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Experimental Approach to Determine the Stress at a Section of Semi Circular Curved Beam Subjected to Out-Of-Plane Load Using Strain Rosette

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Abstract - ***Curved beams are used as machine or structural members in many applications. Based on application of load they can be classified into two categories. Curved beams subjected to In-Plane loads are more familiar and are used for crane hooks, C-clamps etc. The other categories of curved beams are the ones that are subjected to out-of-plane loads. They find applications in automobile universal joints, raider arms and many civil structures etc. The results of this research on semicircular curved beam subjected to out-of-plane loads have revealed some interesting results. For semicircular curved beams subjected to out-of-plane loads, it is shown that every section is subjected to a combination of transverse shear force, bending moment and twisting moment. By using strain rosette it is shown that Maximum principal stress occurs at section 120 degrees from the section containing the loading line. Moreover it is observed that fixed end of this curved beam is subjected to a state of pure shear.***

Key Words: *Semi circular curved beam, Stress in curved beam, Out-of-plane load, Strain Rosette, strain Gauges.*

1.INTRODUCTION

Curved beams are the parts of machine members found in C clamps, crane hooks, frames of presses, punching machines, planers automobile components etc. In straight beams the neutral axis of the section coincides with its centroidal axis and the stress distribution in the beam is linear. But in the case of curved beams the neutral axis of is shifted towards the centre of curvature of the beam causing a non linear distribution of stress. Rakshith et al.[1]derived an expression for semi circular curved beam subjected to out of plane load. Rakshith et al [2] investigated the semi circular beam subjected to out of plane load by help of Ansys tool, Fonseca et al. [3] studied curved pipes subjected to in-plane loads, Stefano Lenci et al.[4] a 3-d mechanical model of curved beam is analyzed by them, Saffari et al.[5] sudies by using circular arc element based on trignometric functions foe in-plane loads, Clive et al.[6] investigated end loaded shallow curved beams of in-plane load type, Öz et al.[7] analyzed in plane vibrations of curved beam having open crack, Aimin Yu et al.[8] made a work on naturally twisted curved beams of thin walled sections that of inplane loads.

Stress analysis of curved beams subjected to out-of-plane loads also is important as such beams are used in many machine and structural applications. This paper is an experimental approachto determine stresses induced in such a curved beam by using strain rosette.

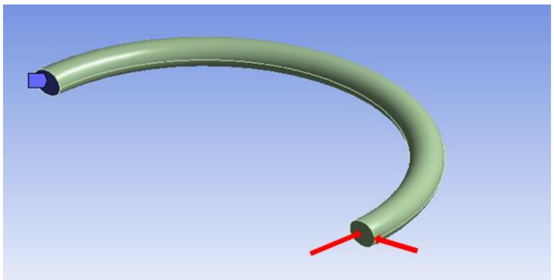


Figure 1.1-Curved beam with In-Plane load

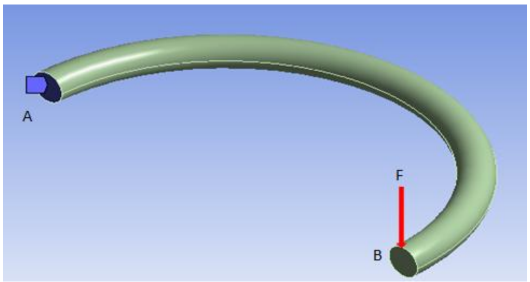


Figure 1.2-Curved beam with Out-Of-Plane load

2. ASSUMPTIONS

Some of the assumptions made to derive expression of principle stress for curved beam subjected to Out-Of-Plane load case are as follows,

- The radius of curvature is assumed much larger than the section radius.
- The material is assumed to be linearly elastic.
- The beam is assumed to be geometrically planar, i.e., the un-deformed axis of the beam is assumed to be a circle lying in the plane of the beam.

The cross section is assumed to be constant and with the same orientation with respect to the plane of the beam, so that there is no initial torsion.

