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Experimental Behavior of Masonry Arches with and without Fiber Reinforced Polymer

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A B S T R A C T

This paper deals with the experimental behavior of solid clay brick masonry parabolic arches. Among all the different structural systems, masonry arches are the most efficient forms, which are mainly used in buildings and bridges. Strengthening of masonry structures with different engineering materials has become a challenge for civil engineers with the advancement in engineering technology. In the last two decades FRP were effectively used for increasing the load carrying capacity of masonry arches and for improving their response against the critical arch failure mechanism. In this paper preliminary tests were carried out on cement, sand, bricks, mortar and their material properties like specific gravity for cement, sand, compression strength on bricks, mortar and water absorption test on bricks, were studied. In this report fabrication of masonry arch of same dimensions were carried out. A total of four specimens were casted out of which two specimens were casted without GFRP. and two other were wrapped with GFRP on extrados and intrados surface of the arch. Specimens are having the span of 1.3m, rise of 0.5 and width of 0.230m. After the casting and curing of the all specimens was carried out, two arches which are without glass fiber reinforced polymer are subjected to monotonic loading and then other two arches were wrapped with glass fiber reinforced polymer and then subjected to monotonic loading. After testing the load carrying capacity of the arches was calculated. The arches were also analyzed by the ANSYS software.

Keywords: Unreinforced and Reinforced Arch, Parabolic Arch, Local Failure, Parabolic Equation, Loading Conditions, GFRP, ANSYS

1. Introduction

An arch is a mechanical arrangement of wedge shaped blocks of bricks or stones supporting each other and supported at the end by abutments. It is actually an aciform which is not really known for their load bearing capability but has an aesthetic, historic, cultural and architectural importance. On synonymous terms arches are often referred to as vaults but a vault is different from an arch as it is a continuous arch which resembles a roof. The history and appearance of arches dates back to 2nd millennium (B.C) Mesopotamia as brick architecture and their efficient and methodic adoption started in Ancient Rome where they applied the technique to a wider range of architectural masterpieces. Arches are known to have lesser tensile strengths and to eliminate the stress it spans over a large area and resolves the forces in such a way that the tensile stress is relieved. This is often called as arch-action. As the force is applied on the arch towards the ground, there is a resultant outward push at the base by the arch referred to as thrust. As the height of the arch decreases, the thrust increases outwards. To prevent the collapse of the arch we need to arrest the thrust action either by internal ties else external bracing, for example by using abutments. Such a structure (arch) is said to be in the form of pure compression and the building materials of an arch like stone and concrete (unreinforced) are able to resist the compression but not tensile stress. The weight of all the constituents is responsible to hold the arch in place, making it problematic to construct an arch. One of the solutions is to construct a frame prior to the construction of an arch resembling exactly the underside of the arch, commonly known as the centering. Until the structure is self-supporting and accomplished Voussoirs are used on it and scaffolding is done for the arches that are higher than the head-height in combination with the structure support. At times the arch would fall down if the frame was dislodged or if the construction be been faulty, as it happened to the A85 Bridge at Scotland in 1940's on its very first attempt. The interior curve of an arch is called as intrados. The old arches often need reinforcements because of the decay of keystones, forming bald arches. The main principle used in the construction of reinforced concrete arches is the strength and stability of the concrete, resisting stress of compression. If the tensile stress or any other kind

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of stress is increased, the resistance is to be increased by placing reinforcement-rods or reinforcement fibers. Mainly three types of arches are used in practice: three-hinged, two-hinged and hinge less arches.

2. Methodology

A. Materials

Cement, sand, bricks and iron rods(which are used to make the steel moulds). In this project the four specimens were casted with span 1.3m, rise 0.5m, and thickness 0.23m as per the dimensions of brick out of which two arches were without GFRP and two with GFRP. The materials used for wrapping of GFRP on arches were G.P resin, woven fibre, normal fibre accelerator, catalyst & pigment.

B. Preparation of steel mould

The mould used for the constructing the arches were made of steel. Same dimensions of steel moulds were used for the entire project . Steel Mould of dimensions of span=1.3m, rise =0.5m and width =0.23m were used. The coordinates of the along the x and y axis are:

X(m)	0	0.125	0.225	0.325	0.425	0.525	0.65	0.725	0.825	0.925	1.025	1.125	1.3
Y(m)	0	0.16	0.27	0.37	0.445	0.49	0.5	0.49	0.445	0.37	0.27	0.16	0

Fig 1: Preparation of steel mould

the mould is prepared as per the coordinates obtained from the design of parabolic curve. The parabolic curve is designed from the equation of parabola and after deriving the mathematical equation we got the coordinates and from those coordinates we got the rise along y axis with respective distances from x axis.

