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Government of India
Ministry of Railways
(Railway Board)

Indian Railway Standard

CODE OF PRACTICE FOR THE DESIGN AND CONSTRUCTION OF MASONRY AND PLAIN CONCRETE ARCH BRIDGES

(Arch Bridge Code)

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Indian Railway Standard

CODE OF PRACTICE FOR THE DESIGN AND CONSTRUCTION OF MASONRY AND PLAIN CONCRETE ARCH BRIDGES

(Arch Bridge Code)

Please See ACS Slip No. 7

1. SCOPE

1.1 This code of practice applies to arch bridges constructed of brickwork, stone or plain concrete.

1.2 Open spandrel and reinforced concrete arch bridges are excluded from the scope of this code.

2. DESIGN LOADS AND THEIR METHODS OF APPLICATION

2.1 Dead Load- The dead load transmitted to the arch is assumed to act vertically. The horizontal component of the earth pressure acting on the arch ring may be neglected.

2.1.1 The dead load shall include the weight of the arch ring itself and all filling above it, also the weight of the road metal in the case of road bridges and track and ballast in the case of railway bridges.

2.1.2 For the purpose of calculations, the dead loads for various materials shall be taken from IS:1911-1967. Schedule of Unit Weights of Building Materials.

2.2 Live Load

2.2.1 Live Load- The live load shall be the appropriate standard of loading with longitudinal and lateral distribution as laid down in the Bridge Rules.

2.2.2 ~~Impact~~ Dynamic effects- The ~~impact~~ Dynamic effects allowance shall be taken as specified in the Bridge Rules.

2.2.3 Horizontal Loads on the Arch- The effect of the tractive effort and braking effect may be neglected in designing or analysing arches covered by this code.

2.3 Temperature Stresses- Temperature stresses may be neglected in designing arches in masonry or plain concrete, where rise-span ratio is not less than 1/3.

2.4 Rib-shortening Stresses- In the design of arch bridges, allowance shall be made for stresses due to rib-shortening under thrust.

2.5 Shrinkage Stresses- Shrinkage stresses are neglected in the design of arch bridges covered by this code. When the arch is, however, built in plain concrete, steps shall be taken to reduce shrinkage stresses by concreting in strips and for spans exceeding 6m, light reinforcements which may not be less than 0.16 per cent of the area of concrete, shall be provided to resist residual shrinkage stresses.

3. SHAPE OF THE ARCH RING

3.1 In order to reduce the horizontal thrust and so to obtain economy in design of abutments, piers and foundations, the rise of an arch should be kept as large as possible. It should not ordinarily be less than 1/3 of the span but in no case less than 1/5.

3.1.1 For spans up to 12m clear, a simple segmental or semi-circular curve may be adopted as no marked advantage is obtained by using multi-centred arches.

3.1.2 For spans exceeding 12m clear, the shape of the arch axis should be designed in such a manner that the axis conforms as near as practicable to the equilibrium polygon for dead load plus 50 per cent of the E.U.D.L. covering the entire span.

4. THICKNESS OF ARCH RIB

4.1 The variation, if any, in the thickness of an arch from one section to another shall be gradual and shall be fixed with due regard to the conditions of stresses, economy and appearance.

For short spans, not exceeding 12m clear, a constant section of arch from crown to springing may be adopted.

5. ANALYSIS OF STRESSES IN THE ARCH RING

5.1 Conditions of Loading- In investigating the stability of the arch ring, it will be sufficient to consider the following conditions of loading with regard to live loads -

5.1.1 For short spans not exceeding 12m clear, with a constant thickness of the arch ring, live load at the end 5/8 of the span.

5.1.2 For short spans not exceeding 12m clear with arch rings of variable thickness, investigation of stresses must be made at three critical sections with the position of U.D.L. specified in Clause 2.3.4.1 of Bridge Rules as given in the table below:-

Section	Moment	
	Max. +	Max. -
Crown ..	Middle ½ of whole span	End 3/8 (both ends)
Quarter Point	End 3/8(adjacent end)	End 5/8(opposite end)
Spring Line	End 5/8(opposite end)	End 3/8(adjacent end).