3. EXPRESSION FOR OUT-OF-PLANE LOAD CONDITION

A semi circular curved beam of circular cross section lying in the plane of paper as shown in figure 3(a). The beam is fixed at one end 'A' and an out-of-plane load 'F' is applied at the other end 'B' [1].

F = Applied load in N
R_o = Outer radius of beam in mm.
R_m = Mean radius of beam in mm.
R_i =Inner radius of beam in mm.
α = angle made by the section X-X w.r.t loading line.
d = diameter at any section X-X .

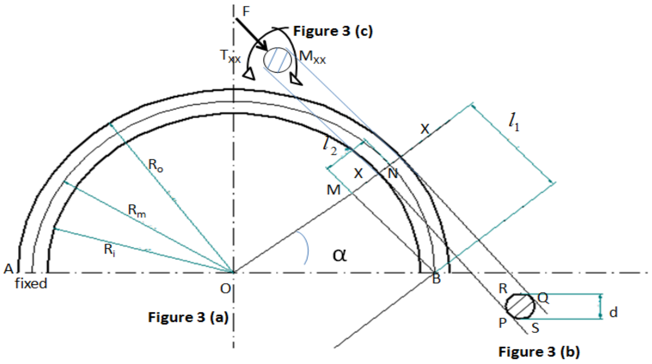


Figure 3(a)-Detailed view of semi circular beam.
Figure 3(b)- Cross section of beam at X-X with Extreme points indicated.
Figure 3(c)-Loads and moments acting on cross section X-X.

Let X-X be a plane passing through the centre of curvature and perpendicular to cross section of the beam. Let the angle made by this plane X-X wit respect to the free end be α as shown in fig 3(b). The effect of Out-Of-Plane load F at the section is to cause i). Transverse shear due to direct force F. ii) A bending moment M_{XX} and iii) A twisting moment T_{XX} as shown in fig 3(c). The magnitudes of the stresses due to these loads can be given by,

$$\sigma_{1,2} = K\left[\sin\alpha \pm 2\sin\frac{\alpha}{2}\right]$$

Where, $K = \left[\frac{16FR_m}{\pi d^3}\right]$

4. STRAIN GAUGES

Strain is the amount of deformation of a body due to an applied force. More specifically, strain (ε) is defined as the fractional change in length. Strain can be positive (tensile) or negative (compressive). Although dimensionless, strain is sometimes expressed inunits such as in./in. or mm/mm. In practice, the magnitude of measured strain is very small. Therefore, strain is often expressed as micro strain (με), which is $\varepsilon \times 10^{-6}$.

A Strain gauge is a sensor whose resistance varies with applied force; It converts force, pressure, tension, weight, etc., into a change in electrical resistance which can then be measured. When external forces are applied to a stationary object, stress and strain are the result. Stress is defined as the object's internal resisting forces, and strain is defined as the displacement and deformation that occur. The strain gage is one of the most important tools of the electrical measurement technique applied to the measurement of mechanical quantities.

4.1 Strain measuring Circuit- Quarter Bridge

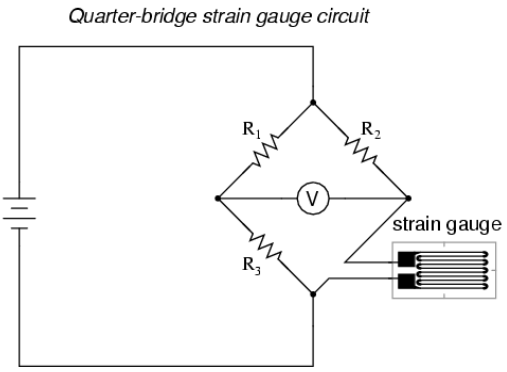


Figure 4- Wheatstone bridge.-Quarter Bridge

Typically, the rheostat arm of the bridge (R_2 in the diagram) is set at a value equal to the strain gauge resistance with no force applied. The two ratio arms of the bridge (R_1 and R_3) are set equal to each other. Thus, with no force applied to the strain gauge, the bridge will be symmetrically balanced and the voltmeter will indicate zero volts, representing zero force on the strain gauge. As the strain gauge is either compressed or tensed, its resistance will decrease or increase, respectively, thus unbalancing the bridge and producing an indication at the voltmeter. This arrangement, with a single element of the bridge changing resistance in response to the measured variable (mechanical force), is known as a quarter-bridge circuit.