C. Design for parabolic curve

The mould used for the constructing the arches was made of steel. Same dimensions of steel moulds were used for the entire project . Steel Mould of dimensions of span=1.3m, rise =0.5m and width =0.23m were used.

$Y= ax^2+bx$

At a= 0.325

0.5= 0.105a+0.325b…………………1

At x = 0.975

0.5= 0950a + 0975b…………………2

From 1 and 2

a= 0.5263 – 1.026b

put the value of a in 1

b =2.2

a= -1.7

$Y = -1.7x^2 +2.2x$

$\frac{dy}{dx}$ = -2.14x +2.2

At x = 0.325

Tan θ = 1.5

$\theta = 56^0$

at x = 0.425

$\theta = 52.22^0$

at x = 0.162

$\theta = 61.73^0$

at x =0.525

$\theta = 47^0$

Value of x(m)	0.162	0.325	0.425	0.475
Value of(θ)	61.73	56	52.22	38.97

Slope at respective lengths

X(m)	0	0.13	0.23	0.33	0.43	0.53	0.65	0.73	0.83	0.93	1.03	1.13
Y(m)	0	0.16	0.27	0.37	0.45	0.49	0.5	0.49	0.45	0.37	0.27	0.16

Coordinates of the parabolic arch

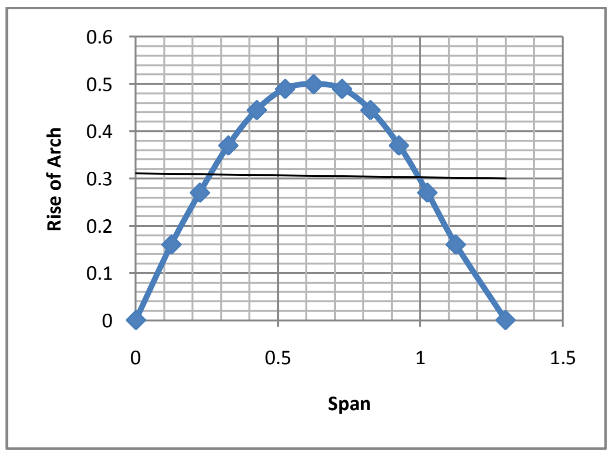


Fig 2: Parabolic curve (plotting the x and y coordinates)

D. Design of parabolic arch

In the case of two-hinged arch, we have four unknown reactions, but there are only three equations of equilibrium available. Hence, the degree of statical indeterminacy is one for two hinged arch. The relative displacement of either hinge with respect to other is zero, so the partial derivative of strain energy of the beam with respect to horizontal reaction is zero. We can easily find out the Va and Vb, by taking algebraic sum of all the moments about A or B equal to 0. To find out the horizontal reactions Ha and Hb many books advise to use the Castigliano's first theorem. The relative displacement of the either hinge with respect to other is zero, so the partial derivative of the strain energy of the beam with respect to the horizontal reaction will be zero.

So first we have to find the equation of the strain energy of the whole beam, and then partially differentiate it with respect to the horizontal reactions, and then equate it to zero. It becomes the fourth equation, and we can get the value of the horizontal reaction. Now as all the support reactions are found, we can easily plot the bending moment diagram, for the arch.

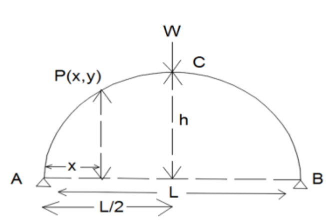
The horizontal thrust of a parabolic arch is given by the general formula;