5.1.3 For spans exceeding 12m clear, stresses shall be worked out throughout the arch, the number of sections depending on the span of the arch.

5.1.4 The line of pressure under the condition of loading enumerated above shall everywhere lie,

(a) within the middle half of the arch ring, if the line of pressure is determined by elastic theory.

(b) within the middle third if graphical or other approximate methods are adopted.

5.2 <u>Method of Analysis</u> - In analysing masonry or concrete arches, the elastic method of analysis should preferably be adopted. Either purely analytical methods or a combination of analytical and graphical methods may be used. In practice the simplest method would probably be a combination of the analytical and graphical methods.

5.3 Existing Arches

5.3.1 Except in case of gauge conversion, certification of existing arch bridges as per para 4,Chapter VI of Rules for the Opening of a Railway, shall be based on physical condition of the structure.
When new types of locomotives and rolling stock are permitted to run on a section for the first time, bridges should be kept under observation as considered necessary by the Chief Engineer.

5.3.2 Heavier loading density or axle load over those allowed at present shall not be permitted on distressed arch bridges, unless they are rehabilitated. However, at the discretion of the Chief Engineer, such heavier trailing load/increased axle load may be permitted on the existing distressed arch bridges, if the strength of the arch bridge is found safe after conducting load test on representative span as per the criteria indicated in para 5.3.3.

5.3.3 The load test shall be conducted on distressed bridge only after complete pressure grouting of the masonry. The criteria for arriving at the safe load shall be:-

(i) Under the proposed load the crown deflection and spread do not exceed 1.25 and 0.4 mm, respectively;

(ii) There is no residual deflection or spread after release of load; and

(iii) There is no crack appearing on the intrados of bridge.

Note: The above criteria will be applicable to segmental and non-segmental arches of span 4.5m to 15 m provided the span/rise ratio lies between 2 and 5.

5.3.4 In regard to gauge conversion, the certification for the safety of all the arch bridges, whether sound or distressed shall be based on load test on representative type of bridges. The criteria for assessing the safe load shall be the same as specified in clause 5.3.3 above, provided the following conditions are also satisfied. Special cases, if any, may be dealt with on individual merits by the Railways in consultation with RDSO.

(i) The condition of masonry and its behaviour under test load are satisfactory;

(ii) Type of foundation and nature of soil on which it is founded are suitable.

5.3.5 <u>Strengthening of weak/distressed existing arches</u>

5.3.5.1 For strengthening weak/distressed arches method of jacketting at the intrados is preferable, if the resultant reduction in the waterway is permissible.

5.3.5.2 In the case of strengthening over extrados of arch, the new arch ring should be designed to take the entire load, viz. dead and live loads.

5.3.5.3 In the case of strengthening below intrados of arch, the new arch ring should be designed as under:-

(a) To take the entire load by itself where the existing arch has transverse crack(s).

(b) To take the entire load by composite action with the existing arch ring, where the existing crack(s) are all longitudinal or there are no signs of distress in the existing arch, provided affective bond could be ensured between the old and new arch ring.

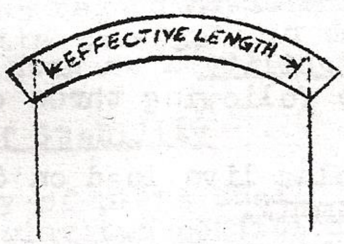
5.3.5.4 In the case of strengthening of abutments and piers of arch bridges, the design should always be on ~~x~~ the basis of composite action of the new material acting along with the existing one. It should, however, be ensured that a proper bond is established between the existing masonry and new material by suitable means such as dowels and post grouting through grout holes to be left while casting the jacket.

5.3.5.5 In all cases of cracked masonry, whether in arches or in abutments and piers, that should be grouted under pressure to plug all the cracks before the additional material is provided.

5.3.5.6 The space between the new arch ring and the existing arch, in the case of strengthening below the intrados of the arch should be grouted under pressure for which grout holes should be provided in the new arch ring.

