Analytical and Numerical Analysis of Ovel Shaped Composite Beam

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Abstract: Composite materials are widely used in aircraft industries because of their superior fatigue characteristics, greater fatigue tolerance and large stiffness-to-weight ratio as compared with their metal counter parts. This paper aims at analysis of Ovel shaped composite beam. Carbon Fiber Composite box beam with 0^0 & 90^0 plies are used for simulation and analytical analysis. The composite beam is fixed at one end and the load is applied at the free end of the beam. The numerical analysis was carried out by using Structural Mechanics module in COMSOL Multiphysics. Ovel shaped composite beam is analyzed for different parameter such as total deflection, strain-stress at different points on beam by varying the point load at its free end. The results are validated with numerical and analytical analysis.

Keywords: Ovel shaped beam, Deflection, Stress, Strain, COMSOL.

1. Introduction

Composite materials are widely used in aircraft industries. In helicopter rotor application composite material bring additional features like drastic reduction in number of parts and bulkiness, especially for rotor hub system which is typical large source of profile drive. The composite box-beams are routinely used for the preliminary design of helicopter rotor blades.

In this study composite beam is considered as cantilever type having Ovel shaped cross section. If beam is considered as solid then there is standard formula to calculate the deflection at free end as well as stress and strain induced by applying the load at free end from 10 N to 80 N. But if beam is hollow then you have to required to make the changes in given formula. The numerical results are carried out for Ovel shaped beam and they are compared with analytical results which are calculated by modified formulae. The both results are matched with each other.

The researches have been conducted on composite box beams. Pawar et al. [1] discussed Eigenvalue Analysis of Composite Box Beam. Alaattin Aktas [2] investigated deflection function of orthotropic cantilever beam subjected to point load. The deflection at the free end of the beam is calculated numerically using obtained formulas. Husain Mehdi et al. [4] discussed Computational modal analysis of a composite beam with and without cracks. Syed Ayesha Yasmeen [5] selected two Fiber-Reinforced Plastic (FRP) materials; Graphite Fibre Reinforced Polyamide and E-Glass Fibre Reinforced Polymer have been selected as beam materials for modal analysis using ANSYS 13.0.

2. Composite Beam Geometry:

The model chosen is Ovel shape composite beam of uniform cross-section having dimension 800x60x22 mm. This is an eight layer sandwich composite box beam. The COMSOL model of the used beam is shown in Fig.1.

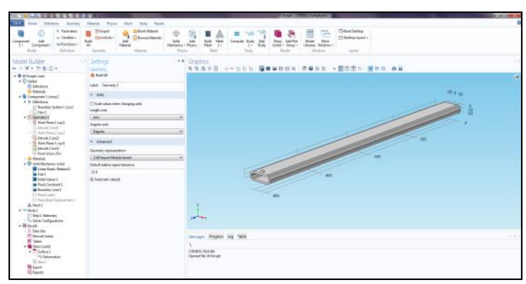


Figure 1 Model of Ovel shape Composite beam

- **Drawing:**

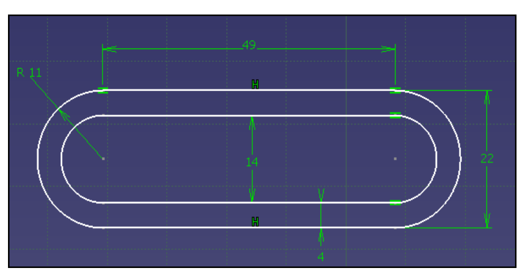


Figure 2 Front view of Composite Beam

- **Material:**
  - Carbon Fibre Unidirectional Fabric
  - 6 KUD Fabric – 360 GSM

- **Lay up Sequence:**
  - 0-0-90-0-0-90-0-0 ($0_3/90_2/0_3$) - 8 Layers Geometry

- **Material Properties:**

Table1 Material Properties of Composite Beam

Material Properties	Carbon Fibre Unidirectional
Young's Modulus	135 Gpa (Ex Dir.)
	10 Gpa (Ey Dir.)
	10 Gpa (Ez Dir.)
Poisson's Ratio	0.26
Mod. of Rigidity	5 Gpa
Density	1.6 kg/m^3

3. Analytical Study:

The theoretical analysis is carried out for cantilever type composite Ovel shaped beam. In this study beam is fixed at one end and at free end load is applied shown in figure below. Due to applied load deflection carried out at free end. There are standard formulas for calculating defined parameters. But if this formula is used for hollow ovel shaped beam, the results are not matched with numerical results. So, the changes are carried out to determine M.I. for hollow (Ovel) shaped composite beam. Then, further calculations are carried out.

