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## Effective Use of Arches in Construction

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**ABSTRACT:** Arches are one of the efficient forms of structural systems. They are widely used in buildings and bridges since ancient times. The behavior of arches depends on the geometric characteristics (i.e. rise, span, thickness and width), materials used for the construction, types of loading and support conditions provided. Arches are constructed normally in masonry. Conventionally masonry arches are constructed using Bricks or Stones in cement mortar. Plain cement arches can also be preferred in constructions. This paper presents the effective use of Arches in construction for various purposes which lead to the increase in strength of structures and reduction in the overall cost of construction. .

**KEYWORDS:** Arch, foundation, Abutments

### I. INTRODUCTION

Arches have been used extensively for the construction of bridges since ancient times. There are several thousand masonry arch road bridges throughout the world, ranging from small span to long multi-span structures. These bridges have given excellent service in terms of strength and durability. In case of buildings arches have also been used to withstand the structural loads above the openings in place of conventional lintels. Now a day's, brick masonry arched panels have been used as roofing elements for low cost buildings to avoid the usage of costly materials like steel and concrete. The use of arches in foundations is very rare even though same has been used extensively for bridges, lintels and roofs. Sarangapani (2002) of Mysore, Nagireddy (2003) of Hyderabad and Pradeep Kumar (2003) of Shimoga have successfully used stone masonry arches in foundations for walls as a replacement to the conventional spread footings. Ganesh Mogaveera and G Sarangapani (2015) have successfully carried out research work on Laterite block masonry arches and Plain cement concrete arches. There is around 40 to 50 percent reduction in cost of foundation if arches are used instead of spread footings. Conventionally spread footings are widely used for wall foundations. This type of constructing foundation in India goes back to great antiquity. The modern spread footing consists of stone masonry in 1:6 cement mortars of 5 to 6 courses. Minimum width of the footing at the bottom being 1m.

Arch can also be defined as a beam, which is curved in the lateral direction. Arches are pre-dominantly subjected to compressive stresses. A typical arch with its components are shown in Figure 1. Arches are more economical than the ordinary beams particularly for large spans because the bending moments and shears acting over the cross section of the arches are considerably smaller to that of beams of same span and carrying the same load. The choice of type of arch depends upon the span, the available rise and the architectural effect desired. The semicircular arch gives minimum reaction on the abutments and is used where light abutments are available. The parabolic arch is suitable for uniform loads and elliptical arch is more suited for loads which increase towards the springing as in case of filled spandrel arch. Information available on the behavior of arches is scanty.

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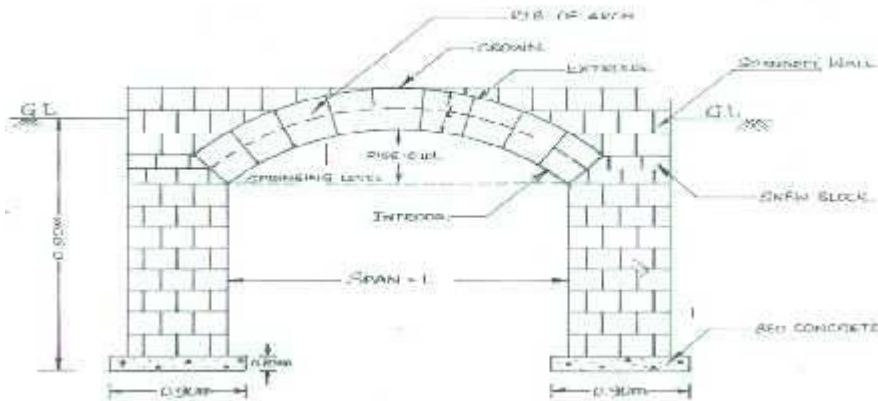


Figure 1. Components of Arch

## II. RELATED WORK

Review of literature regarding the behavior of arches and other related topic has been made thoroughly. The results and conclusions arrived in various research papers will be helpful in understanding the behavior of arches.

Pippard A.J.S and Baker J.F (1957), have carried out a detailed analysis of Engineering Structures and covered a detailed discussion the load carrying capacity of different types of arches.

