Shear Lag Effects on Buckling Behaviour of Composite Laminate Box Girder using ABAQUS

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Abstract - *Nowadays, the usage of laminate composite material is highly recommended for civil constructions, naval and aircraft structures due to its highlighting properties such as in-plane stiffness, bending stiffness, high strength, durability, coefficient of thermal expansion, and many more. Hence, the effect of transverse shear deformation should be considered. Based on the theory it is assumed that plane sections initially normal to the mid surface before deformation remain plane and normal to that surface after deformation. The stress distribution on the flange will be irregular due to the shear lag effects. So this will change the strength of the thin-walled member and it could be computed by using buckling criteria. The combination of box-girder with laminated composite is perfect for light weight long span bridges. Herein, the effects of shear lag on buckling stress of laminate composite box girder will be investigated and analyzed by ABAQUS.*

Key Words: **Shear lag, Buckling behaviour, laminate composite material, Box girder and ABAQUS**

1. INTRODUCTION

The uneven stress transfer across the cross section causes uneven stress distribution of the section due to that section cannot be utilized effectively and instead of average it fails under the minimum strength across the cross section. This phenomenon is understood as a shear lag effect. Some of the flanged section is not connected to the gusset, this cross-section which is not joint as efficient because of the connected leg in transferring loads. The larger the unjoin leg, the transfer of tensile and compressive stress are less, the effect of unequal stress distribution in an unconnected flange is named shear lag. According to the Euler-Bernoulli beam theory, a plane section remains plane before and after bending. Therefore, the variation of bending stress in the cross-section along flange and web panels must be varying linearly. The laminate composites are widely used in all construction fields such as long-span bridge decks, ship deck hulls, and superstructure of offshore oil platforms.

The paper studied analysis for the effects of shear lag on the buckling behaviour of box girder bridges made of laminated composite material.

1.1 Box Girder

When two web plates are joined by a common flange at both the top and the bottom, then the structure is termed as box girder. Box girders are highly recommended because the closed-cell which is made features a much greater torsional stiffness and strength than an open section. The box girders are typically rectangular or trapezoidal in cross-section and they can be formed with single, twin or multiple box sections.

On the basis of materials used for the construction of the box girder, the box girder can be classified into steel, concrete, composite and prestressed. On the basis of its geometry, it can be classified as skew, curved, and a combination of both. Finally, on the basis of their shape, box girders can be classified into single and multi-cell sections.

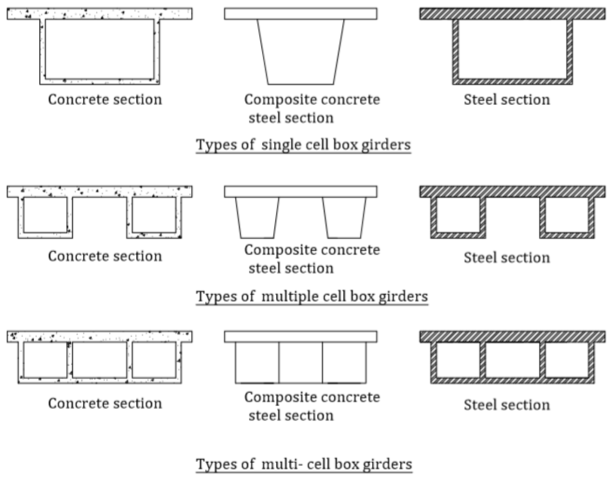

Fig- 1: Classifications of box girder

Merits of box girders over plate girders are:

- Due to its open cross-section, it has high strength and torsional stiffness
- Hollow space can be converted to many service stations
- Interior wall of the box girder has less chance of getting corrode
- Its aerodynamic shape, box girder can withstand torsional stiffness of both large suspension and cable-stayed bridges

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- Pier design and slender of the box girder gives a more attractive and high aesthetic appearance

1.2 SHEAR LAG

This is a term used by engineers to account for the unequal stress distribution among bolts or other fasteners. Let consider an angle in tension bolted to a gusset plate with 3 bolts in one leg of the angle. In the horizontal leg of 12 the angle there is a relatively equal stress distribution whereas, in the vertical leg, distributed stress will be uneven. Stress will be evenly distributed up to some particular distance from the connection. Thus as we start with unequal stress distribution and as we move along we encounter even stress we say that the shear stress was lagging, hence it is termed as shear lag.