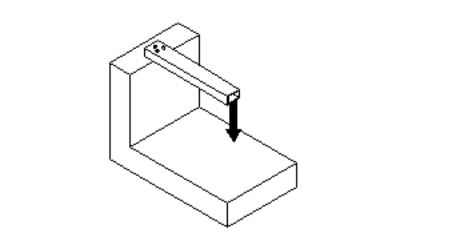


Figure 3 Cantilever Composite beam

3.1 Moment of Inertia for hollow Ovel shaped composite beam:

The standard formula for calculating the deflection at free end is given below:

$$\delta = \frac{Pl^3}{3EI} \quad (1)$$

In Hollow shaped beam consist of two rectangles and two half circles shown in figure 2. M.I. is calculated for this by using formula given below.

We calculate the M.I. for Ovel shape cross section,

$$I = \frac{bd^3}{12} \quad (2)$$

$$I = \frac{\pi}{64}(D^4 - d^4) \quad (3)$$

M.I. for Ovel shape beam = 38975.75 mm4 (4)

3.2 Deflection at free end:

By using M.I. calculated above, deflection at free end by varying point load at free end from 10N to 80 N is calculated and presented in table 2. Sample calculation for deflection is given below.

Deflection for 10 N:

$$\delta = \frac{10 \times 800^3}{3 \times 135 \times 10^3 \times 38975.75}$$

$$\delta = 0.32\ mm$$

Table 2 Deflection at free end (Analytical Results)

Sr. No.	Force (N)	Analytical Deflection (mm)
1.	10	0.32
2.	20	0.64
3.	30	0.97
4.	40	1.29
5.	50	1.62
6.	60	1.94
7.	70	2.27
8.	80	2.59

3.3 Stress and Strain induced at Fixed end and mid of beam:

Due to load applied at free end strain induced at fixed end and mid of the composite beam. For cantilever beam there is standard formula to calculate the stress induced in it. By using that can calculate stress and once stress is calculated, we can calculate strain by using the stress-strain relationship; by means Hook's Law. Stress and Strain induced at fixed end and mid of beam by varying point load at free end from 10N to 80 N is calculated and presented in table 3. Sample calculation for Stress and Strain is given below.

First of all calculate the section modulus of Cantilever Composite beam by using the formula given below. Then, values of stress and strain are found out.

$$Z = \frac{2 \text{ x } I}{h} \quad (1)$$

$$Z = \frac{2 \text{ x } 38975.75}{22} \quad (2)$$

$$Z = 3543.25 \text{ mm}^3 \quad (3)$$

3.3.1 Stress Calculation:

Stress for 10 N:

1. Stress at fixed end:

$$\sigma_1 = \frac{P \text{ x } L}{Z} \quad (4)$$

$$\sigma_1 = \frac{10 \text{ x } 720}{3543.25} \quad (5)$$

$$\sigma_1 = 2.02 \text{ N/mm}^2$$

$$= 2.02 \text{ x}10^6 \text{ N/m}^2 \quad (6)$$

2. Stress at mid:

$$\sigma_1 = \frac{P \text{ x } L}{Z} \quad (7)$$

$$\sigma_1 = \frac{10 \text{ x } 400}{3543.25} \quad (8)$$

$$\sigma_1 = 1.12 \text{ N/mm}^2$$

$$= 1.12 \text{ x}10^6 \text{ N/m}^2 \quad (9)$$

3.2 Strain Calculation:

Strain for 10 N:

1. Strain at free end:

After calculating the stress, strain values are calculated by multiplying Young's Modulus to stress values.