Otto Mohr (1957) made two important contributions to the elastic theory of arches. The first appeared in a paper published in 1970. In which Mohr presented the idea of computing the influenced lines for the horizontal reactions component of a two hinged arch or the B.M. diagram for a conjugate beam loaded with the  $Y/EI$  diagram of the arch. The term  $Y$  is the vertical distance from the plane of the hinges to the arch axis at any section and  $EI$  is the flexural rigidity. Mohr obtained these diagrams by graphical methods. Chiefly as a result of the work by Mohr, supplemented by carefully controlled tests conducted by the society of Australian Engineers and Architects, the elastic theory was fully accepted for the analysis of arches. Consequently revised theory and methods of arch analysis were evolved.

It appears that no particular attention has been given to the question of the most advantageous shape of the arch axis until yvon villarceau (1883) presented a famous memoir on arches to the French academy of science in 1845. He understood that the complete solution is required. He reasoned that sufficient information was not available regarding the elastic properties of materials and hence considered the arch blocks to be absolutely rigid. His conclusion was that the best arch axis to use in a given case would be that which coincides with the funicular polygon.

## III. USES OF ARCHES

### ARCH CONSTRUCTION IN ANCIENT TIMES:

The arch is one of the oldest structural elements of traditional architecture. It is an incredible architectural discovery, dating back to ancient times but still in wide use. The arch has been found in many different cultures, as early as Mesopotamia. Arches appeared as early as 2nd millennium BC in Mesopotamian brick architecture and their systematic use started with the ancient Romans who were the first to apply the technique of using a

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arches to a wide range of structures. The Egyptians used it in tombs and vaults but never for monumental architecture. The Greeks also used the arch solely for practical constructions, but many of the principles they developed were later exploited by the Romans. Saratov Arch Bridge across the Volga River in Saratov, Russia was the longest bridge in the Soviet Union and has been inaugurated in 1965. Its length is 2,803.7 meters and connects Saratov on the right (west) bank of the Volga, with the city of Engels on the left (east) bank. The bridge consists of 5 spans. It is shown in Figure 2. The aqueduct of Segovia is one of the world's best-preserved examples of Roman architecture. It runs through the center of Segovia in northern Spain. The aqueduct is 2,950 feet long, contains about 170 arches and rises 90 feet. Builders constructed the aqueduct with 20,400 granite blocks without using the mortar. The details are shown in Plate 1.3.



**Figure 2: Saratov Arch Bridge, Russia(Snipview.com)**



**Figure 3: Segovia Ancient Roman Architecture**

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### ARCHES IN INDIA:

It is generally believed that arch construction was brought to India by the Muslims. Although some writers argue that arch construction was known but rarely used in the pre-Islamic period. Some literature mentions the possibility of arch bridges in Bangladesh before the Muslim conquest. The emergence for bridge and building was however, widespread from the thirteenth century onwards.

Figure 4 shows the use of arches in exterior walls of the Humayun's tomb in New Delhi. The Humayun tomb of Indian architecture is located at the centre of a huge garden complex. In Vijayavittala temple of Hampi-Vijayanagara (Figure 5), stone masonry arches have been extensively used. The India Gate is a large arch, built in 1931. It is a war memorial to the Indian soldiers who died during World War 1 and the 3rd Anglo-Afghan War. The names of some 70,000 Indian soldiers who died in World War in "France and Flanders, Mesopotamia, Persia, East Africa and elsewhere in the near and the far-east" between 1914-19 are inscribed on this memorial arch. Figure 6 shows the Red fort Mogul Arch. The fort took nearly nine years to complete. Within the walled city, the fortress is in the shape of a rectangle 900 meters by 550 meters. The rampart walls are about 34 meters high. The main entrance to the fort is through the Lahori Gate. A covered passage with shops on either side leads to the palaces inside the fort. The uses of arches in the buildings for various purposes are shown in Figure 7 to Figure 8.



Figure 4: Ornamental arches of Humayun's tomb in New Delhi(Masterfile.com)



Figure 5: Hampi-Vijayanagara(thinkingparticle.com)

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Figure 6: Red fort Mogul Arch(nomadicdecorator.com)



Figure 7: Use of arches in Lintels (dotyourself.com)