$$H = \frac{\int \frac{MY}{EI} ds}{\int \frac{Y^2}{EI} ds}$$

value of the m $= V_a \,.x - \sum mx$

where m is the moment at a distance x from the support

E. When the load is at crown



As H = $\frac{\int Mydx}{\int y^2 dx}$

Taking first part of integral

$\int_0^l Mydx = 2\int_0^l Mydx$

M = $\frac{W}{2}x$

Y = $\frac{4hx(l-x)}{l^2}$

$$\int_0^l Mydx = 2\int_0^l \frac{w}{2}x \cdot \frac{4h}{l^2}x(l-x)dx$$

$= \frac{4wh}{l2}\left[\frac{lx3}{3} - \frac{x4}{4}\right]\frac{l}{2}$

$= \frac{4wh}{l2} l4\left[\frac{1}{24} - \frac{1}{64}\right]$

$$\int_0^l Mydx = \frac{5}{48}whl^2$$

2nd part of integral is

$$\int_0^l y2dx = 2\int_0^{\frac{l}{2}} \frac{16h2}{l4}x2(l-x)2\,dx$$

$= \frac{32h2}{l4}\int_0^{\frac{l}{2}} x2\,(l-x)2\,dx$

$= \frac{32h2}{l4}\,[x2\,(l-x)2\,dx\,]$

$= \frac{32h2}{l4}\left(\frac{l^2x^3}{3} + \frac{x^5}{5} - \frac{2l.x^4}{4}\right)^{l/2}$

$$\int_o^{\frac{l}{2}} y^2dx = \frac{8}{15}\left(\frac{h^2}{l}\right)$$

As per the general equation of the parabola , the horizontal thrust for the load acting at the crown is given by dividing the ist integral by the second integral

H = $\frac{\frac{5}{128}Whl^2}{\frac{8}{15}(h^2l)}$

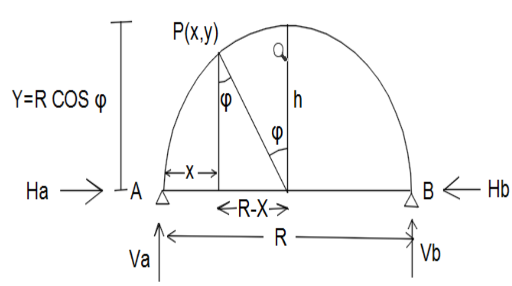
H = $\frac{5}{128}\frac{Wl}{h}$

Where h is the rise of arch and l is the total span of arch.

This is the required expression for the horizontal thrust when the load is acting on crown

Where h is the rise of arch and l is the total span of arch.

F. *When concentrated load acting on arch*



The concentrated load acting on a arch is given by

In above fig

Y=RcosΦ

R-x = RsinΦ

X= R- RsinΦ

X = R(1 – sinΦ)

dΦ= $\frac{ds}{dr}$

ds = RdΦ

now $\int Myds = \frac{WR^3}{3}$

$\int Y^2\,ds = 2\int_0^{\frac{\pi}{2}} R^2\,cos^2\emptyset$ R dΦ

$= 2R^3\int_0^{\frac{\pi}{2}} cos^2\,\Phi\,d\Phi$

$= 2R^3 \int_0^{\frac{\pi}{2}} \frac{(1+COS^2\Phi)}{2} d\Phi$

$= R^3\{\frac{\pi}{2} - 0\}$

$= \pi\frac{R^3}{2}$

Therefore horizontal thrust will be

H= $\frac{W}{\pi}$

At any angle value = θ

$$H = \frac{W}{\pi}Cos^2$$

In case if the load acting is distributing load ,then the normal and tangential shear will occur

$$N_{shear} = V_p cos\theta - H_p sin\theta$$

$$T_{shear} = V_P sin\theta + H_P cos\theta$$

G. *Calculation Of Ordinate Points Of P($x_1 y_1$),*

P(x_2y_2), P(x_3y_3),P(x_4y_4),and P(x_5y_5).

The values of ordinates can be calculated by the equation of parabola

$$y_1 = \frac{4 \times 0.5 \times 0(1.3 - 0)}{1.3^2}$$

y_1=0

$$y_2 = \frac{4\times0.5\times0.125(1.3-0.125)}{1.3^2}$$

$y_2 = 0.160$

$$y_3 = \frac{4 \times 0.5 \times 0.225(1.3 - 0.225)}{1.3^2}$$

y_3 =0.270

$$y_4 = \frac{4 \times 0.5 \times 0.325(1.3 - 0.325)}{1.3^2}$$

$y_4 = 0.370$

$$y_5 = \frac{4 \times 0.5 \times 0.425(1.3 - 0.425)}{1.3^2}$$

$$y_5 = \frac{4 \times 0.5 \times 0.525(1.3 - 0.525)}{1.3^2}$$

$y_5 = 0.445$

$$y_6 = \frac{4 \times 0.5 \times 0.650(1.3 - 0.650)}{1.3^2}$$

$y_6 = 0.5$

H. Casting Of Arches

The arches were casted with the same dimensions which were obtained as per design criteria in which the span of arch is 1.3m width of arch is 0.23m and rise of arch is 0.5m. The thickness of the arch is as per the thickness of the brick dimensions which is 0.110m.

