. 2 STRUCTURAL CLASSIFICATION OF CONCRETE ARCH

4.2 Based on construction, an arch can be identified as:

a) filled spandrel arch,

b) open spandrel arch, and

c) tied arch or bow-string girder.

4.2.1 *Filled Spandrel Arch* — This arch consists of an arch slab carrying a filling of earth or any other suitable material on its back in the spandrel portion (*see* Fig. 1).

4.2.2 *Open Spandrel Arch* — It consists of an arch slab carrying a system of walls, piers or columns on its back to support the decking; or arch ribs supporting the decking at any level above the crown or between the crown and springings, through a system of columns or suspenders or both (*see* Fig. 3).

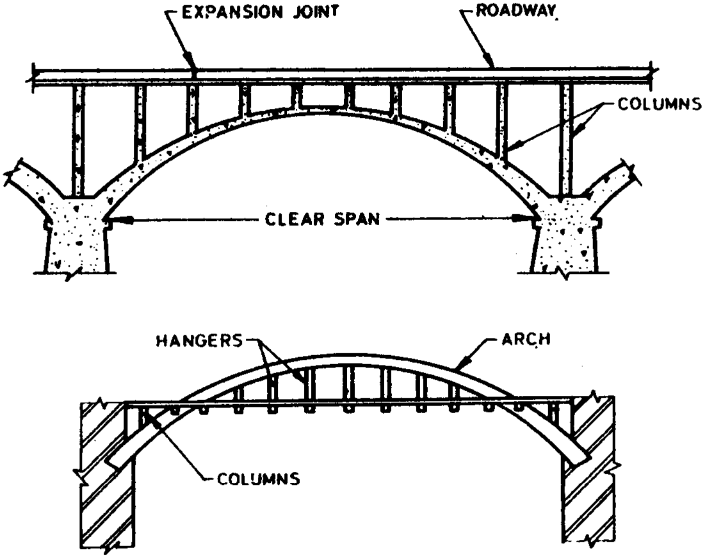

Fig. 3 Classification of Concrete Arches Based on Construction — Typical Open Spandrel Arch

4.2.3 *Tied Arch or Bow-String Girder* — Where supports cannot resist the horizontal reaction effectively, a tie at the level of springings is used to take up the horizontal thrust and such an arch is called a tied arch (*see* Fig. 4).

Note — A bow-string girder is a form of tied arch. It consists of arch ribs with horizontal ties, and suspenders supporting the ties.

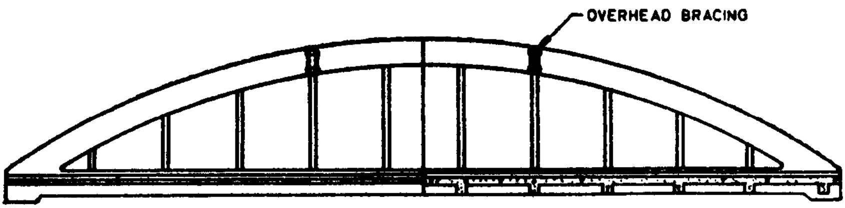

Fig. 4 Classification of Concrete Arches Based on Construction — Typical Tied Arch or Bow-Strings Girder

5. LOADS

5.1 For the purpose of design of reinforced concrete arches, the following loads shall be considered:

a) Dead load;
b) Live load;
c) Wind load;
d) Seismic load;
e) Tractive force; and
f) Snow load, where applicable.

The effect of temperature variations and shrinkage shall also be taken into account.

5.2 Dead Loads

5.2.1 *Filled Spandrel Arches* — In these arches, the load carried by the arch includes the self weight, the weight of fill and the roadway, if any. If the fill consists of loose material like earth, it exerts pressure on the arch which has horizontal besides vertical components.

5.2.1.1 When the ratio of depth of fill above the crown to the span of the arch exceeds one, the fill is treated as a deep fill.

5.2.1.2 When the depth of fill is less than indicated above, full weight of fill will be borne by the arch.

5.2.2 *Open Spandrel Arches and Tied Arches* — In these arches, the arch segment supports the self weight, the reaction transmitted by the decking, and the weight of the spandrel supports. While calculating the dead load reactions on these supports, the effect of continuity of the decking, may be taken into account and the spandrel supports may be treated as hinged at both ends.

5.3 Live Loads

5.3.1 The live loads for design should correspond to the relevant standard code of practices for buildings or bridges as the case may be.

5.3.2 *Filled Spandrel Arches* — In these arches, if the live load is uniformly distributed, it can be treated as such for analysis. If it is a wheel load covering a small area, it is taken to disperse at an average angle of 45° with the vertical through the fill and the arch slab, and the dispersion area at the level of the arch-axis gives the effective area of the arch bearing the load. When the dispersed loaded area due to two or more adjoining loads overlaps, as shown in Fig. 5, the loads are treated jointly and their total load taken as dispersed over the area $A\ B'\ C'\ D$.

