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# Study on the Shear Lag Effect

**Bhaskar Bhatt, Ashish Kumar Chaudhary**

***Abstract: Shear lag effect increase as we move away from the section thereafter, the effects becomes predominant especially for the unsymmetric structures. The force transmission between the structure and patch occurs through bond layer, via shear mechanism, invariably causing shear lag. In the present study, an attempt is made to correlate the average shear stress in the bond layer obtained using the Bhalla & Soh model (2004) & BSC(Bhatt Saxena Chaudhary) model. In BSC model overall deformation of the bond layer is considered. It is simplified model of the complex shear lag phenomenon as with force transmission among PZT (lead zirconate titanate) patch and host structure .PZT is one of the world's most widely used piezoelectric ceramic materials. When fired, PZT has a perovskite crystal structure, each unit of which consists of a small tetravalent metal ion in a lattice of large divalent metal ions. PZT is used to make ultrasound transducers both for loudspeakers and microphones and other sensors and actuators, as well as high –value ceramic capacitors and FRAM chips. PZT is also used in the manufacture of ceramic resonators for reference timing in electronic circuitry. PZT has a high dielectric constant, ferroelectric, piezoelectric, & pyroelectric properties. The ideal properties of PZT have made its application to transducer, sensor and actuator devices ubiquitous. Piezoelectric ceramics, when mechanically activated with pressure or vibration, have the capacity to generate electric voltages sufficient to spark across an electrode gap. Piezoelectric energy harvester has good compression performance, fatigue resistance and waterproof performance. Piezoelectric effect is the ability of certain materials to generate an electric charge in response to applied mechanical stress. The word Piezoelectric is derived from the Greek piezein, which means to squeeze or press ,& piezo , which is Greek for "push". The main advantage of BSC model is that it does not involve solving the complex differential equations. Shear stress distribution is practically independent of excitation frequency except near pressure. BSC model can be made use of for carrying out the preliminary design in structural control related problems.***

***Keywords: Negative Shear lag, Shear lag, Shear Lag after effect, Shear flow***

## I. INTRODUCTION

The uneven stress distribution occurring in tension member adjacent to a connection is referred to as shear lag effect. It reduces design strength of the member. Shear lag effects in bolted tension members are in American Institute of Steel Construction (AISC) allowable stress design specification (ASD) since 1978.

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As with box I-shaped c/s, under shear force is known that normal stresses on c/s of points with same vertical distance to neutral axis are same. When shear force flow passing from web to flange normal stress distribution of flange is non homogeneous. Flat section assumption is non applicable corresponding normal stress is smaller. Shear wall with height-thickness ratio between 4 to 8 is called short-leg shear wall. Under action of axial and horizontal forces on T-shaped short-leg shear wall, normal stress distribution of flange appears so middle is bigger of two sides. Shear lag caused by shear deformation is shear lag effect. If shear lag effect is not considered, it leads to transverse cracks on flange plate. Shear lag changes distribution of normal stresses inside c/s, but do not change longitudinal distribution of internal forces along girder.