Fig 3: Casting of brick arch

Fig 4: Casting of brick arch

I. Application of GFRP on arches

The application of the strengthening was carried out on the arches. In the strengthening phase, three arches were casted and one arch is wrapped with GFRP on intrados and extrados surfaces. Two types of polymers were used for strengthening. All rough spots were cleaned up and then the two adhesives were prepared one adhesive was prepared with Araldite AW 106 epoxy and HV 953 hardener and other with resin of 1 liter mixed with 20g of catalyst and accelerator and then it was mixed properly to make it a paste. After that, a thin layer was applied on the intrados and extrados surface. The specimen was left to dry for 48 hours.

Fig 5: Application of GFRP on extrados

Fig 6: Application of GFRP on intrados

3. Experimental Setup and Testing

The self-straining load frame and the Hydraulic loading jack along with Load cell are arranged in such a way to apply the concentrated force over the centre of the arches specimen Care is taken to avoid eccentricity during loading. Linear Variable Differential Transformer (L VDT) is mounted where the deflections are required in the specimen. Arches are placed on loading frame and subjected to central concentrated force and the corresponding deflections are measured within the elastic range using data logger.

Fig 7: Loading Frame & Hydraulic jack attached to arch

Fig 8: Initial cracks on arch

Fig 9: Major crack on arch

Fig 10: Testing of GFRP arches

Fig 11: crack pattern on GFRP arches

Failure is defined as the point when the specimen can no longer bear the load and the specimen collapses. The arches failed at crown point.

4. Results and Discussions

4.1 Experimental Analysis Of Arches Without Gfrp

The 1.3m span arches were fabricated with 20 brick courses and characterised by a rise of 0.5m, width of 0.23mm and thickness of 0.110mm. All the arches were built over a strong rigid steel frame. All the specimens were tested, which presented a similar structural behaviour, essentially characterised by the development of three hinge mechanism. The parameters of the arches were checked. The main things we can get from the testing are – load-deflection characteristics of a specimen and modes of failure. Load vs. deflection of the three specimens are given below;-

A. Load Vs Deflection Behaviour of 1.3 M Span Arch (1).

An ultimate load for 1.3m span arch was found to be 6kN experimentally with a maximum deflection of 0.42.

Table 1: Load Vs Deflection

LOAD (KN)	DEFLECTION (mm)
0	0
1	0.05
2	0.09
3	0.14
4	0.22
5	0.35
6	0.42

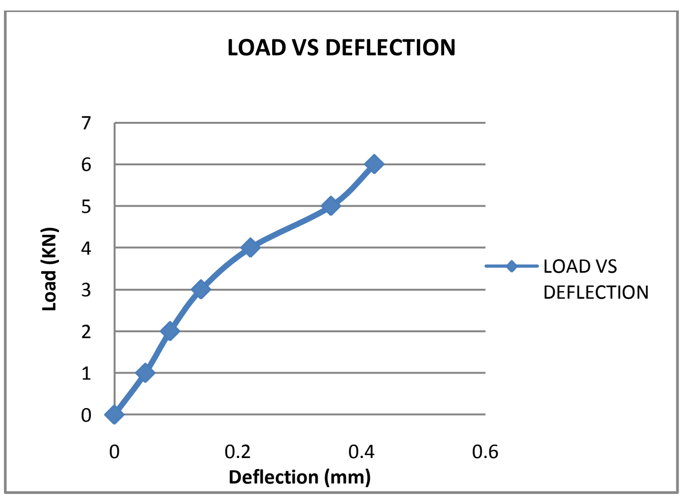


Fig 7: Graph showing load v/s deflection curve

B. LOAD VS DEFLECTION CURVE FOR 1.3M SPAN ARCH (2);-

An ultimate load for 1.3m span arch was found to be 6kN experimentally with a maximum deflection of 0.43.

