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Comparative Studies on Curved Beam Under Different Loading Conditions using Strain Gauges and ANSYS

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***Abstract*— Curved beams are plays a important role in different field like house roofing, bridges, cranes, automobiles chasses etc. whereas the higher bending stresses will be developed under different loading conditions. In present work, curved beam subjected to different loads 1, 3 and 5kgs. The bending stress are investigating by using three methods, first analytical method is used to analyze stresses are developed due to application of given loads with the help of design data hand book. Second method is used FEA package ANSYS and third is an experimental analysis using strain gauge technique for bending stress analysis of curved beam under different boundary conditions. Finally the results are correlated with analytical values.**

Keywords—Curved beam; boundary condition; steel material bending stress analysis; FEM; strain gauge.

I. INTRODUCTION

Curved beam are important component for structural applications in which maximum failure will occurs due inner stress will be reaches to maximum, there analysis is play an important role for safety applications, this analysis is used for the effects of loads on physical components when components are subjected to different loads, such as roofing, chasses, machine main body etc.

The comparative study will be carried out on curved beam is subjected to different loads will be predicts an bending stresses. Base of work is collecting from literature background (from the text books) for curved beam like material properties, geometrical parameter, boundary conditions which help with experimental results on bending stress analysis. Three methods are using for bending stress analysis such as first finding stresses by analytically with the help of design data hand book [4], secondly numerical stress analysis using FEA package ANSYS software will be carried out on curved beam [8] [9] [10], finally Experimental Investigation using strain gauge technique for curved beam behavior using curved beam apparatus under bending [3]. finally the analytical results are correlating with other resultant values.

II. PROBLEM DEFINITION AND SCOPE OF PRESENT EXPERIMENT

A. Definition

1. In present scope of work, curved beam is subjected to different loads will be predict bending stresses?
2. Three methods used for bending stress analysis,

a) Analytical method is used to analyze stresses are developed due to application of different loads with the help of design data hand book.
b) Numerical analysis using FEA package ANSYS.
c) Experimental analysis using strain gauge technique.

B. Methodology

1. literature review on curved beam from text books
2. Collecting dimensions and boundary conditions from design data hand book as per the ASME standards.
3. Primarily, finding stresses by analytically with the help of design data hand book.
4. Secondly, Modeling and applying loads using ANSYS, then analyzing the two dimensional carved beam under bending load acting at a point to know the inner bending stress distribution and deformed shape of the model using ANSYS.
5. Experimental analysis using strain gauge technique for two dimensional curved beam behavior.
   a. Fabricating steel model.
   b. Analyzing bending stress by using curved beam apparatus under bending.
6. Finally analytical results are compared with ANSYS and Experimental valves, then correlating the percentage error of both methods with analytical results.

C. Assumptions

- component under bending stresses.
- Properties of material is elastic, homogenous and isotropic in nature.
- Temperature is constant before and after loading of material.
- Modulus of elasticity same for tension & compression.

C. Geometrical Parameters of The Problem

i. Specifications (refer [4])

Model: Carved beam
Material: Steel

r_i : Inner radius of curved beam : 27.5 mm
r_o : Outer radius of curved beam : 37.5 mm
r_c : Radius of centroidal axis : 32.5 mm
r_n : Radius of neutral axis : 32.24 mm
b : Width : 10 mm
t : Thickness: 8 mm
μ : Poisson's ratio (Steel): 0.3
E : Young's modulus(Steel) : 2×10^5 N/mm^2
A : Area of cross section : b x h : 10 x 8 : 80 mm^2
C_i : Distance from neutral axis to inner radius of curved beam : $r_n - r_i$: 32.24-27.5 : 4.74 mm
C_o : Distance from neutral axis to outer radius of curved beam : $r_0 - r_n$: 37.5-32.24 : 5.26 mm
e : Eccentricity : $r_c - r_n$: 32.5-32.24 : 0.26mm
F : Applied load or Force. (1Kg, 3 Kg & 5 Kg)

ii. Formulae used in calculations [4]

Formulas from design data hand book.