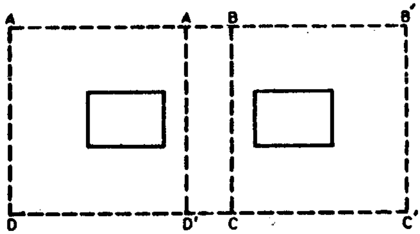

FIG. 5 LOAD DISPERSION DIAGRAM DUE TO TWO ADJOINING LOADS

5.3.3 *Open Spandrel Arches and Tied Arches* — In these arches, the live load acts on the arch as a series of loads transmitted by the decking supports, assuming that the supports are hinged to the arch. In calculating the effect of wheel loads, the longitudinal dispersion of the load need not be considered as the effect of such dispersion is negligible.

NOTE — The decking supports are assumed to be hinged to the arch. In actual practice, the bars are not crossed to form a hinge, but are anchored straight. However, being of smaller section compared to the arch, the supports can be assumed to be hinged to the arch.

5.4 Wind Force — The wind force can be estimated to the requirements of IS : 875-1964*. It is supposed to act transversely to the structure and the live load.

5.4.1 In the filled spandrel arches, the arch slab is analysed as a curved beam to take up the transverse wind forces.

5.4.2 The open spandrel arch is analysed in the same way as for transverse seismic force (*see also* **5.5.3**).

5.5 Seismic Force

5.5.1 Seismic force can be estimated to the requirements of IS : 1893-1966†. It can act either parallel to the arch longitudinally or transverse to it. It is taken acting at the centre of gravity of each mass and live load on the structure.

5.5.2 *Filled Spandrel Arches* — The seismic forces may be ignored in the filled spandrel arches. However, these shall be considered in the design of the sub-structure, including piers, abutments and foundations.

5.5.3 *Open Spandrel Arches*

5.5.3.1 *Under longitudinal seismic force* — The force on the live load and decking is transmitted to the arch in the same way as tractive force. The force on arch and spandrel supports acts at the centre of gravity of the respective segments of the arch.

*Code of practice for structural safety of buildings : Loading standards (*revised*).

†Criteria for earthquake resistant design of structures (*first revision*). (Third revision issued in 1975).

5.5.3.2 *Under transverse seismic force* — The force on the live load causes increased load on one portion of the arch slab (or one of arch rib) and a corresponding decrease in load on the other portion of the arch slab (or the other arch rib). Arch should be checked for these increased loads. The decking is supported on masonry abutments or reinforced concrete portals at the ends, strong enough to receive transverse forces transmitted by the decking acting as a horizontal girder. If the arch consists of an arch slab, the transverse force on the arch and spandrel supports is taken by the arch slab acting as a curved beam, and the force on the live load and decking by the decking acting as a horizontal girder. If the arch consists of an arch slab the transverse force on the arch and spandrel supports shall be assumed to be resisted by the arch slab acting as a curved beam and the force on the live load and decking by the decking acting as a horizontal girder. If the arch consists of arch ribs, the transverse force on the ribs and spandrel supports shall be assumed to be transmitted to the decking and the decking assumed to carry the entire transverse force to the end abutments or portals as a horizontal girder. When joints are provided in the decking, the transverse force on the portion of the decking in between the joints, shall be assumed to be transmitted to the arch ribs. Alternatively, the arch ribs should be braced suitably to bear the resulting bending moments and torsion. Vertical acceleration need not be considered.

5.5.4 *Bow String Girders*

5.5.4.1 *Under longitudinal seismic force* — The force on live load and decking is carried directly to the supports. . The force on suspenders may be assumed to be transferred half on the arch and half on the decking. The force on the arch rib itself shall be assumed to act at the centre of gravity of its various segments.

5.5.4.2 *Under transverse seismic force* — The transverse force on the live loads causes increased loads on the leeward arch rib, and it should be checked for these. The force on the arch ribs and suspenders is transmitted by the suspenders acting as cantilevers fixed to the decking. The decking carries the entire transverse force to the supports as a horizontal girder. Where possible as an alternative arrangement, the two ribs may be suitably braced to bear the resulting moments and torsion.

5.6 Tractive Force

5.6.1 Tractive force should be considered in case of bridges and can be estimated by referring to relevant codes.

5.6.2 *Filled Spandrel Arches* — In these arches, the tractive force can be ignored.

5.6.3 *Open Spandrel Arches* — If the decking is provided at the level of the crown, the tractive force shall be assumed to act at the crown only, as spandrel supports are comparatively too flexible to transmit this force at other points of the arch. But if the decking is supported at any other level by means of columns and suspenders, this force shall be distributed at the panel points along the arch in the ratio of the stiffnesses of spandrel supports. If the decking is supported by the abutments at the ends, all the tractive force shall be assumed to have been directly transmitted to the abutments. If horizontal bracings are used to connect the spandrel supports, these shall transmit their share of the longitudinal force to the arch through the top-most horizontal brace connecting spandrel supports with the arch.

5.6.4 *Bow-String Girders* — In these, the tractive force is transmitted by the decking directly to the supports.

5.7 Temperature — Variation of temperature occurs due to heat of hydration during setting of cement as well as due to fluctuation of air temperature.