Table 2: Load Vs Deflection

LOAD (KN)	DEFLECTION (mm)
0	0
1	0.06
2	0.10
3	0.15
4	0.23
5	0.36
6	0.43

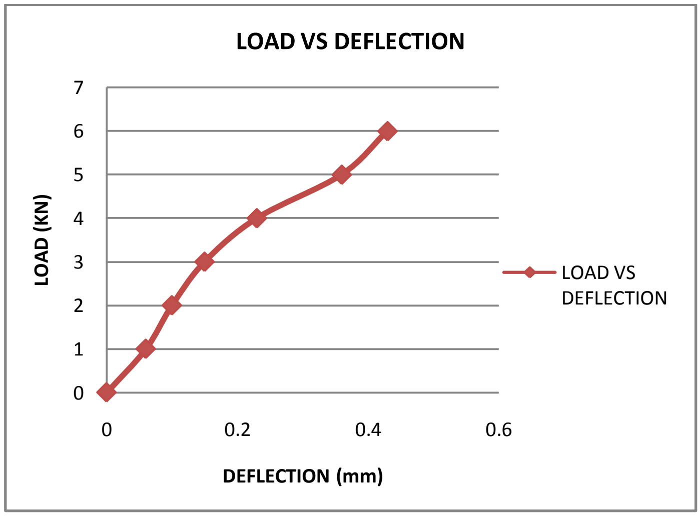


Fig 8: Graph Showing Load Vs Deflection

C. Combined Load Vs Deflection Curve For 1.3m Span Arches ;-

The Mean load carrying capacity of the arches without GFRP is 6 KN with a mean deflection of 0.425mm and the mean stiffness of the arches without GFRP was found to be 14.115 KN/mm also the failure of the arches was found to be three hinged experimentically.

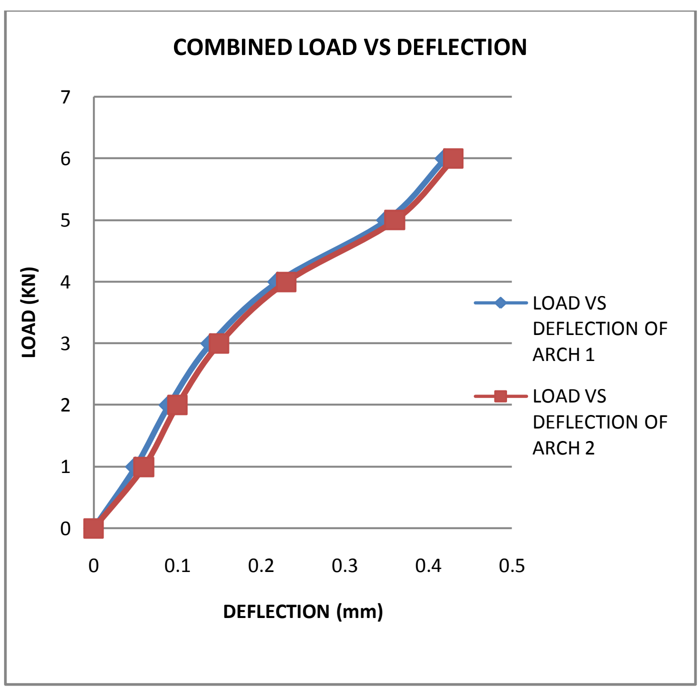


Fig 9: Combined graph showing Load Vs Deflection

4.2 ANALYTICAL ANALYSIS OF ARCHES WITHOUT GFRP BY ANSYS

With the help of ANSYS WORKBENCH 3D models were prepared of dimension 1.3m span, rise of 0.5m , width of 0.23m and thickness 0.110m. An extra layer of 1mm in thickness was added to intrados and extrados surfaces. Load applied to the arch was monotonic load at the crown and in the center. Properties like poisons ratio and young's modulus were applied.

Analytically it is found that the total deformation of the arch was found out to be 0.42mm.