Bending stress at the outer fiber, $\sigma_{bo} = -\frac{M_b C_o}{A\, e\, r_o}$ – (1)

Bending stress at the inner fiber, $\sigma_{bi} = \frac{M_b C_i}{A\, e\, r_i}$ – (2)

Bending Moment, $M_b = F\,(l + r_c)$ – (3)

Direct Stress, $\sigma_d = \frac{F}{A}$ – (4)

Combined stress at the inner fiber, σ_{ri}

$$\sigma_{ri} = \sigma_d + \sigma_{bi} \quad -(5)$$

Combined stress at the outer fiber, σ_{ro}

$$\sigma_{ro} = \sigma_d - \sigma_{bo} \quad -(6)$$

iii. Two Dimension FEM Geometrical Models And Boundary Condition.

Geometrical model and Boundary Conditions.

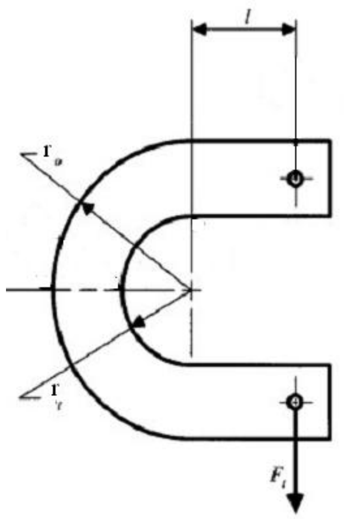

Fig. 1. 2D Model of curved beam under bending load (F)

Two dimensional model of the curved beam shown in fig. 1. the Boundary condition applied at centrally (displacement on upper end and force on lower end) on the axis of curved beam. Various loads are applied on lower node such as 1kg, 3kg and 5kg.

iv Two Dimension strain gauge Model and Boundary Conditions

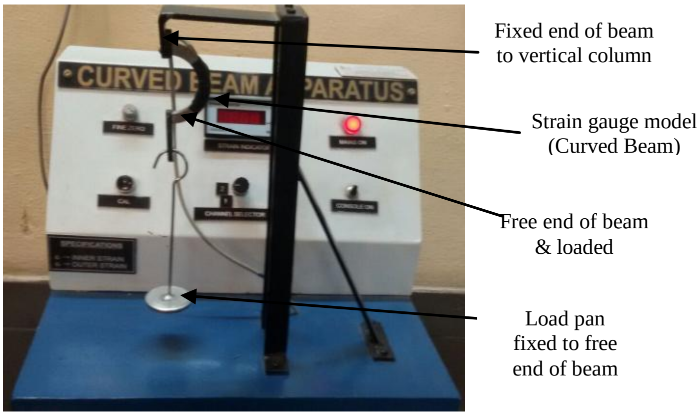

Fig. 2. Curved Beam Apparatus

Strain gauge model of the curved beam is fabricated with a specified dimension and then boundary conditions will be applied by using strain gauge apparatus as shown in fig. 2. Various loads are applied through load pan on beam such as 1kg, 3kg and 5kg.

III. Result and Discussion

A. Results

i. Analytical investigation.

Case (i): For F=1Kg, F= 1 x 9.81=9.81N.