5. EXPERIMENTAL APPROACH

5.1 Experimental setup

For the Out-Of-Plane loading of curved beam initially Aluminum rod of Young's modulus 70GPa and poisons' ratio of 0.32 is used. A straight rod of 20 mm diameter cross section is bent to mean radius of 125mm. 2-d and 3-d model of prepared specimen is shown as in figure 5.2.

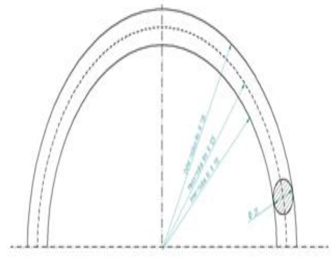


Figure 5.1-Specimen geometry
Figure5.2- Specimen prepared

Setup

Figure 5.3 shows strain gauges mounted on specimen at intervals of α is equal to 90, 120 and 180 degrees.

Figure 5.3 - Strain gauges mounted on specimen.

Digital Strain Indicator

Figure 5.4 is a 10 channel digital strain indicator is used to indicate the value of strains obtained by strains gauges.
Specifications of strain indicator as given below,

- Number of channels : 10
- Input sensor : strain gauge bridge(1,2,4 arm selectable)
- Gauge resolution : 350 ohms
- Excitation voltage : 10volts DC
- Range : 1000 micro strains

Figure 5.4- 10 channel strain indicator

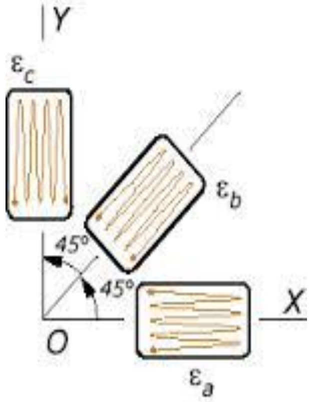
6 METHODOLOGY

Strain gauges mounted specimen is inserted in the fixture prepared. The whole thing is fixed firmly to a fixed base; here UTM s work table is used as base for fixing of fixture firmly. Connect each strain gauge to strain indicator with wires to separate channels. Here the gauges are connected to form an quarter bridge type of wheat stone bridge. In Quarter Bridge only one gauge is variable out of gauges i.e. is the gauge what we use as strain measurement.

Initially balance all 10 channel bridges to 0(zero) reading by adjusting knob provided in strain indicator. Now a pan attachment is made to hang on curved beam specimen dead end, so as to get the Out-of-Plane load condition as shown in figure 5.8 A set of weights are arranged i.e. 5,10 kg weights of enough quantity. Now add an initial weight of 5 kg to pan leave it for 5 to 10 seconds and then start to take strain readings from channel 1 to 9 separately, by indicating ε_a ε_b and ε_c, in each set . Now add 10 kg to pan and note all the readings as earlier ones procedure.

Take a sufficient numbers of readings for calculation. Consider the weight of pan also. using the values obtained from experimentation and material properties of specimen material calculate the ε_x and ε_y by formulations mentioned below. And calculate principal strains ε_1 and ε_2 by using ε_x and ε_y. And proceed to calculate principal stress by the formulations mentioned below, since we mounted strain gauges in form of 3 element rosette we uses expressions related to 3 element rectangular rosette.

Three element rectangular rosette is given by,



- $$\varepsilon_x = \varepsilon_a$$
  $$\varepsilon_y = \varepsilon_c \qquad (a)$$
  $$\gamma_{xy} = 2\varepsilon_b - (\varepsilon_a + \varepsilon_c)$$
- Principal strains are given by,

$$\varepsilon_{1,2} = \frac{1}{2}(\varepsilon_x + \varepsilon_y) \pm \frac{1}{2}\sqrt{(\varepsilon_x - \varepsilon_y)^2 + \gamma_{xy}{}^2} \qquad (b)$$

- Principal stress are given by,

$$\sigma_1 = \frac{E}{1-\nu^2}(\varepsilon_1 + \nu\varepsilon_2)$$
$$\sigma_2 = \frac{E}{1-\nu^2}(\varepsilon_2 + \nu\varepsilon_1) \qquad (c)$$

7 EXPERIMENTATION

By following the methodology the values obtained are noted. The following are figures during experimentation,

Figure 7.1-Show the experimental setup before loading.