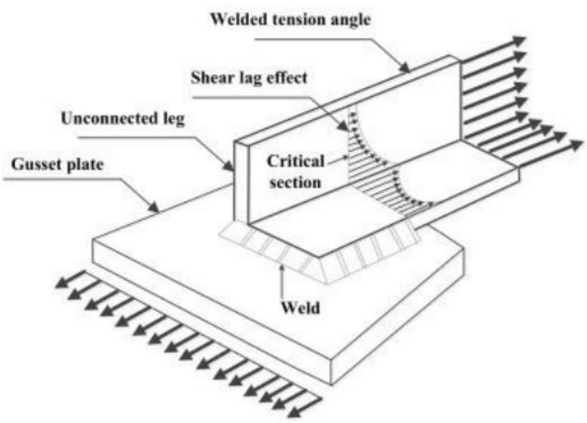

Figure-2: Effects of shear lag on the ultimate tensile capacity of high strength steel angles

The width of the box girder increases, the shear lag effect will increase and so it is important for modern bridge designs which often feature wide single-cell box cross-sections. The ratio of the width of the box girder to the length of span, where the shear lag effect becomes more specific. Plane Beam theory assumes plane section before the bending remains plane after the bending which signifies that the structure should have infinite lateral stiffness or there is no shear force acting at the beam section. Therefore, the bending stress diagram for a beam has to be in a linear pattern.

2. ABAQUS

Abaqus FEA (ABAQUS) is a software platform for the analysis and modeling of finite elements and computer-aided engineering. Shear lag effects on buckling behaviour of box girders can be studied by using finite element methods. The prediction of shear lag effects on buckling can be done by using any FEM programs. For this study, 'ABAQUS CAE 2020' was used for the investigation.

2.1 Material and its properties

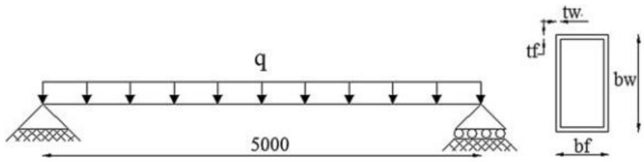

Fig -3: Schematic view of box girder

For this analysis, a simply supported box beam was considered. The hinged supports were in X, Y and Z directions and constraint at one end. For this study, all the cases were considered as uniform line load over the length of flange and web junction.

For the finite element modelling of different elements of the box girder, shell element 281 was adopted. It has 8 nodes and each node has six degree of freedom. And its translation and rotation in x, y and z-direction. Before it is applied for the analysis it is very important to verify its accuracy. So, the results obtained by Kollar(2003) and Qiao et al. (2005)were considered for the analysis.

Table-1: Properties of laminated composite material

Properties	Unit	Value
E_1	Gpa	145
E_2	Gpa	16.5
G_{12}	Gpa	4.48
ρ	Kg/m^3	1520
μ_1	-	0.314
μ_1	-	0.037

2.2 Shear lag parameters

The effective width of the box girder made of isotropic material is affected by two parameters ω and κ in addition to L/b (ratio of span to the width of box beam) (Nand Yoo (1988)). ω, represent the orthotropic parameter of the flange plate and κ represent cross-sectional parameter respectively. The expressions for the study were adopted from Upadhyay and Kalyanaraman (2003):

$$\omega_1 = \{(1/2) \times (A11/A66)_{TF} + (1/6)\,(A11/A66)_{W}\}$$

$$\kappa 1 = [(EA)_{TF} / (EA)_{G} + [(D11)_{TF} + [(D_{11})_{TF} / [(D11)_{TF} / (EI)_{G}]$$

Where,

$$(EA)_{G} = [(EA)_{TF}] + (EA)_{BF} + (EA)_{W}$$

The magnitude of the shear lag effect on the buckling coefficient of the box girder is computed by the shear lag factor. The shear lag factor was determined by the following equation.

$$S_F = \sigma_{x,max}/\sigma_{x,avg}$$

Where to calculate the average normal stress with a beam width at the L/2 , the trapezoidal rule of integration was used

3. NEED FOR STUDY

The shear lag determination by using analytical methods is a time taking task and the solution will not be an accurate one due to its high orthotropic character. Hence, finite element programs have been used to study the shear lag factor and buckling coefficient. Considering the geometry of the box girder and fiber orientation such a high orthotropic nature of the laminated composite material. Significantly, the numerical methods remain feasible if various elements are different. That is the fiber orientation in flange and web are changed with the width and thickness. Let us consider three conditions of fiber orientations 0°, ±45°, and 90°. In each condition, buckling on the flange will be the first mode when the stresses are distributed to the section.