6. " EFFECTIVE LENGTH" OF ARCH RING

6.1 The effective length shall be the full length from skew back to skew back. Where however spandrel filling with masonry or concrete is done in conjunction with the arch ring, so as to provide proper bonding between the arch ring and the masonry or concrete in the spandrel filling the effective length of the arch may be taken between the points obtained by producing the inside vertical faces of skew backs to cut the extrados as shown in the sketch.



7. ABUTMENTS FOR ARCH BRIDGES

7.1 Thickness at the Skew-backs - The thickness at the skew back should be determined with due regard to the shearing stress produced by the horizontal thrust from the arch ring, which shall be assumed to be resisted by the combined friction and shearing strength of the joint. The coefficient of friction in this case may be taken as 0.7 and the safe shearing stress as given in Clause 12.

7.2 Forces Acting on an Abutment

7.2.1 The forces acting on an abutment are as follows:

(a) Reaction from the arch.
(b) Pressure of earth at back.
(c) Weight of abutment and overlying fill.
(d) Water pressure and buoyancy- These should be considered when depth of water may exceed 6m the calculations being made both with and without the effect of the water pressure and buoyancy acting together.

7.2.2 In calculating the thrust of the arch ring for designing the abutment, ~~impact~~ Dynamic effects may be neglected.

7.2.3 The total thrust from the live load may be assumed to be distributed over the whole length of the abutment, or a length bounded by lines drawn at a slope of 1 horizontal to 2 vertical from the bottom edges of sleepers to the section under investigation whichever length is less. Over this length, the thrust due to dead load may be assumed to have a uniform value, corresponding to that produced by the maximum height of the filling.

7.2.4 The active earth pressure at the back of an abutment(which adds to its stability) shall not be taken to be more than the pressure of a fluid weighing 2353 N/m^3(240 kg/m^3). This pressure shall be assumed to act over a height from bed level to springing only, due allowance being made for the surcharge of the overlying fill. No allowance shall be made for the surcharge due to the live load.

7.3 Conditions of Stability - An arch abutment shall be investigated for the following three conditions of loading -

(a) Dead load plus live load on 5/8 span adjacent to the abutment.

(b) Dead load plus live load on the other 5/8 span.

(c) Dead load plus live load on the entire span.

For each of the above conditions of loading, the line of pressure in the course enumerated above shall lie within the middle half of every section of the abutment. The stresses at any section shall not exceed the working stresses specified in Clause 12. The shearing stresses at any place shall be assumed to be resisted by the frictional forces and the safe shearing strength of the masonry.

7.4 Foundations for Abutments

7.4.1 Arches shall only be built where foundation conditions are such that there will be no risk of unequal settlement or horizontal movement.

7.4.2 The permissible pressure on the soil shall not exceed that specified in Clause 13.

7.4.3 The line of pressure shall lie within the middle third of the foundation and every effort should be made to keep it as near the centre of the base as possible, to ensure a uniform distribution of pressure.

7.4.4 The depth of foundation shall be determined by the Engineer with due regard to the conditions at the site but should not, ordinarily, be less than 1.25 m.

8. PIERS OF ARCH BRIDGES

8.1 <u>Thickness at Top</u> - The thickness at the top shall be adequate to accommodate the skew backs on both sides and to resist the stresses imposed under the most unfavourable conditions of loading.

8.2 <u>Forces Acting on the Pier</u>

8.2.1 The forces acting on the pier are as follows:-

(a) reactions from the adjacent arches,

(b) weight of masonry and fill and the weight of the pier itself.

(c) water pressure and buoyancy with the same provision as for abutments in Clause 7.2.

8.2.2 The provisions regarding ~~impact~~ Dynamic effects and distribution of thrust shall be the same as laid down for abutments in Clause 7.2.

8.3 <u>Conditions of Stability</u>

8.3.1 The stability of piers shall always be investigated for the following two conditions of loading:-

(a) when only one of the adjacent spans carries live load - This condition will usually give the maximum stresses in the masonry of the pier.

(b) when both adjacent spans carry live load- This condition usually gives the maximum intensity of foundation pressures.

8.3.2 The provision of Clause 7.3 regarding the location of the line of pressure and the stresses, apply to the piers also.