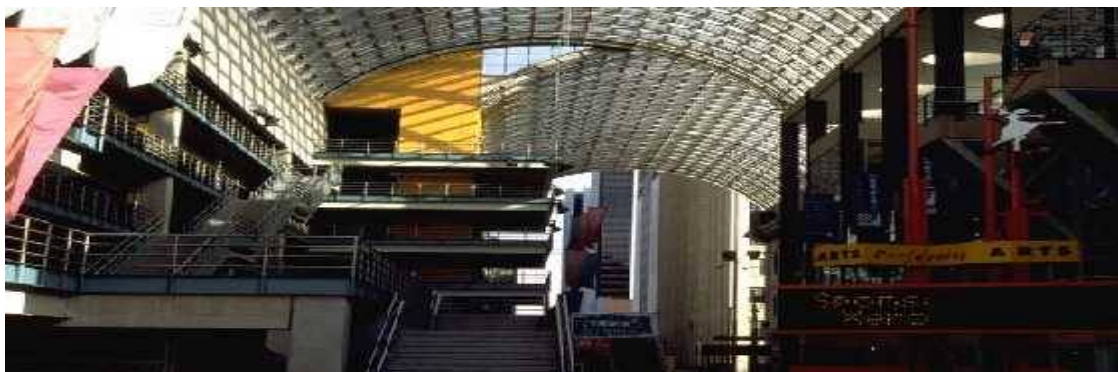


Figure 8: Use of arched panels in roofs(nomadicdecorator.com)

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## USES OF ARCHES IN FOUNDATIONS

Arches have been used as an economic alternative to the conventional spread footings of walls of residential buildings. The arch can be constructed using masonry, plain cement concrete and reinforced cement concrete. Any shape of the arch can be chosen. Parabolic arches are preferable to other shapes as it is stronger than the circular arches. The study carried out by Deodhar (1992) has shown that the load carrying capacity of parabolic arches is twice that of circular arches. Arches are analysed as two hinged arches subjected to uniformly distributed throughout the span. The uniformly distributed load that gets realised on the arch is due to the brick masonry wall and the slab supported by the wall. The thickness of the arch depends on the magnitude of load acting.

The step by step procedures of constructing arches in foundations are as given below (Refer Figures 9 to 11)

- (i) The spans and positions of the arches are fixed suitably based on the positions of walls in building. In general the span varies from 2m to 4.5m. Spans of around 3m are the best.
- (ii) Pits of suitable size are excavated for pillars at all junctions of arches. The size of pit depends on the load acting and soil characteristics. A minimum pit size of 1m x 1m x 1m should be provided.
- (iii) Natural ground in between the pits is trimmed to the arch shape so that crown of the arch is at the ground level. The rise of the arch should be as high as feasible to keep the horizontal thrust low. If the crown of the arch is required at higher level than ground level then suitable mud formwork has to be prepared for the arches.
- (iv) In the excavated pits, pillars (masonry or cement concrete or reinforced cement concrete) upto springing level are constructed over 1:4:8 cement concrete bed of thickness 100mm. These pillars supports the arches and transfer the loads from arch to the soil. In addition they resist the horizontal thrust of the arch by providing reaction for arch action to take place. If the horizontal thrust is very large, tie rods are provided at the springing level for the end arches.
- (v) Arch of designed thickness is constructed. If masonry is used then arch is constructed by placing the masonry units radially on the prepared surface starting from the springing level and proceedings towards the crown.
- (vi) Spandrel walls are constructed upto the crown level.

Table 1 shows the details of masonry arches in foundations that have been used in buildings of Mysore. Few researchers concluded that arches in foundations can be effectively used as an alternative to conventional foundation upto two storied buildings located on soils which do not have the tendency of settlements

**Table 1 Details of Mysore buildings with arches in foundations.**

Year	Building type	User	Location	No. of Stories	SBC (kN/m <sup>2</sup> )	Span (m)
1999	Residential	Pramoda Devi	A.Nagar	2	250	3.6
1999	Residential	Mr. Shashidar	K.Nagar	1	300	3.6
2000	Residential	Mr. M.N. Urus	R.K.Nagar	2	350	4.9
2000	Industrial shed	Mr. Ramaswamy	Hebbal	1	400	6.0
2000	Residential	Mr. Raghavendra	K.Nagar	2	300	4.0
2001	Residential	Mr. H.S. Prasanna	J.P.Nagar	2	300	4.9
2003	Residential	Dr. G.S. Suresh	C.Puram	2	300	3.6
2003	Residential	Mr. Gopal Krishna	R.K.Nagar	1	350	3.6
2003	Demonstration centre	Demonstration Centre, NIE, Mysore	NIE Campus	1	300	3.0

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**Figure 10: Construction of Arches in foundations**



**Figure 11: Construction of spandrel walls**

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## IV. CONCLUSIONS

1. Arches can be effectively used in structural components such as lintels, beams and roofing elements
2. Arches can be used in foundations as an economic alternative to the conventional footings
3. It can also be used in Bridges

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