Therefore,

$$\varepsilon_1 = \sigma_1/E \quad (10)$$

$$\varepsilon_1 = \frac{1.12}{135\text{x}10^3} \quad (11)$$

$$\varepsilon_1 = 1.50 \text{ x } 10^{-5} \quad (12)$$

2. Strain at mid:

$$\varepsilon_1 = \sigma_1/E \quad (13)$$

$$\varepsilon_1 = \frac{1.12}{135\text{x}10^3} \quad (14)$$

$$\varepsilon_1 = 8.36 \text{ x } 10^{-6} \quad (15)$$

Table 3 Stress-Strain at fixed end and mid of beam (Analytical Results)

Sr. No.	Force (N)	Stress (N/m^2)		Strain	
		Fixed end	Mid	Fixed end	Mid
1.	10	2.02 x10^6	1.12 x10^6	1.50x 10^{-5}	8.36x 10^{-6}
2.	20	4.06 x10^6	2.25 x10^6	3.01x 10^{-5}	1.67x 10^{-6}
3.	30	6.08 x10^6	3.37 x10^6	4.51x 10^{-5}	2.50x 10^{-5}
4.	40	8.12 x10^6	4.50 x10^6	6.02x 10^{-5}	3.34x 10^{-5}
5.	50	10.15 x10^6	5.64 x10^6	7.52x 10^{-5}	4.18x 10^{-5}
6.	60	12.19 x10^6	6.84 x10^6	9.03x 10^{-5}	5.07x 10^{-5}
7.	70	14.17 x10^6	7.89 x10^6	1.05x 10^{-4}	5.85x 10^{-5}
8.	80	16.2 x10^6	9.01 x10^6	1.20x 10^{-4}	6.68x 10^{-5}

The above table indicate the Stress and strain induced at fixed end and mid of the beam for different loading conditions.

4. Numerical Study:

Simulations were done with the help of COMSOL Multiphysics software package. COMSOL Multiphysics is a powerful interactive environment for modeling and solving all kinds of scientific and engineering problems. This is used to perform the modeling of the composite box beam and calculation of Deflection at free end, Stress-Strain induced at fixed end and mid of the beam. This is used to simulate both the linear & nonlinear effects of structural models in a static and dynamic environment.

1. Specification of Problem:

The Composite beam has a ply lay-up [0_3/90] s on all four sides the composite beam contain 8 layers. With the help of solid mechanics module in the COMSOL Multiphysics, Deflection, Stress and Strain are calculated. Figure 4 shows geometry of Composite cantilever beam.

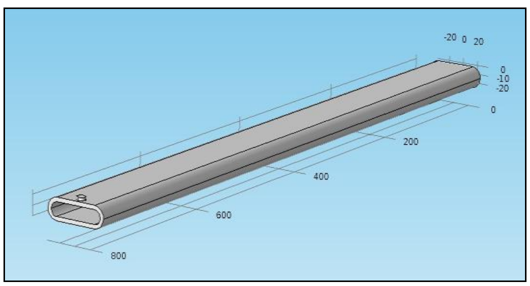


Figure 4 Geometry of beam in COMSOL

2. Meshing of Geometry:

Meshing method is used for meshing the geometry in COMSOL Multiphysics. The geometry of composite beam with extremely coarse mesh is shown in figure below.

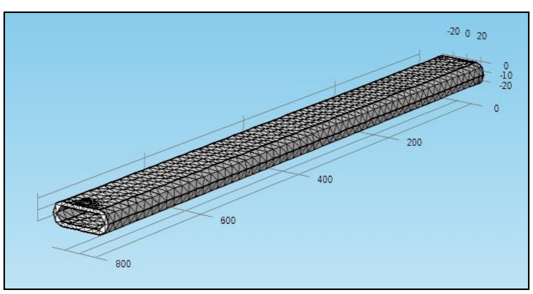


Figure 5 Meshing of Composite beam

3. Boundary Conditions:

The Composite beam is considered as cantilever type. So, in step one end of the beam is fixed and at other end point load is applied from 10N to 80N. Figure 6 shows boundary conditions for given geometry.