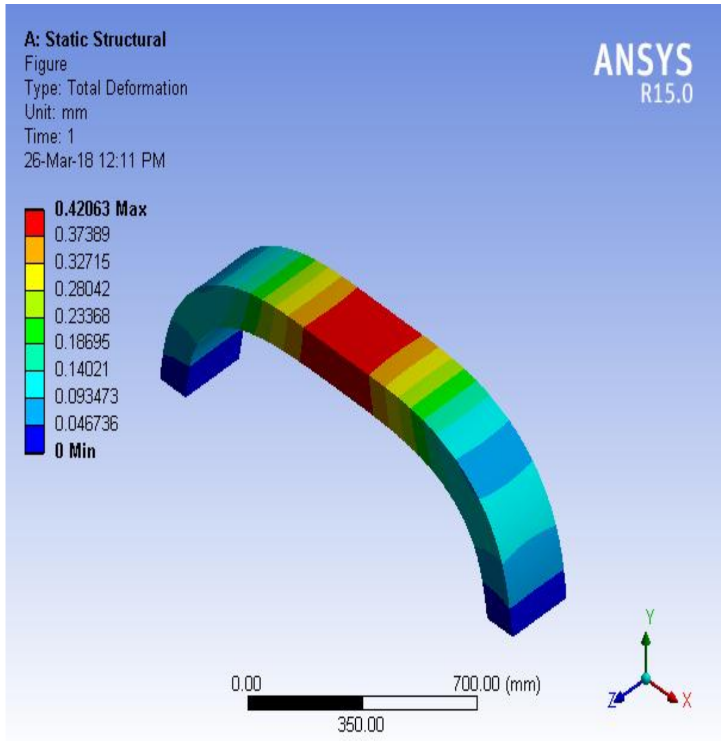


Fig 10: Analytical analysis of arch without GFRP

4.3 Experimental Analysis of Arches with GFRP

Masonry Arches were strengthened by GFRP wrapped on the intrados and extrados surfaces. All the specimens were tested under monotonic loading. The Parameters for the arches were checked. The major areas of interest are load – deflection characteristics of the specimen. Load v/s deflection of specimens are shown below

A. LOAD VS DEFLECTION CURVE OF ARCH OF SPAN 1.3M WITH GFRP

An ultimate load of 13 KN was achieved for 1.3m span of arch with a maximum deflection of 0.12mm.

Table 3: Load Vs Deflection

LOAD(KN)	DEFLECTION(mm)
0	0
1	0.01
2	0.02
3	0.03
4	0.03
5	0.04
6	0.04
7	0.05
8	0.06
9	0.07
10	0.08
11	0.10
12	0.11
13	0.12

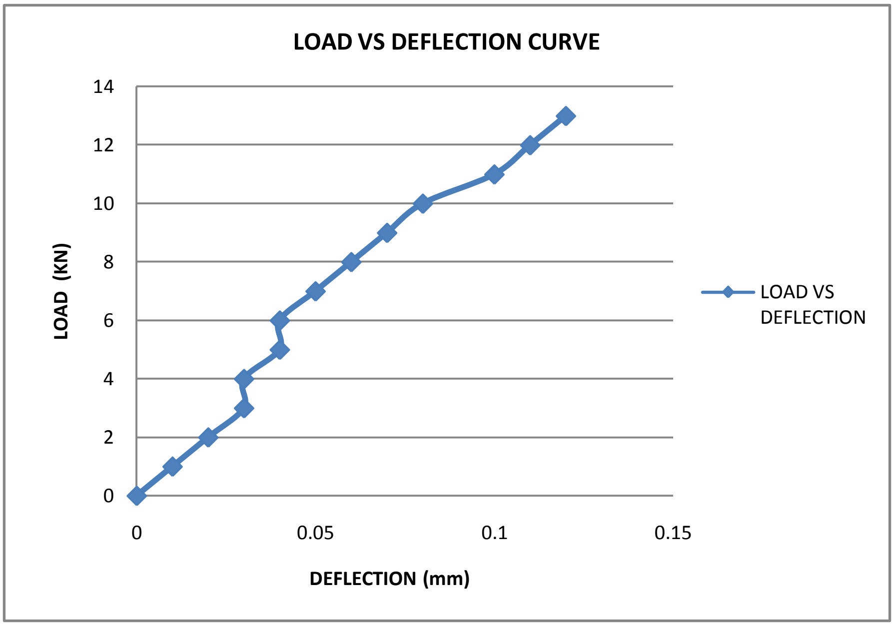


Fig 11 Load Vs Deflection Curve

B. LOAD VS DEFLECTION CURVE OF ARCH 1.3 M SPAN WITH GFRP;

An ultimate load of 12 KN was achieved for 1.3m span of arch with a maximum deflection of 0.10mm.