Bending Moment, M_b = 9.81(0+32.5) =318.825 N-mm [From Eq. (3)]

Direct Stress, σ_d = F/A =9.81/80 =0.122 N/mm^2 [From Eq. (4)]

Bending Stress at inner fibre,
σ_{bi} = ((318.825X4.74)/ (80X0.26X27.5) =2.642 N/mm^2 [From Eq. (2)]

Bending Stress at inner fibre,
σ_{bo} = -((318.825X5.26)/(80X0.26X37.5))7 =-2.132 N/mm^2 [From Eq. (1)]

Combined stress at the inner fiber,
σ_{ri}= 0.122+2.642 = 2.764 N/mm^2 [From Eq. (5)]

Combined stress at the outer fiber,
σ_{ro}= 0.122-2.132 =-2.01 N/mm^2 [From Eq. (6)]

Case (ii): For F=3Kg , F = 3 x 9.81 = 29.43 N

Bending Moment, M_b= 29.43(0+32.5) = 956.475 N-mm [From Eq. (3)]

Direct Stress, σ_d =29.43/80 =0.367 N/mm^2 [From Eq. (4)]

Bending Stress at inner fibre,
σ_{bi} = ((956.475X4.74)/ (80X0.26X27.5)) =7.926 N/mm^2 [From Eq. (2)]

Bending Stress at inner fibre,

σ_{bo} = -((956.475X5.26)/ (80X0.26X37.5)) = -6.45 N/mm^2 [From Eq. (1)]

Combined stress at the inner fiber,

σ_{ri} =0.367+7.926 = 8.293 N/mm^2 [From Eq. (5)]

Combined stress at the outer fiber,

σ_{ro} =0.367-6.45 = - 6.083 N/mm^2 [From Eq. (6)]

Case (iii): For F=5 Kg, F = 5 x 9.81 = 49.05 N

Bending Moment, M_b = 49.05(0+32.5) =1594.125 N-mm [From Eq. (3)]

Direct Stress, σ_d =49.05/80 =0.6131 N/mm^2 [From Eq. (4)]

Bending Stress at inner fibre,

σ_{bi} = ((1594.125X4.74)/ (80X0.26X27.5)) =13.21 N/mm^2 [From Eq. (2)]

Bending Stress at inner fibre,

σ_{bo} = -((1594.125X5.26)/ (80X0.26X37.5) =-10.75 N/mm^2 [From Eq. (1)]

Combined stress at the inner fiber,

σ_{ri} = 0.6131+13.21 = 13.823 N/mm^2 [From Eq. (5)]

Combined stress at the outer fiber,

σ_{ro} =0.6131-10.75 =-10.1369 N/mm^2 [From Eq. (6)]

ii. FEM investigation

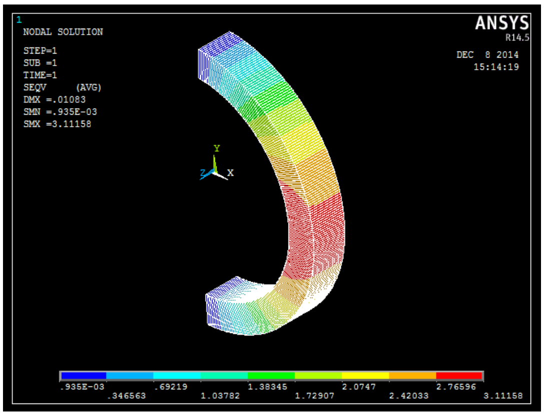

Fig .3. Maximum Combined stress at inner fibre for 9.81N Load

In Fig. 3. shows maximum stress distribution by the bending load acting on the free end of the beam (σ_{Avg} = 3.11158N/mm^2).

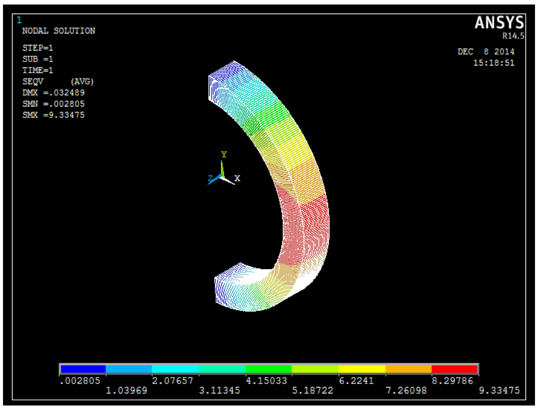

Fig .4. Maximum Combined stress at inner fibre for 29.43N Load

In Fig. 4. shows maximum stress distribution by the bending load acting on the free end of the beam (σ_{Avg} = 9.33475N/mm^2).