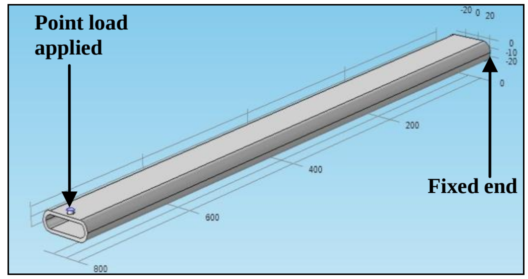
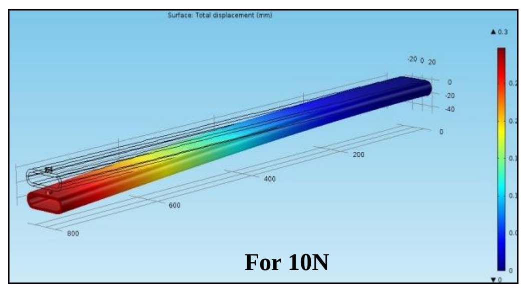


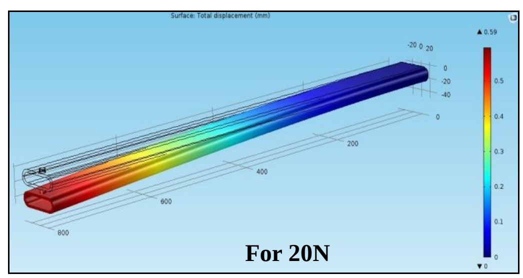
Figure 6 Boundary conditions applied to beam

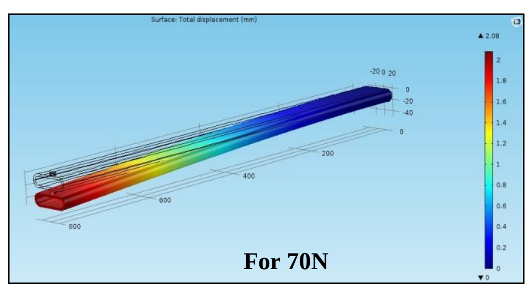
4. Numerical or Simulation Result:

Simulation is done for Composite beam by varying load at free end. The simulated results are given below by figures and in tabulated form.

4.4.1 Simulated results for Deflection at free end of beam:







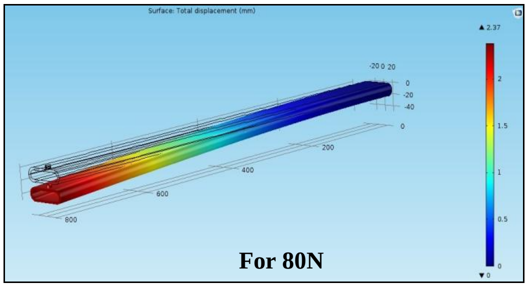


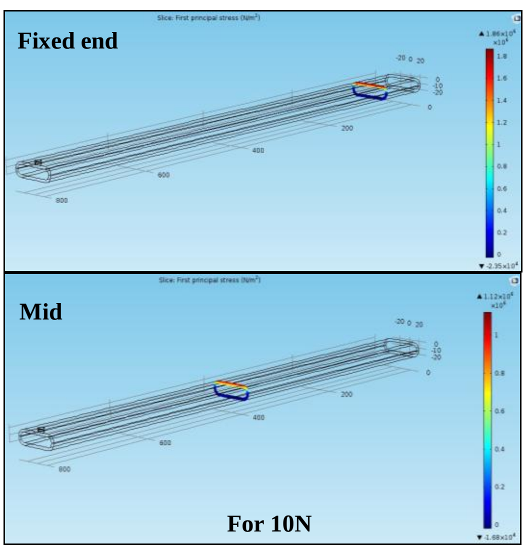
Figure 7 Simulation results for Deflection at free end of beam

The Numerical or Simulated results for Deflection of beam at free end to other forces are represented by the table 4:

Table 4 Deflection at free end (Numerical Results)

Sr. No.	Force (N)	Simulated Deflection (mm)
1.	10	0.3
2.	20	0.59
3.	30	0.89
4.	40	1.19
5.	50	1.48
6.	60	1.78
7.	70	2.08
8.	80	2.37