## II. LITERATURE SURVEY

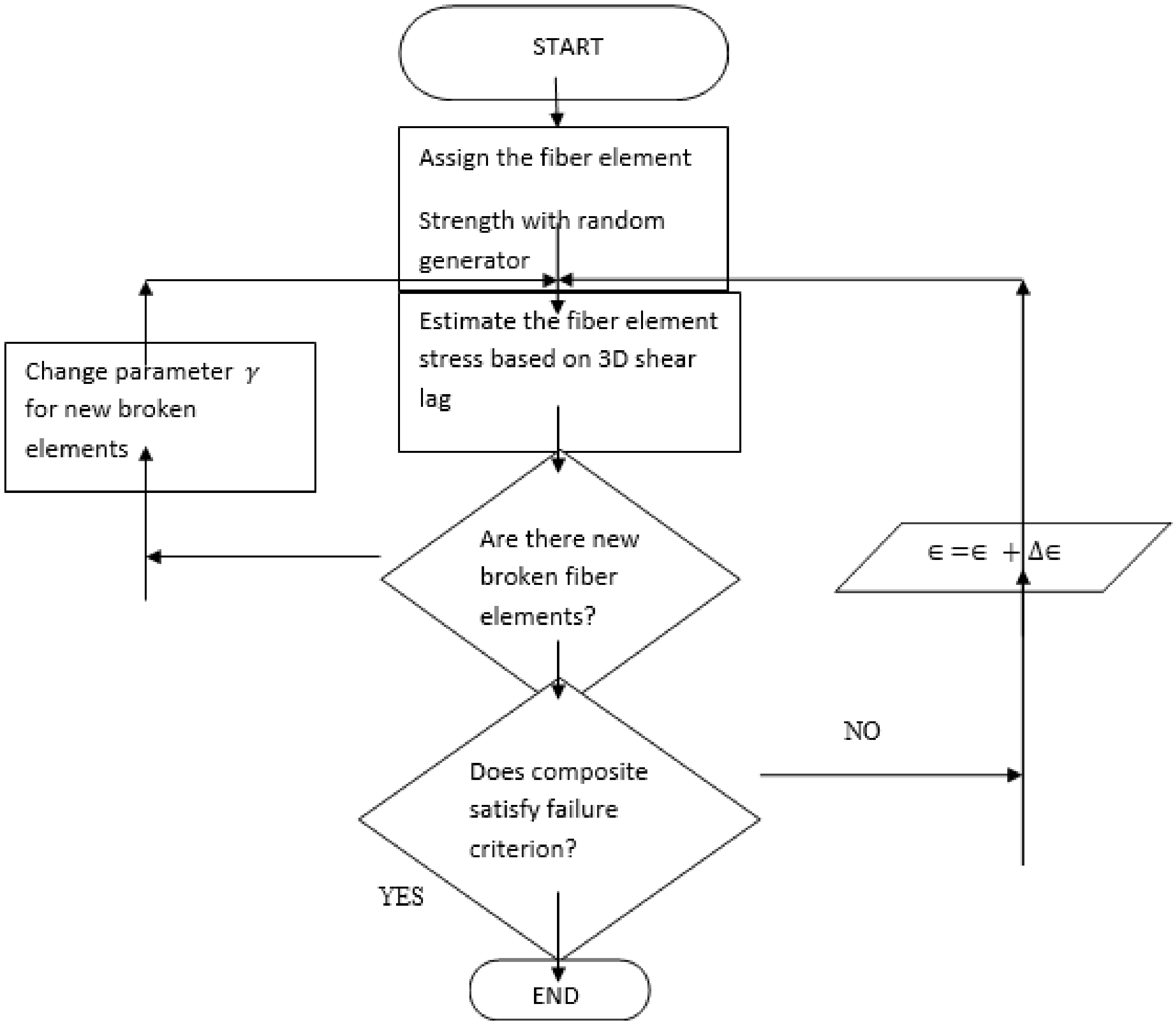
Shear lag effect was known long ago. Since 1930s researches were conducted to study shear lag effect. Beam theory assumes plane section remains plane after bending resulting in linear distribution of bending stress in c/s of beam. Shear flow between flange and web of box, panels displace longitudinally in way that middle portion of flange and web lag behind that of portion closer to corner of box section. In 1982 Foutch and Chang [1] saw ¼ cantilever length from fixed end, bending stress in box section at corners lower than stresses at middle of flange panel called negative shear lag.

Chang and Zheng (1987) [2] saw negative shear lag by finite element analysis and analytical method. Shushkewich (1991) [3] said negative shear lag occurs when load components create positive shear lag.

A study by Lee, Yoo and Yoon (2002) [4] explains origin of negative shear lag. They told that as uniformly distributed load is formed by superimposing distributed loads acting on differential length, negative shear lag occurs in cantilever box girder under uniformly distributed load could occur also in cantilever box girder under concentrated load. Stress distribution occurs at zero bending moment zones where there should be no bending stresses as per bending theory of beams. The deformation and stress distribution equals compatibility requirement: "shear lag after effect".