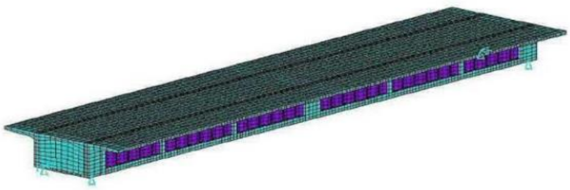

Fig -4: Basic plan for box girder

4. PARAMETER STUDY

4.1 Effects of fiber orientation

Considering both flange and web elements, geometric parameters such as length, breadth and width are taken as constant and the fiber orientation of three extreme conditions were taken.

Table-2: Parameters

L (mm)	b_f (mm)	t_w (mm)	Fiber orientation (degree)	t_f (mm)	b_w (mm)
5000	500	20	0/0/0/0	2.5	500
			90/90/90/90		600
			45/-45/45/-45		700

Generally, fiber orientation affects the stress of the box girder. If the fiber orientation varies, it affects the stress distribution along with the beam width. Various flange–web combinations of the top flange stress are shown in fig 5, 6 and 7. The stress distribution varies considerably in each combination.

Fig 5: 0° (θf) – 0° (θw)

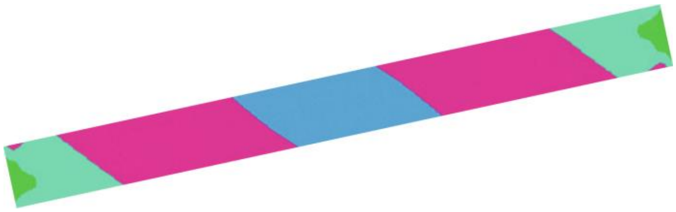

Fig -6: ±45° (θf) – 0° (θw)

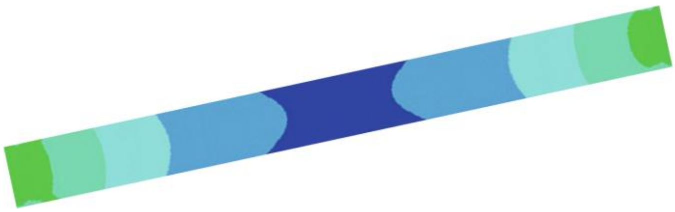

Fig -7: ±90° (θf) – 0° (θw)

Fig-8: 0°(θ_f) – ±45°(θ_w)

Fig-9: ±45°(θ_f) – ±45°(θ_w)

Fig-10: 90°(θ_f) – ±45°(θ_w)

From Fig 8 to 10, shear lag is varied with fiber orientation considerably. For this condition, the shear lag factor was calculated by the above equation. Chart -1 represents the variations of shear lag factor and fiber orientations with three different flanges. From this chart, it can be observed that web fiber orientation remains constant, then the shear lag factor and flange fiber orientation are inversely proportional. However, the shear lag factor is less than 90° when the flange has ±45° fiber orientation because ±45° provide adequate shear stiffness to laminate. In such conditions, the shear lag is nearly constant.

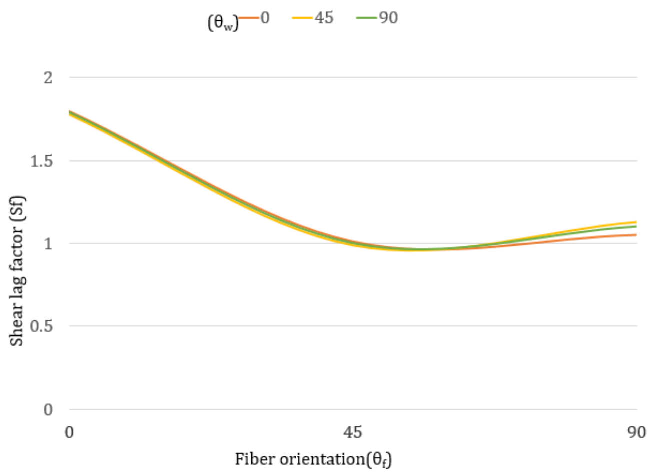

Chart-1: Shear lag factor variation with θ_f and θ_w

From chart -1 shows the variation trend of fiber orientation and shear lag factor with varying flange. This chart implies that flange fiber orientation and shear lag factor is inversely proportional when fiber orientation of web remains constant However, when ±45° fiber orientation of flange, then shear lag factor is lower than 90° due to shear stiffness to laminate material at ±45° and the shear lag is remains same.

The shear lag factor effect on the corresponding buckling coefficient is explained in chart 2. From this chart, the buckling coefficient decreases when shear lag factor increases.