Table 4: LOAD VS DEFLECTION

LOAD (KN)	DEFLECTION(mm)
0	0
1	0.01
2	0.02
3	0.03
4	0.03
5	0.04
6	0.04
7	0.05
8	0.05
9	0.06
10	0.07
11	0.09
12	0.10

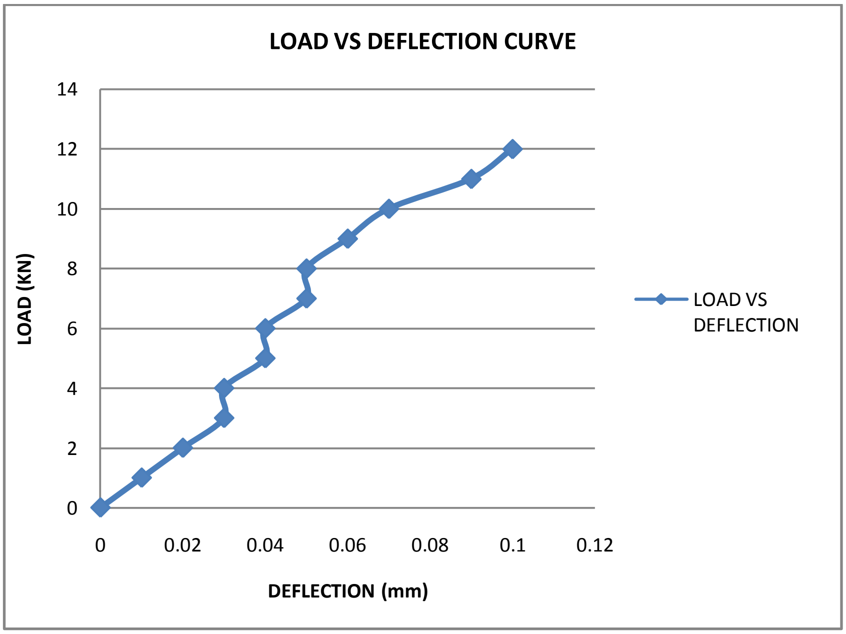


Fig 12 Load Vs Deflection Curve

C. Combined Graph of The Arches with GFRP

The Mean load carrying capacity of the arches without GFRP is 12.5 KN with a mean deflection of 0.11mm and the mean stiffness of the arches without GFRP was found to be 108.33 KN/mm.

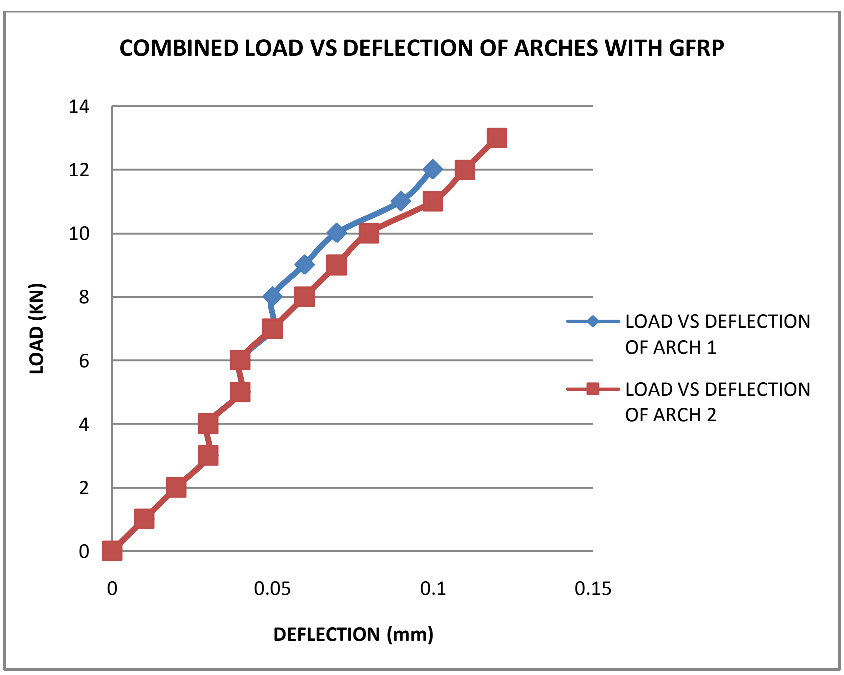


Fig 13 Load Vs Deflection Curve

4.4 Analytical Analysis of Arches with GFRP By Ansys

With the help of ANSYS WORKBENCH 3D models were prepared of dimension 1.3m span, rise of 0.5m, width of 0.23m and thickness 0.110m. An extra layer of 1mm in thickness was added to intrados and extrados surfaces. Load applied to the arch was monotonic load at the crown and in the center. Properties like poisons ratio and young's modulus were applied. Analytically it is found that the total deformation of the arch was found out to be 0.14mm.