## III. RESEARCH METHODOLOGY

### A. Flowchart




Shear Stress Prediction In Bond Layer :

Shear stress in bond layer ,

$$\delta = \Psi\, \bar{S}_m \qquad (1)$$

where, $\delta$ = Interfacial Shear Stress

$\Psi$ = Shear Strain in bonding layer

$\bar{S}_m$ = Complex shear modulus of elasticity of bonding layer

$$\delta = \frac{(a_p - a)}{n_s}\, \bar{S}_m \qquad (2)$$

where, $a_p$ = Deformation in PZT patch

$a$ = Displacement at surface of host structure at end point of PZT patch

$n_s$ = Thickness of adhesive bond layer

Bhalla & Soh model (2004)

$$a = A_1 + A_2\, x + B\, e^{\lambda_3 x} + C\, e^{\lambda_4 x} \qquad (3)$$

where $A_1, A_2, B, C, \lambda_3, \lambda_4$ are constants.

$$a_p = (A_1 + \bar{n} A_2) + A_2\, x + B\,(1 + \bar{n}\,\lambda_3) e^{\lambda_3 x} + C(1 + \bar{n}\,\lambda_4) e^{\lambda_4 x} \qquad (4)$$

Where, $\bar{n}$ = Complex term

Shear stress in bond layer –

$$\delta = \frac{F}{A} \quad - \qquad (5)$$

Where, F = Force on PZT patch

A = Area

$$\delta = -\frac{\Lambda\, \gamma i\, a_p}{A\left(1 - \frac{\Lambda\, \gamma\, n_s}{A\, \bar{S}_m} i\right)} \qquad (6)$$

Where, $\Lambda$ = Mechanical Impedance of PZT patch

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$\gamma$ = Angular frequency of excitation

$i = \sqrt{-1}$

eqn (2) & eqn (6)-

$$\frac{(a_p - a)}{n_s}\bar{S}_m = -\frac{\Lambda\,\gamma\, i\, a_p}{A\left(1-\frac{\Lambda\,\gamma\, n_s}{A\,\bar{S}_m} i\right)} \qquad (7)$$

$$(a_p - a) = -\frac{\Lambda\, i\, \gamma a_p n_s}{(A\,\bar{S}_m - \Lambda\gamma\, n_s\, i)} \qquad (8)$$

$$a_p\left[1 + \frac{\Lambda\gamma n_s\, i}{(A\bar{S}_m - \Lambda\,\gamma n_s\, i)}\right] = a \qquad (9)$$

$$a_p = \frac{a}{\left[1 + \frac{\Lambda\gamma n_s\, i}{(A\bar{S}_m - \Lambda\,\gamma n_s\, i)}\right]} \qquad (10)$$

substituting a= $a_r$ + i $a_i$

where , $a_r$ = real part

$a_i$ = imaginary part

& z= x + iy

$$a_p = \frac{(a_r + \mathrm{i}\, a_i)}{\left[1 + \frac{(\mathrm{x}+\mathrm{iy})\gamma n_s\, i}{A\,S_m\,(1+\bar{\eta}\, i) - (\mathrm{x}+\mathrm{iy})\gamma n_s\, i}\right]} \qquad (11)$$

Where, $S_m$ = Shear modulus elasticity of bonding layer

$\bar{\eta}$ = Mechanical loss factor associated with bond layer

$$a_p = \frac{(a_r + \mathrm{i}\, a_i)\,[AS_m\,(1+\bar{\eta}\, i) - (\mathrm{x}+\mathrm{iy})\gamma n_s\, i\,]}{AS_m\,(1+\bar{\eta}\, i)} \qquad (12)$$

$$a_p = \frac{(a_r + \mathrm{i}\, a_i)\,[(A\,S_m + \gamma n_s\, y) + (A\,S_m\,\bar{\eta} - x\,\gamma\, n_s)i\,]}{A\,S_m\,(1+\bar{\eta}^2)}\,(1 - \bar{\eta}\, i) \qquad (13)$$

$$a_p = \frac{(a_r + \mathrm{i}\, a_i)\,[(A\,S_m + \gamma n_s\, y) + (A\,S_m\,\bar{\eta} - x\,\gamma\, n_s)i - \bar{\eta}\,(A\,S_m + \gamma n_s\, y)i + \bar{\eta}(A\,S_m\,\bar{\eta} - x\,\gamma\, n_s)]}{A\,S_m\,(1+\bar{\eta}^2)} \qquad (14)$$