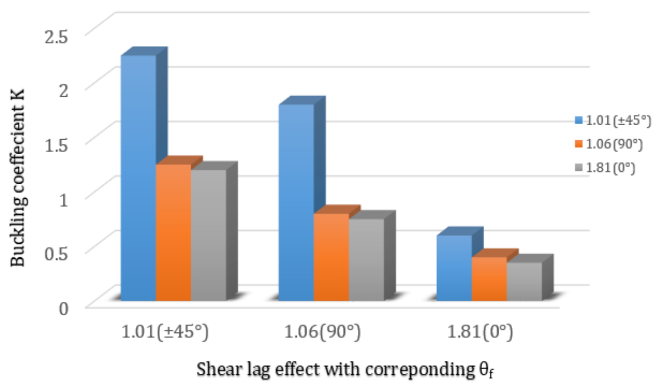

Chart-2: Buckling coefficient varies with S_F for different θ_w

It implies that when σ_{xavg} decreases, θ_f also decreases, which means the variation of stress across the beam gets raised at less flange fiber orientation. Corresponding value of θ_f with various buckling coefficient and shear lag effects given in chart-2.

4.2 Effects of B/D ratio

The shear lag of the box girder was determined by considering B, L fiber orientation remains constant and changing B/D ratio. In chart-3, it shows that variations of shear lag factor correspond with the slenderness ratio of the flange with various thickness of web. It signifies that the shear lag factor is directly proportional to the slenderness ratio.

Table-3: Shear lag of box beam and B/D ratio, B=500, L=3200 and Fiber orientation = (0/0/0/0) s

B/D	Shear lag
1.5	0.78
1.8	0.76
2.2	0.74
2.5	0.72
3.2	0.69
4.4	0.66

Table-4: Shear lag of box beam and B/D ratio, B=400, L=2500 and Fiber orientation = (45/-45/45/-45)s

B/D	Shear lag
1.5	0.965
1.8	0.96
2.2	0.95
2.5	0.94
3.2	0.93

4.4	0.92

Table-5: Shear lag of box beam and B/D ratio, B=380, L=2300 and Fiber orientation = (90/90/90/90)s

B/D	Shear lag
1.5	0.92
1.8	0.91
2.2	0.89
2.5	0.88
3.2	0.87
4.4	0.85

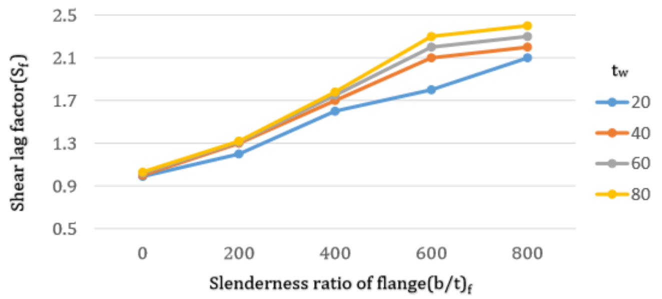

Chart-3: shear lag factor variation with $(b/t)_f$ for different t_w

In chart-4 represent another relation between buckling coefficient with shear lag factor. From this chart, it is clear that the buckling coefficient and shear lag factor are inversely proportional, this is because flange stiffness is decreases when flange width increases.

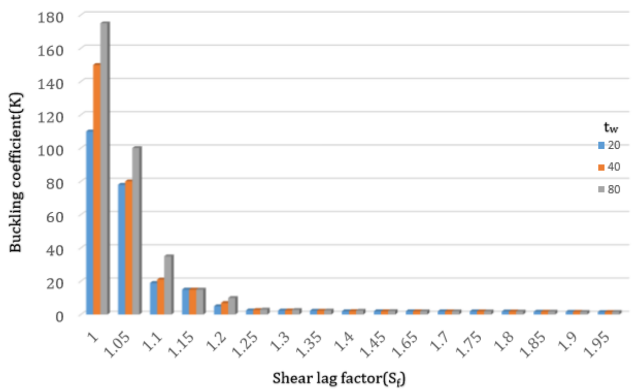

Chart-4 Buckling coefficient variations with S_f and t_w

5. CONCLUSIONS

In this study, the shear lag effect on buckling behaviour of box-girder was observed and analyzed by using 'ABAQUS CAE 2020.' The fiber orientation and geometry of different elements of the box girder have been changing correspondingly, the effects of shear lag on the buckling coefficient were studied. The study clearly observed the relation between fiber orientations and shear lag. The fiber orientation of ±45° and 90° was a low shear lag factor and also variation in non-uniform stress in beam width was less. In addition to that, the buckling coefficient has been increased because of the combined effect of the fiber orientation and shear lag effect. Furthermore, the web thickness and slenderness ratio of the flange on shear lag were also studied. The shear lag factor and slenderness ratio of the flange are directly proportional due to the stiffness of the flange reduced. Meanwhile, the coefficient of buckling and shear lag factor is inversely proportional.

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