4.4.2 Simulated results for Stresses induced in Composite beam:



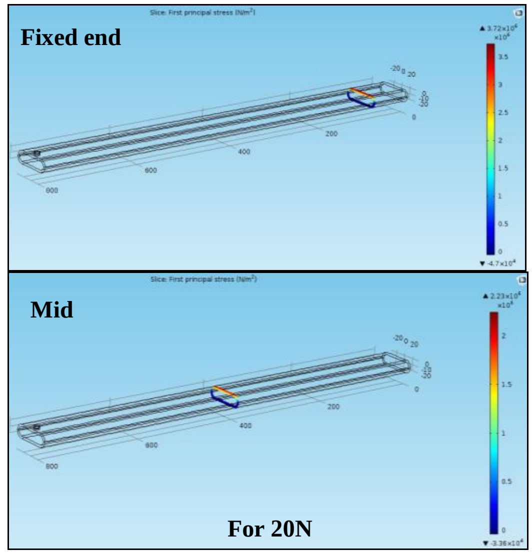
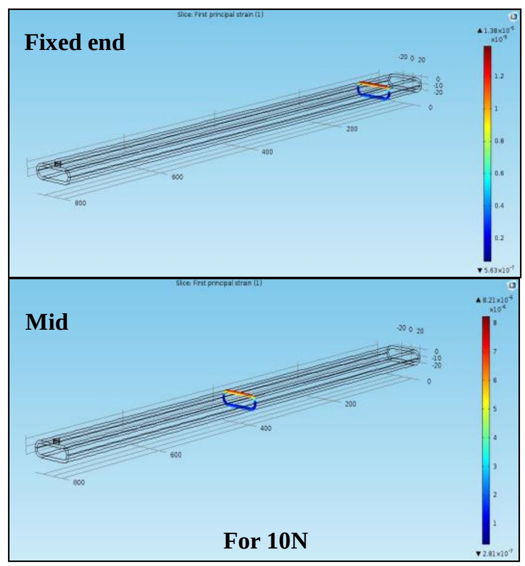
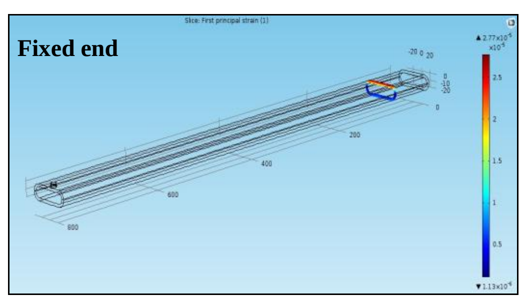


Figure 8 Simulation results for Stress induced in beam

4.4.2 Simulated results for Strain induced in Composite beam:





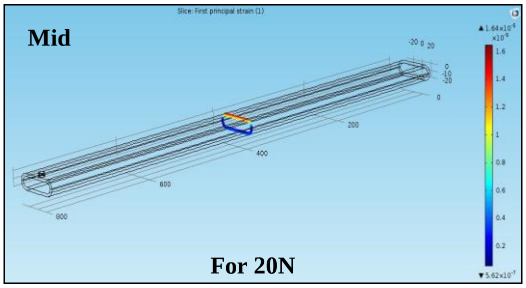


Figure 9 Simulation results for Strain induced in beam

The Simulated results for Stress and Strain to other forces are represented by the table 5.

Table 5 Stress-Strain at fixed end and mid of beam (Numerical Results)

Sr. No.	Force (N)	Stress (N/m^2)		Strain	
		Fixed end	Mid	Fixed end	Mid
1.	10	$1.86x 10^6$	$1.12x 10^6$	$1.38x 10^{-5}$	$8.21x 10^{-6}$
2.	20	$3.72x 10^6$	$2.32x 10^6$	$2.77x 10^{-5}$	$1.67x 10^{-6}$
3.	30	$5.59x 10^6$	$3.35x 10^6$	$4.15x 10^{-5}$	$2.46x 10^{-5}$
4.	40	$7.45x 10^6$	$4.47x 10^6$	$5.53x 10^{-5}$	$3.28x 10^{-5}$
5.	50	$9.31x 10^6$	$5.58x 10^6$	$6.91x 10^{-5}$	$4.1x 10^{-5}$
6.	60	$12x 10^6$	$6.7x 10^6$	$8.3x 10^{-5}$	$4.92x 10^{-5}$
7.	70	$13x 10^6$	$7.82x 10^6$	$9.68x 10^{-4}$	$5.74x 10^{-5}$
8.	80	$16.2x 10^6$	$9.01x 10^6$	$1.20x 10^{-4}$	$6.68x 10^{-5}$

5. Results and discussion:

The comparison between analytical and simulation results for Ovel shape Composite beam are presented in the graphs as follows:

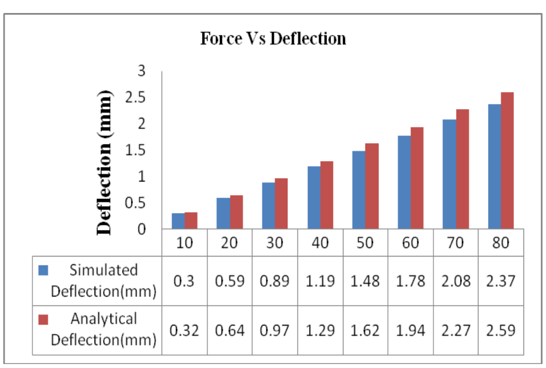


Figure 10 Graph for Deflection at free end of beam

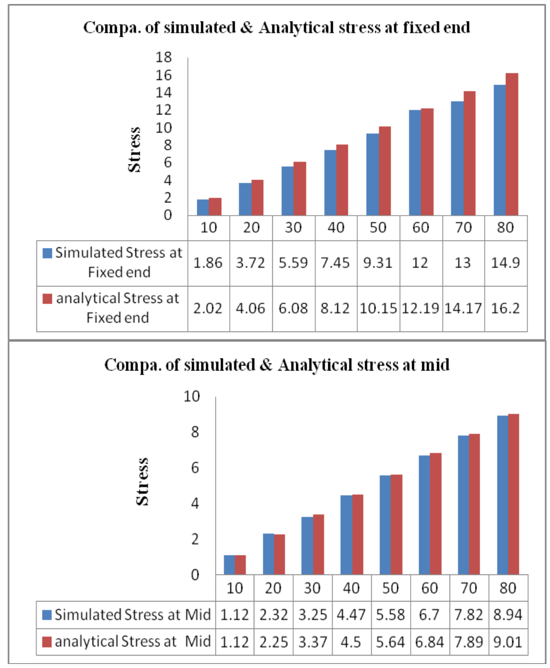


Figure 11 Graph for Stress induced at fixed end and mid

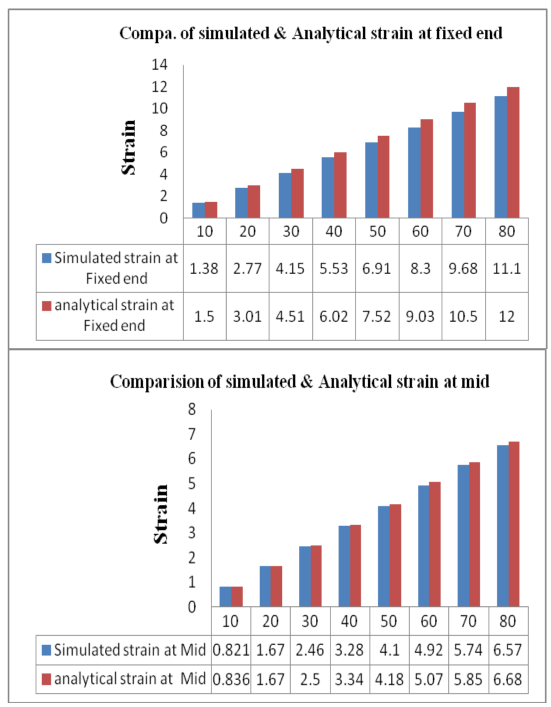


Figure 12 Graph for Strain induced at fixed end and mid

The comparison between Analytical and Numerical (Simulation) results for Deflection, Stress and Strain are shown by graph 10, 11 and

12. From that results, as value of point load increases from 10N to 80N then deflection at free end, stress-strain at fixed end and mid of beam also increases. This is shown by above graphs. By doing the comparison for Stress-Strain values for fixed end and mid of the beam, values at fixed end are greater than values for mid of the beam, it is also shown by graph 11 and 12. Also, there is no more difference between analytical and numerical results by making comparison with all above graph.

6. Conclusion:

From the above results, as value of point load increases then deflection at free end is increases, and stress-strain at fixed end and mid of beam also increases. By doing the comparison for Stress-Strain values for fixed end and mid of the beam, values at fixed end are greater than values for mid of the beam. Also, there is no more difference between analytical and numerical results by making comparison. Finally, simulated results are compared with analytical results and a percentage error between them is observed within 10%.

7. References:

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