Here ,

If $a_p = a_{pr} + i\, a_{pi}$ (15)

Then ,

$$a_{pr} = \frac{a_r[(A\,S_m + \gamma n_s\, y) + \bar{\eta}(A\,S_m\,\bar{\eta} - x\,\gamma\, n_s)] - a_i[(A\,S_m\,\bar{\eta} - x\,\gamma\, n_s) - \bar{\eta}\,(A\,S_m + \gamma n_s\, y)\,]}{A\,S_m\,(1+\bar{\eta}^2)} \qquad (16)$$

$$a_{pr} = \frac{a_r}{(1+\bar{\eta}^2)}\,[(1 + G\, y) + \bar{\eta}(\bar{\eta} - Gx)] - \frac{a_i}{(1+\bar{\eta}^2)}\,[(\bar{\eta} - Gx) - \bar{\eta}(1 + Gy)] \qquad (17)$$

where $G = \frac{\gamma n_s}{AS_m}$

Similarly , $a_{pi}$ =

$$\frac{a_i}{(1+\bar{\eta}^2)}\,[(1 + G\, y) + \bar{\eta}(\bar{\eta} - Gx)] + \frac{a_r}{(1+\bar{\eta}^2)}\,[(\bar{\eta} - Gx) - \bar{\eta}(1 + Gy)] \qquad (18)$$

put eqn (17) & (18) into eqn (6) --- $\Lambda_{eq} = X_{eq} + iY_{eq}$

$\Lambda_{eq}$ = Equivalent mechanical impedance of PZT patch

$$\delta = \frac{-(X_{eq} + iY_{eq})i\gamma(a_{pr} + i\, a_{pi})}{A} \qquad (19)$$

$$\delta = \frac{\gamma}{A}\left(X_{eq}a_{pi} + Y_{eq}a_{pr}\right) + \frac{\gamma}{A}\,(Y_{eq}a_{pi} - X_{eq}a_{pr})i \qquad (20)$$

if $\delta = \delta_r + \mathrm{i}\,\delta_i$ (21)

Then ,

$$\delta_r = \frac{\gamma}{A}\left(X_{eq}a_{pi} + Y_{eq}a_{pr}\right) \qquad (22)$$

$$\delta_i = \frac{\gamma}{A}\,(Y_{eq}a_{pi} - X_{eq}a_{pr}) \qquad (23)$$

$$|\delta| = \sqrt{\delta_r^2 + \delta_i^2} \qquad (24)$$

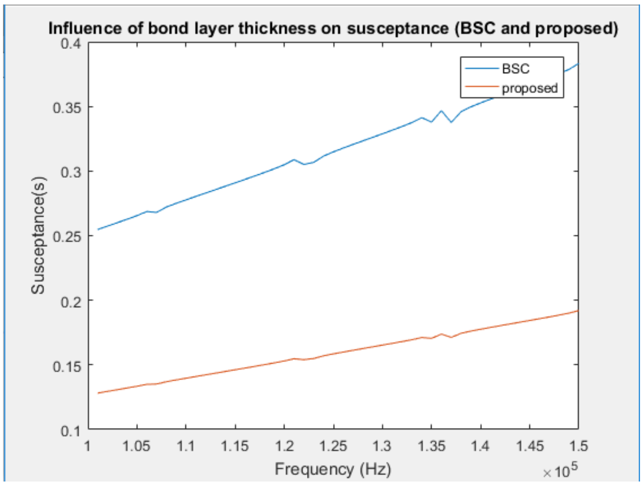
$$\delta = \frac{-\Lambda\, i\, \gamma\,[B\,\lambda_3(e^{\lambda_3 x} - 1) + C\,\lambda_4\,(e^{\lambda_3 x} - 1)]}{W_p} \qquad (25)$$