5.7.1 *Heat of Hydration* — The stresses due to this cause can be eliminated if the key section of the arch is poured after most of the heat of hydration has been dissipated. The period required to dissipate a major portion of this heat depends on the conditions and the sequence of pouring the arch. Normally this period is 8 to 15 days.

5.7.2 *Variation of Air Temperature* — Temperature variation will have no appreciable effect on tied arches, which are free to move at the ends. Relevant recommendations of IS : 456-1964* may be followed.

5.8 Shrinkage — Shrinkage produces direct as well indirect effects. Direct effect is of a local nature and results in merely a redistribution of stresses on the section. This redistribution of stresses does not affect the ultimate strength of the section and hence may be neglected.

5.8.1 The indirect effect is caused by a decrease in the length of axis and the stresses caused are of the same nature as due to a fall of temperature. The shrinkage coefficient of concrete in arches is of the order of 0·000 15. However, about 60 percent of its effect on stresses is relieved by creep of concrete. It is recommended to take shrinkage as equivalent to a fall of temperature of 15°C, for purposes of calculating stresses. For calculating deflections, shrinkage strain may be taken equal to 0·000 15. Shrinkage may be considered in design only if it produces worse effects.

5.9 Creep — As it does not affect the ultimate strength of the section, its effect need not be considered in the calculations.

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

6. MATERIALS

6.1 The materials for reinforced concrete arches shall conform to the requirements of **4** of IS : 456-1964*.

6.2 Concrete — Concrete mix shall be controlled concrete conforming to **5** of IS : 456-1964*. Since arches carry primarily compressive stresses, it is economical to use high strength concrete as in columns. The maximum quantity of cement in the concrete mix shall preferably not exceed 530 kg/m^3 of concrete as richer mixes may give rise to excessive shrinkage.

6.3 Steel — The steel reinforcement shall be mild steel or medium tensile steel bars conforming to IS : 432 (Part 1)-1966†.

7. STRESSES

7.1 The basic permissible stresses in concrete and steel should be in accordance with requirements of IS : 456-1964*.

7.2 Combination of Stresses — When a section is subjected to combine bending and direct stresses, the conditions specified in **11** of IS : 456-1964* should be satisfied.

7.3 Increase in Stresses — For various combination of loads specified in **5**, the basic permissible stresses may be increased as recommended in IS : 456-1964* for arches in buildings and as recommended in relevant Indian Standards for bridge arches.

8. CONFIGURATION

8.1 Shape of the Axis — The shape of the arch axis should, as far as possible, coincide with the funicular polygon for dead loads.

8.1.1 *Fixed Arches* — For preliminary design, the shape of arch axis as given by the following equation may be adopted (*see* Fig. 6), taking origin of the coordinates at the crown of the arch:

$$y = \frac{h}{m-1} \left(\text{Cosh} \frac{2px}{L} - 1 \right)$$

where

y = vertical distance of any point on the arch axis from the crown,

h = rise of the arch,

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

†Specification for mild steel and medium tensile steel bars and hard-drawn steel wire for concrete reinforcement : Part 1 Mild steel and medium tensile steel bars (*second revision*).

$$m = \frac{W_s}{W_c},$$

W_s = average load on the arch per unit length of span near springing,

W_c = average load on the arch per unit length of span near crown,

$p = \log e \; (m + \sqrt{m^2 - 1}),$

x = horizontal distance of any point on the arch axis from the crown, and

L = span of the arch measured from the centre line at the springing.

NOTE — The value of m varies from 1·4 to 3 for open spandrel arches and from 3·5 to 8 for filled spandrel arches.

8.1.1.1 If the decking is provided below the crown level, the arch axis may be taken to be a parabola.

8.1.2 *Bow String Girders* — The dead loads on such arches being almost uniform, their axis should preferably be kept parabolic.

8.2 Rise of Arch — The rise of arches should generally be between one third to one sixth of the span for economy, the smaller value being applicable to relatively longer spans and the larger value for relatively smaller spans. Flatter arches have greater moments due to temperature, shrinkage etc, and those with bigger rise have greater length and higher cost of formwork.

8.3 Section of the Arch — In fixed arches, the section is increased from crown towards springing. The increase in depth at the springing should be 50 to 75 percent over that at the crown. The variation in the moment of inertia of the arch section is provided by the following relation (*see* Fig. 6):

$$I = \frac{I_c}{\left(1 - (1 - n) \dfrac{4x^2}{L^2}\right) \text{Cos}\, \theta}$$

where

I = moment of inertia of the arch rib at any section,

I_c = moment of inertia of the arch rib at the crown,

$$n = \frac{I_c}{I_s \text{ Cos } \theta_s},$$

θ_s = angle which the tangent to the arch axis makes with the horizontal at the springing,

x = horizontal distance of the section from crown,
L = span of the arch,
θ = angle which the tangent to the arch axis makes with the horizontal at the section under consideration, and
I_s = moment of inertia of the arch rib at the springing.