Figure 7.2- Experimental setup with weights during loading (for open angle 0 to 180deg).

Figure 7.3- Experimental setup with weights during loading (for open angle 0 to 90deg).

Table 1: Comparisons of values of principal stress (σ_1) obtained by Theoretical and Experimental approach.

F (N)	α(deg)	σ_1(Theoretical) Mpa	σ_1(Experimental) Mpa	Percentage Error %
60	90	11.53287	11.57746	0.345
60	120	12.41119	11.57578	6.6
60	180	9.55414	7.552567	10.4
110	90	21.14359	21.38621	1.1
110	120	22.75385	21.49972	6
110	180	17.51592	14.02303	19.6
160	90	30.75431	31.24812	1.6
160	120	33.09651	31.24606	5.3
160	180	25.47771	19.96338	21.4
210	90	40.36504	41.93886	3.6
210	120	43.43917	42.02467	3.1
210	180	33.43949	26.72249	20
260	90	49.97576	49.50427	0.94
260	120	53.78183	51.59474	4
260	180	41.40127	32.79004	20.7
310	90	59.58648	62.39494	4.3
310	120	64.12449	62.30384	3.2
310	180	49.36306	39.16871	20.6
360	90	69.1972	71.80174	3.6
360	120	74.46715	71.6952	3.6
360	180	57.32484	45.03629	21.4
410	90	78.80793	82.69999	4.7
410	120	84.80981	82.13606	3.1
410	180	65.28662	51.42746	21.2

For semi circle curved beam ($0^0 < \alpha < 180^0$) case with end Out-Of-Plane load the principal stress in geometry is due to combined effect of Bending stress because of Bending arm as well as Torsional stress because of Twisting arm. Maximum principle stress increases from free end to fixed end up to a certain extent and goes high at that extent then goes on decreasing towards fixed end. Here we can observe the max value of maximum principle stress is at $\alpha = 120^0$ The values obtained from Theoretical and Experimental approaches are matching shown in table 1. Hence it validates.

RESULTS AND DISCUSSIONS

Results of above analysis are tabulated in Table 1 and plotted in figure 7 (a). At any cross section making an angle 'α' the applied force 'F' induces transverse shear stress, torsional shear stress and bending stress. Magnitudes of these stresses will be varying over the cross section.

For semi circle curved beam ($0^0 < \alpha < 180^0$) case with end Out-Of-Plane load the principal stress in geometry is due to combined effect of Bending stress because of Bending arm as well as Torsional stress because of Twisting arm. Maximum principle stress increases from free end to fixed end up to a certain extent and goes high at that extent then goes on decreasing towards fixed end. Here we can observe the max value of maximum principle stress is at $\alpha = 120^0$. Table 1 tabulates the values of maximum principal stress (σ_1) and minimum principal stress (σ_2) at points R for different values of α varying from 10^0 to 180^0. Torsional shear stress also increases gradually as α increase and is maximum at the fixed end. The values of principal stresses at the extreme points R on the cross section for different angles α shown that, the maximum principal stress σ_1 is tensile in nature and minimum principal stress σ_2 is compressive. Magnitude of maximum principal stress increases gradually from the loading and acquires maximum value at $\alpha = 120^0$ and then decreases and becomes equal to maximum torsional shear stress at the fixed end. The minimum principal stress acquires its minimum value at the fixed end. At the fixed end the magnitude of maximum principal stress is numerically equal to the minimum principal stress but is of opposite sign. This clearly indicates that at the fixed end of semi circular beam subjected to out-of-plane load a state of pure shear prevails.

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