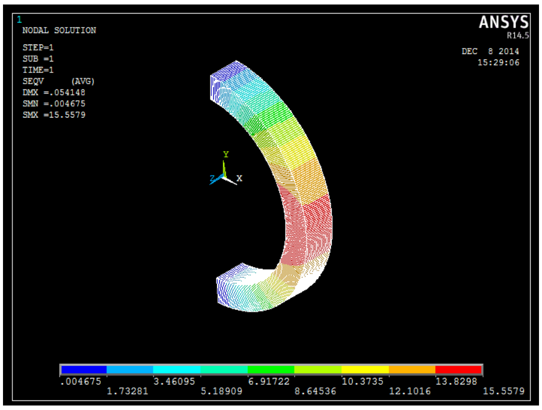

Fig .5. Maximum Combined stress at inner fibre for 49.05N Load

In Fig. 5. shows maximum stress distribution by the bending load acting on the free end of the beam (σ_{Avg} = 15.5579N/mm^2).

ii. Strain gauge investigation

a. Observations and procedure

- Switch on the System.
- Set the channel selector to A position it will indicate ε_i i.e., Inner strain value.
- Turn the knob to set to zero position in no load condition.
- Press cal button until the displays shows cal.
- Now gradually increase the load from 1 Kg to 5 Kg & note down the experimental strain readings which are displaying in the strain indicator.
- Repeat the above procedure ε_o value for outer strain.
- Calculate the Inner & Outer Stress by using the formula $\sigma=\varepsilon E$.

TABLE I. STRAIN GAGE INSTRUMENT READINGS

Sl. No.	Load on pan	Strain for Zero Load(A)		Strain for definite Load(B)		Net load(A-B)		Stress(N/mm²) σ = εE	
		ε_i	ε_o	ε_i	ε_o	ε_i	ε_o	σ_i	σ_o
1	1 Kg (9.81N)	0	284	12	273	12	11	2.4	-2.2
2	3 Kg (29.43N)	0	284	37	258	37	26	7.4	-5.2
3	5 Kg (49.05N)	0	284	59	240	59	44	11.8	-8.8

B. Discussions

TABLE II. CORRELATING RESULTS

Sl. No.	Load on Curved Beam(F) in N	Analytically Calculated Stress (N/mm²)	Experimentally Measured Stress using Strain gage (N/mm²)	ANSYS Results (N/mm²)
1	9.81 N	2.764	2.4	3.11158
2	29.43 N	8.293	7.4	9.33475
3	49.05 N	13.823	11.8	15.5579

TABLE III. PERCENTAGE ERROR

Sl. No.	Load on Curved Beam (F) in N	Percentage Error between Analytical calculation & Strain gage measurement	Percentage Error between Analytical calculation & ANSYS results
1	9.81 N	13.16%	22.86%
2	29.43 N	10.76%	20.72%
3	49.05 N	14.63%	24.15%

Table iii. shows that the calculated percentage error between the analytical & Strain gage measurement methods are obtained a average percentage error of 12.85%. it also shows that percentage error between the analytical & ANSYS methods are obtained a average percentage error of 22.57%.

IV. CONCLUSION

The experimental measurements is compared to predicted stress levels obtained using analytical solutions, experimental solutions as well as the numerical solutions from finite element analysis (FEA). The induced stresses as obtained from the analytical calculations are compared with results obtained from experimental values as well as FEA software (ANSYS). The results are in close with an acceptable percentage error of 20%-25%.

From the table 2 it is clear that the theoretical calculations are almost closer to the FEA values (ANSYS calculations), as well as to the experimentally determined values. We are getting error percentage within the safer limit as per ASME standards as shown in table 8. Hence the design is Safe.

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