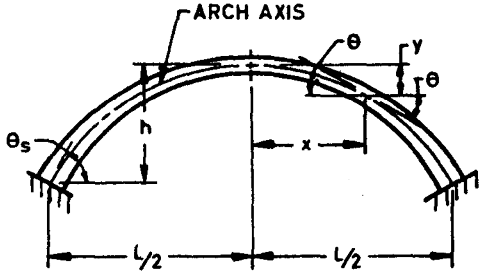

FIG. 6 SHAPE OF AXIS OF FIXED ARCH

9. ANALYSIS

9.1 General

9.1.1 *Arch Axis* — In the analysis, the centroidal axis of the concrete section may be taken as the arch axis.

9.1.2 *Moment of Inertia* — The moment of inertia of reinforced concrete section shall be calculated in accordance with requirements of **6.4** of IS : 456-1964*.

9.1.3 *Modulus of Elasticity of Concrete* — Unless otherwise determined by tests, the modulus of elasticity of concrete, E_c should be in accordance with IS : 456-1964*.

9.1.4 *Modulus of Elasticity of Steel* — Unless otherwise specified, the modulus of elasticity E_s for mild steel and medium tensile steel shall be in accordance with IS : 800-1962†.

9.2 Preliminary Analysis

9.2.1 *Arch Axis* — The arch axis for preliminary design may be assumed as in **8.1.1**.

9.2.2 *Dead Load Thrusts* — Certain arbitrary dimensions of the arch section may be assumed for the computation of dead loads at the springing and the crown.

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

†Code of practice for use of structural steel in general building construction (*revised*).

The dead load horizontal thrust H is given by the following expression:

$$H = \frac{m-1}{4p^2} \quad \frac{W_c L^2}{h}$$

where

$$m = \frac{W_s}{W_c},$$

W_s = average load on arch per unit length of span near springing,

W_c = average load on arch per unit length of span near crown,

$p = \log e \left(m + \sqrt{m^2 - 1} \right),$

L = span of the arch, and

h = rise of the arch.

9.2.3 *Live Load Moments and Thrusts* — The influence lines for moments at crown, quarter-point and springing point and for horizontal thrust and shear corresponding to equations in **8.1.1** and depth variation in **8.3**, are given in Fig. 7 to 12.