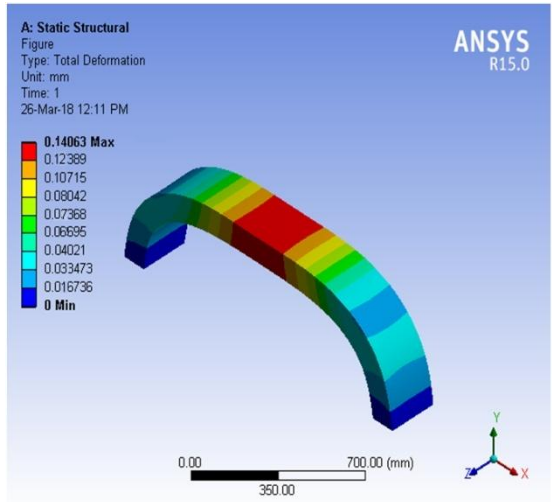


FIG 14 Analytical analysis of GFRP arch by ANSYS

5. Conclusion

Based on the experimental investigation, it can be concluded that

1. An ultimate load of 6kN was achieved for 1.3m span of arch 1 without GFRP (glass fiber reinforced polymer) with a maximum deflection of 0.42 mm.
2. An ultimate load of 6kN was achieved for 1.3m span of arch 2 without GFRP (glass fiber reinforced polymer) with a maximum deflection of 0.43 mm.
3. Mean load carrying capacity of the arches without GFRP is 6 KN with a mean deflection of 0.425mm.
4. An ultimate load of 13 KN was achieved for 1.3m span of arch 1 with GFRP (glass fiber reinforced polymer) with a maximum deflection of 0.12 mm.
5. An ultimate load of 12 KN was achieved for 1.3m span of arch 2 with GFRP (glass fiber reinforced polymer) with a maximum deflection of 0.10mm.
6. The mean load carrying capacity of the GFRP arches was found to be 12.5 KN with a maximum mean deflection of 0.11mm
7. It can be concluded that by application of GFRP on the arches the load carrying capacity is increased by 48 % for span of 1.3m arch.
8. Mode of failure of the arches was found to be three hinged.
9. Stiffness of the arch for experimental test was found out to be 14.11 KN/mm for 1.3m arch span which is without GFRP (glass fiber reinforced polymer).
10. Stiffness of the arch for experimental test was found out to be 108.33 KN/mm for 1.3m arch span which is with GFRP (glass fiber reinforced polymer).
11. It can be concluded that stiffness of the GFRP arches are 7.5 times more than the stiffness of the arches without GFRP.
12. It is concluded by experimentally that with increase in span, ultimate load carrying capacity of the arch decreases and vice versa.
13. The total deformation of the arch without GFRP (glass fiber reinforced polymer) as per ANSYS is 0.4206mm.
14. The total deformation of the arch with GFRP (glass fiber reinforced polymer) as per ANSYS is 0.1406mm.

REFERENCES

[1] Ferit Cakir , Habib Uysal , Volkan Acar Experimental modal analysis of masonry arches strengthened with graphene nanoplatelets reinforced prepreg composites Measurement 90 (2016) 233–241.

[2] Valerio Alecci a, Giulia Misseri ,et.al. Experimental investigation on masonry arches strengthened with PBO-FRCM cosmposite Composites Part B 100 (2016) 2281-239

[3] Giulio Castori, Antonio Borri, Marco Corradi b Behavior of thin masonry arches repaired using composite materials Composites Part B 87 (2016) 311-321

[4] Ahmed M. Anwar Performance of masonry arches strengthened with CFRP sandwich , Journal of Engineering Sciences Assiut University Faculty of Engineering Vol. 43 No. 6 November 2015 PP. 823 – 836

[5] Ferit Cakira,Habib Uysalb Experimental modal analysis of brick masonry arches strengthened prepreg composites, Journal of Cultural Heritage (2014)

[6] Leire Garmendia, Ignacio Marcos,et.al. Strengthening of masonry arches with Textile-Reinforced Mortar experimental behaviour and analytical approaches Materials and Structures (2014) 47:2067-2080

[7] S. Briccoli Bati, L. Rovero, and U. Tonietti Strengthening Masonry Arches with Composite Materials Journal of Compos. Constr., 2007, 11(1): 33-41

[8] Maria Rosa Valluzzi et.al. Behaviour of brick masonry vaults strengthened by FRP Laminates J. Compos. Constr., 2001, 5(3): 163-169

[9] M. A. Bradford, B. Uy, and Y.-L. Pi In-Plane Elastic Stability of Arches under a Central Concentrated Load J. Eng. Mech., 2002, 128(7): 710-719

[10] Bolger KoIsch Carbon fibre cement matrix overlay system for masonry strengthening J. Compos. Constr. 1998.2:105-109