8.4 <u>Foundations for Piers</u> - These shall be governed by the same provisions as laid down for abutments in Clause 7.4.

9. DESIGN OF RETURN AND WING WALLS

9.1 The return and wing walls should be designed in acc-ordance with the Indian Railway Standard "Code of Practice for the design of sub-structure of bridges".

10 ECONOMY IN ARCH BRIDGE DESIGN

10.1 In the case of arch bridges in high banks, the height of the springing, the length of the arch barrel and, in the case of multiple span bridges, the size of the span of the arches should be so fixed that the total cost of the bridge for the required water-way is a minimum.

10.2 In order to avoid excessive lateral tension in the arch ring or excessive load on the ends of the barrel, the height of the parapet wall above the crown of the arch should, generally, not exceed 1000mm when the depth of fill is considerable.

11. TYPE OF MASONRY

11.1 Arch rings shall be constructed either with voussoirs of precast cement concrete or sound durable building stone, or brick work in first class bricks and 1:4 cement mortar. Plain cement concrete cast in situ may also be used in which case reinforcement shall be provided as per Clause 2.5.

12 WORKING STRESSES

12.1 Masonry Arches

12.1.1 Where actual compression tests are made, the maximum permissible compressive stress in masonry shall not exceed one-eighth of its crushing strength. Tensile and shear stresses may be permitted upto one-fortieth of the crushing strength.

12.1.2 In the absence of tests, sound brick-work in lime mortar, which has hardened, shall be assumed to have a crushing strength of 4.3 N per sq mm(43.75 kg per sqcm) and brick-work in cement mortar 6.9 N per sq mm(70 kg. per sqcm).

12.2 Plain Cement Concrete Arches- The working stresses shall not exceed those laid down in the Indian Railway Standard "Concrete Bridge Code".

13. FOUNDATION PRESSURE

13.1 Owing to the wide variation in safe bearing pressures on foundations in different parts of India, it is not possible to specify permissible bearing pressures which will have universal application. Designs should be based on local conditions and permissible pressures may be established on the basis of tests or on previous experience. Normally, foundations, unless resting directly on rock, shall not be less than 1.25m in depth. It is, generally, safe to increase the permissible bearing pressure at the rate of 17647 N/m^2 (1800 kg per sq m) for each additional metre of depth below 1.25 m.

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14 SEISMIC EFFECT

14.1 Masonry or plain cement concrete arches shall not be constructed in zone V. Masonry or plain cement concrete arches shall not be constructed with spans exceeding 6 m in Zone IV and 10m in Zone III .

15. SKEW ARCHES

15.1 Skew arches shall be so constructed that the courses are everywhere at right angles to the lines of thrust.

16. WEEP HOLES

16.1 Weep holes should be provided through abutments, wing or return walls, and parapets, as may be necessary, adequate arrangements being made to lead water to the weep holes.

17. FILLING OVER ARCHES

17.1 It is recommended that the depth of the fill between the underside of the sleeper and the crown of the arch should not be less than 1 m.

17.2 Filling of a porous nature, such as brickbats or ballast, should be used to cover the whole extrados of the arch to a depth of at least 300 mm over the crown.

17.3 Earth filling should be done in layers, each being consolidated by ramming and by sprinkling with water. Black cotton soil should not be used.

17.4 In existing arches the filling should be disturbed as little as possible as, after a time, the arch action in the filling relieves the arch ring of a considerable portion of the superimposed load.

18. STRIKING OF CENTRES AND APPLICATION OF LOAD

18.1 The centres should not be struck before one week after the completion of the arch.

18.2 After completion of any portion of the masonry of an arch bridge, the following minimum periods of time should be allowed to elapse before loads as specified below may be imposed on that portion of the masonry:-

Description	50% of design load	75% of design load.	Full design load
Ordinary cement mortar and concrete.	7 days	14 days	28 days
Rapid-hardening cement mortar and concrete.	5 days	10 days	28 days

NOTE - 1. The expression "load" means the total calculated load with the appropriate ~~impact~~ Dynamic effects allowance specified for the speed at which the load is permitted to run.

2. The above periods shall be suitably increased where the mean air temperature is less than 16°C.