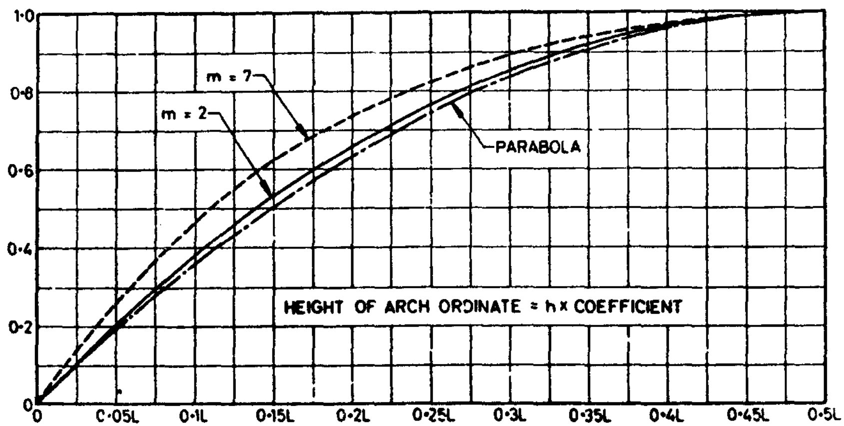

Fig. 7 Arch Axis

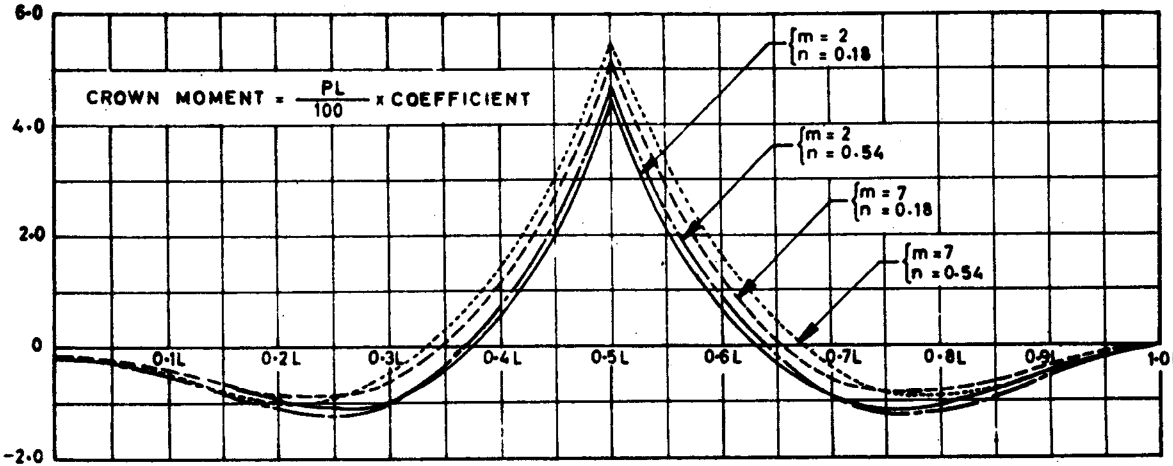

Fig. 8 Influence Lines for Moment at Crown

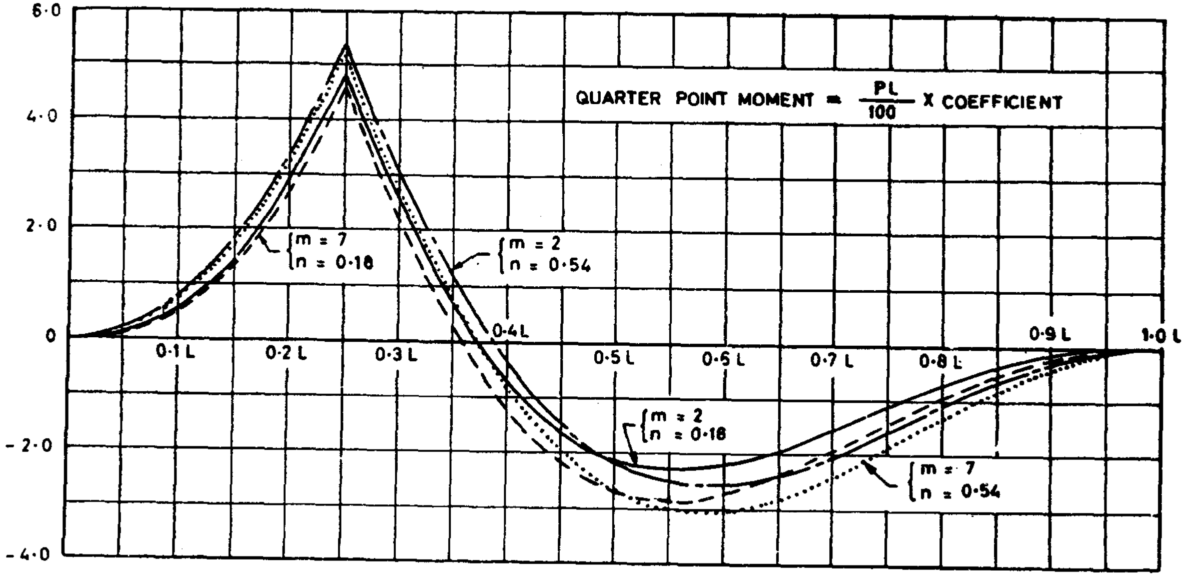

Fig. 9 Influence Lines for Bending Moment at Quarter Point

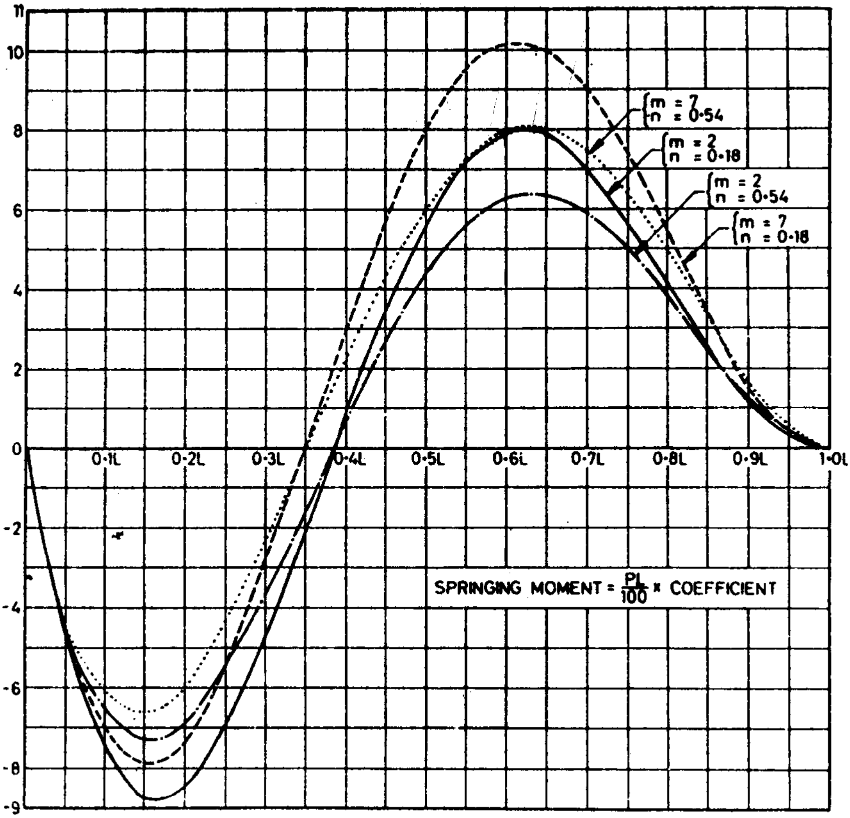

FIG. 10 INFLUENCE LINES FOR MOMENT AT SPRINGING

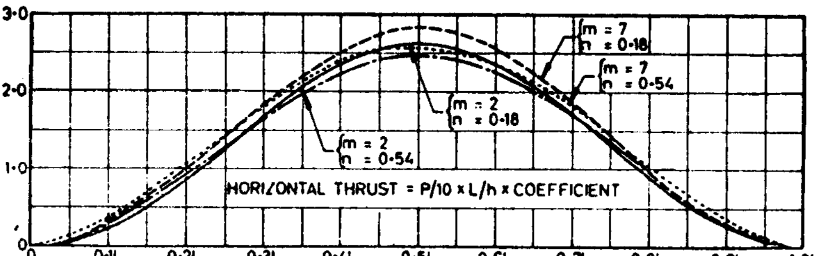

FIG. 11 INFLUENCE LINES FOR HORIZONTAL THRUST AT CROWN

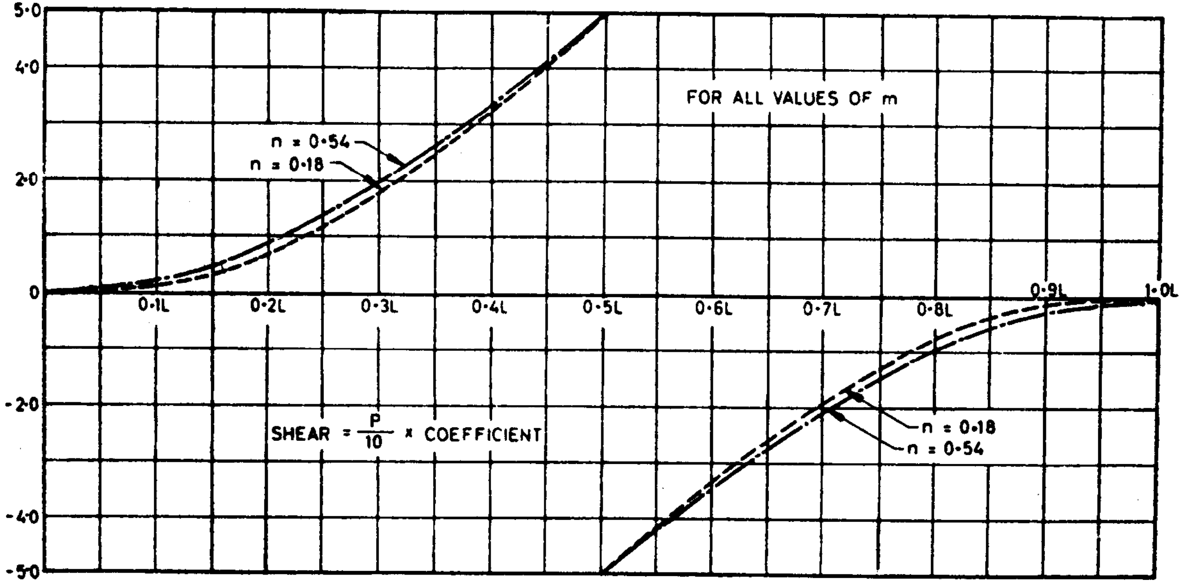

FIG. 12 INFLUENCE LINES FOR SHEAR AT CROWN

9.2.4 *Temperature Stresses* — The horizontal thrust and the moment at crown due to a change in temperature are given by the following expressions:

$$H_T = T.\alpha\, E_c \frac{(m-1)^2}{h} I_c \frac{f_1}{f_3}$$

$$M_{CT} = T.\alpha\, E_c \frac{(m-1)}{h} I_c \frac{f_2}{f_3}$$

where

H_T = horizontal thrust due to temperature,

M_{CT} = moment at crown due to temperature change,

T = rise in temperature (*see* **9.2.4.1** *and* **9.2.4.2**),

α = coefficient of linear thermal expansion of concrete,

E_c, m, n, I_c, h = as defined in **3**, **8.1.1** and **8.3**, and

f_1, f_2, f_3 = coefficients given in Table 1.

TABLE 1 COEFFICIENTS

(*Clause* 9.2.4)

n	f_1	$m = 2$		$m = 7$	
		f_2	f_3	f_2	f_3
0·18	0·726 7	0·157 6	0·029 4	0·779 8	0·886 4
0·54	0·846 7	0·226 8	0·052 7	1·532	1·671 0

9.2.4.1 The rise and fall in temperature shall be fixed for the locality in which the structure is to be constructed and shall be figured from an assumed temperature at the time of erection. Due consideration shall be given to the lag between air temperature and the interior temperature of massive concrete members or structures.

9.2.4.2 Unless otherwise stated, the following range of temperature may generally be assumed in the design:

	Temperature rise °C	*Temperature fall* °C
Moderate climate	17	17
Extreme climate	25	25

NOTE — Intermediate values may be allowed at the discretion of the engineer responsible for design.