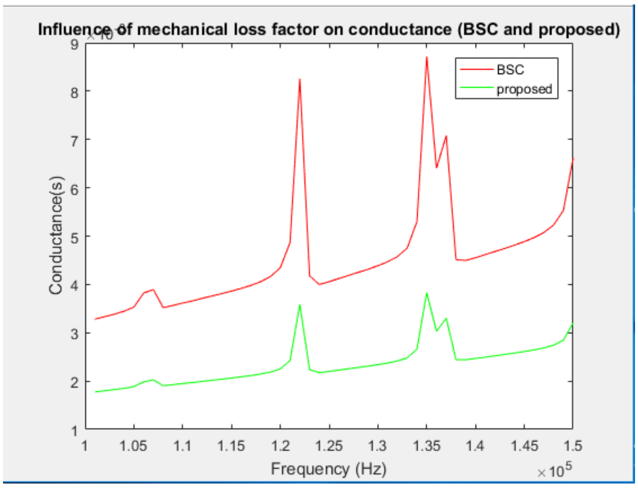
where, $W_p$ = width of PZT patch

The reason for getting explicit expressions in the Bhalla and Soh model (2004) was that it was developed using the elemental formulations of the bond layer. However, in the case of the BSC model, the overall deformation of the bond layer is considered as simplifications. In the present study, an attempt is made to correlate the average shear stress in the bond layer obtained using the Bhalla and Soh model (2004) and the BSC model.

## IV. RESULTS

The conductance and susceptance signatures were extracted for BSC model and Bhalla and Soh (2004) [5] 1D impedance model. As the bond layer thickness decreases, the conductance given by BSC model and Bhalla and Soh model (2004) [6] are quite close. This part has a weak interaction with the structure and bond layer does not seem to influence the susceptance signatures.






## V. CONCLUSION

**(i)** The BSC (Bhatt Saxena Chaudhary) model developed is found to predict conductance and susceptance signatures in close proximity with Bhalla and Soh 1D impedance model (2004) [7]. However this proximity is not maintained at all frequencies of excitation. Near the resonant peaks, there is somewhat large difference in values of conductance predicted by these models. But at higher resonance peak frequencies, difference in values of conductance predicted by BSC model and the Bhalla and Soh model (2004) is very small.

**(ii)** The susceptance signatures predicted by three models are found to be in close proximity with each other for different thicknesses of bond layer. This part has a weak dependence on the bond layer.

**(iii)** Parametric study conducted using BSC model suggests apparent resonant frequency increases due to decrease in shear modulus (i.e. degradation in bond layer quality) and due to increase in bond layer thickness. It is suggested that in order to achieve best results, PZT patch should be bonded to structure using an adhesive of high shear modulus and smallest practicable thickness.

**(iv)** The most important result derived from study of shear stress distribution in adhesive bond layer is that shear stress distribution is marginally affected by frequency of excitation except near resonance peaks. This result has been verified both by the BSC model and the Bhalla and Soh 1D impedance model. Hence, it can be said that the shear stress distribution is practically independent of excitation frequency, except near resonance.

**(v)** Another important result obtained from the analysis of shear stress distribution in adhesive bond layer is that the peak shear stress obtained using the Bhalla and Soh model (2004) [8] is close to the average shear stress value obtained using the BSC model. This result shows that the BSC model can be made use of for carrying out the preliminary design in structural control related problems.

**(vi)** The advantages of the BSC model developed are quite apparent. This model is a quite simplified model of the complex shear lag phenomenon as with force transmission among PZT patch and host structure attached together with adhesive bond layer. The main advantage of this model is that it does not involve solving the complex differential equations. However, simple it may be, it is not a substitute for Bhalla and Soh model (2004) particularly when accuracy is of utmost importance.

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