9.2.5 *Rib Shortening* — The horizontal thrust (H_s) and the moment at the crown (M_{cs}) due to rib shortening for the assumed arch axis are given by the following equations:

$$H_s = -H\left(\frac{m-1}{h}\right)^2\left(\frac{I_c^2}{12b^2}\right)^{\frac{1}{3}}\beta\frac{f_1}{f_3}$$

$$M_{cs} = H\left(\frac{m-1}{h}\right)\left(\frac{I_c}{12b^2}\right)^{\frac{1}{3}}\beta\frac{f_2}{f_3}$$

where

$$\beta = \left[1 + \frac{16}{9}\left(\frac{h}{L}\right)^2 - (1-n)\left\{\frac{1}{9} + \frac{16}{15}\left(\frac{h}{L}\right)^2\right\}\right]$$

H = horizontal thrust due to dead load,

b = width of arch rib or unit width of arch slab, and

f_1, f_2, f_3 = coefficients given in Table 1.

9.3 Exact Analysis — After the preliminary analysis and design of the arch has been completed, the arch axis can be modified to follow the line of thrust of dead loads. The moments and thrusts at crown, quarter point and springing may be computed by any suitable procedure of arch analysis.

9.3.1 In an open spandrel arch, the arch may be designed without taking account of the monolithic connection with the supported structure.

9.3.2 Expansion joints in the deck should preferably be placed at each end of the span so that the deck may act as a horizontal girder to bear transverse forces.

9.3.3 A bow-string girder may be analysed as a virendeel girder or as a two hinged arch. The effect due to elastic extension of the tie should be accounted for in the design.

9.4 Settlement of Supports — The arches are normally built on the firm ground where there is practically no relative settlement of supports. If the settlements can be precalculated taking soil conditions into account, these may be taken into consideration in calculating moments and thrusts.

10. WORKING LOAD DESIGN

10.1 Critical Sections — For purposes of design, it is usual to check three sections of the arch, that is, crown, quarter point and springing.

10.2 Dead Load — Any possible variation in the magnitude or distribution of dead load or in the axis of the arch is allowed for by checking the arch for a moving point load equal to $\pm 2 \cdot 5$ percent of the total dead load thrust at crown so as to produce worst effect at the section.

10.3 Minimum Width of Arch Rib — Minimum width of the arch rib should not be less than 1/30th of its axial length. For more slender ribs, lateral bracing should be provided.

10.4 Deflection Moments — Deflection moments should be taken into account while designing arches having span greater than 120 m.

10.4.1 To obtain deflection moments, the analysis is first made for separate loads. Then the moments and thrusts due to various causes are combined as to obtain maximum moment at a section. Under the same condition of loading deflection moments are calculated for that section. In these calculations, the properties of the undeflected arch axis may be used without much error.

10.5 The arch sections shall be checked for the following combination of loads:

$$\left.\begin{array}{l}\text{a) } DL + LL \\ \text{b) } DL + LL + WL\end{array}\right\}\text{ with normal permissible stresses}$$

where

DL = dead load on the arch,

LL = any other load for which an increase in permissible stresses is not allowed, and

WL = loads with which an increase in permissible stresses is allowed.

10.5.1 Where stresses due to wind (or earthquake), temperature and shrinkage effects are combined with those due to dead, live and impact loads, the permissible increase in stresses shall be in accordance with the recommendations of IS : 456-1964*. No relaxation shall be made when stresses due to shrinkage are considered.

11. ULTIMATE LOAD DESIGN

11.1 Elastic method of analysis is used to compute the maximum bending moment and thrust, and the strength of the section may be computed on the basis of ultimate load formulae.

11.1.1 The arch section should be designed with the following ultimate strengths to provide an adequate factor of safety against over loads and freedom from excessive cracking:

$$U = DL + 3\ LL$$

$$U = 2(\ DL + LL\ )$$

where

U = ultimate strength capacity,

DL = dead loads of the arch, and

LL = live loads including impact.

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

The strength of the arch section should be checked with the live load placed to give maximum moment as well as maximum thrust.

11.2 Ultimate Strength of Section — The ultimate strength of sections under direct and bending stresses shall be calculated as per requirements of IS : 456-1964*.

12. REINFORCEMENT

12.1 Longitudinal Reinforcement — The cross-sectional area of longitudinal reinforcement should be not less than 0·8 percent of the area of the arch section.

The practice of placing bars only on the tension face and bending them to the other face where the bending moment changes sign is not recommended.

12.2 Lateral Ties — Lateral ties conforming to the requirements of **10** of IS : 456-1964*, should be provided to tie the longitudinal bars in the arch ribs.

12.3 Transverse Reinforcement — In arch slabs, transverse reinforcement shall be provided for distribution, temperature and shrinkage. The minimum transverse reinforcement on each face of the slab shall be 0·2 percent of the sectional area.

12.4 Shear Reinforcement — In bow-string girder, special shear reinforcement shall be provided at the junctions of arch and tie.

12.5 Splicing and Anchorage — The main reinforcement bars may be anchored into the abutments or spliced to develop their full strength by bond.

12.5.1 In the case of ties and suspenders of the bow-string girders, no reliance can be placed on bond alone to transmit tension at laps or from member to the arch. The bars should be spliced by welding or other suitable mechanical means and joints in bars should be staggered. The ends of the bars may be provided with nuts and washers to bear against concrete.

13. SUPPORTS

13.1 The supports are built in masonry or plain and reinforced concrete unless the arch is supported on a rock directly.

13.2 All the piers and abutments shall be checked jointly as well as individually for block stability, stresses under the reactions from the arch and other forces directly coming on them.

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

13.2.1 In fixed arches, the reactions from the arch should be calculated under two conditions of loading, one giving maximum horizontal thrust and the other giving maximum moment at springing.

13.2.2 For intermediate piers, the stability should be checked with the combined effect of both spans giving a) maximum side thrust and b) maximum overturning moment.

13.3 Bearings in Bow String Girder — Any suitable bearing which allows the full expansion of the tie may be used. One end of the bow string girder may be put on rocker bearing and the other on roller bearing. For efficient working, the roller bearing may be of steel.

14. HINGES

14.1 In concrete arches, hinges are usually not provided on a permanent basis. Temporary hinges may be provided during construction to eliminate the moments due to rib shortening, shrinkage, settlement of abutments etc. These are provided at the springings and at the crown.

14.2 Temporary Hinge — It is made as flexible as possible by providing a small section and a high percentage of compression steel together with spiral reinforcement. The compressive stress in concrete is kept about 80 percent of its ultimate strength. The hinge section is designed as a column having about 8 percent longitudinal reinforcement and maximum amount of spiral reinforcement as given in IS : 456-1964*. The length of the hinge should not be greater than twice the smaller dimension of its section. Suitable steel meshes should be provided to distribute the load from the hinge to the main member.

The main reinforcement of the arch should continue on either side of the hinge. When the hinge has to be eliminated, the arch rib is filled with concrete round the hinge and the full section becomes effective to resist moments (*see* Fig. 13).

15. CONSTRUCTION JOINTS

15.1 The number of joints should be kept minimum. The joints in the arch should be radial and a shear key should be provided at the joints. The longitudinal reinforcement should be continuous at the joints. To obtain good joints, the precautions in laying new concrete against the old surface should be followed as recommended in IS : 456-1964*.

15.2 Filled Spandrel Arches — If the face walls on either side are built in concrete, these should be properly anchored into the arch slab and a shear key should be provided at the junction. Vertical expansion joints should be provided in face walls so that they do not put up any resistance

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

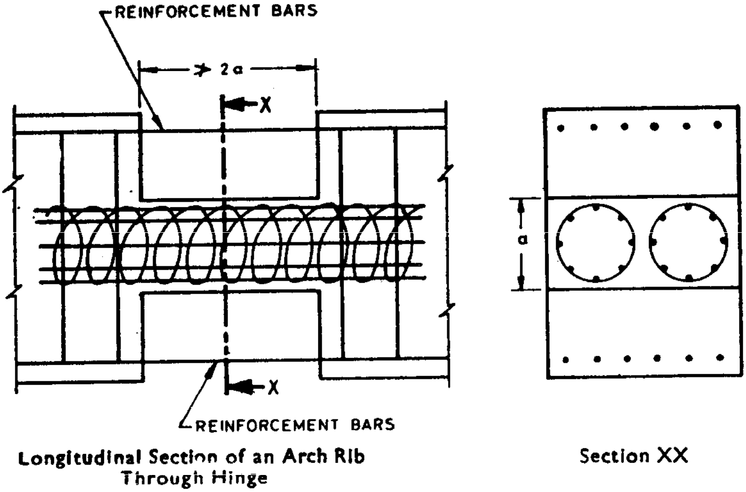

FIG. 13 TYPICAL TEMPORARY HINGE (CONCRETE NOT SHOWN)

to the arch slab when it deforms under load; this will also avoid unsightly cracks in the walls.

15.3 Open Spandrel Arches — The spandrel supports should have construction joints over the arches and under the deck beams. Their reinforcement should be fully anchored into the arch ribs and the deck beams.

15.3.1 Joints in the columns braces can be given at face of columns with a recess of about 12 mm.

15.3.2 Construction joints in the deck beams should be given at the centre of columns and those in the deck slab over cross beams. The reinforcement at the joint should be continuous in both cases.

15.4 Bow String Girders—In these, the decking and arch ribs should be concreted first leaving the reinforcement of suspenders and ties open. After the concrete has hardened, the centering of arch and decking should be removed so that the tie and suspenders take their full dead load stresses. These should then be concreted in the stressed condition.

16. STRIKING THE CENTRING

16.1 To avoid unsymmetry of dead loads on the arch which will cause heavy moments, the centring should be removed gradually and in stages symmetrically from the crown. For this purpose, it will be better if the centring is erected on screw jacks, wedges or sand boxes which can be lowered symmetrically.

Centring should not be struck till the concrete has attained a strength of at least double the stresses developed on decentring.

16.2 Filling in the spandrel portion shall be done after decentring and when the concrete has attained full strength.

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