Chapter-7

DISCUSSION OF RESULTS
TEMPERATURE LOAD TYPE: NVT
7.1 INTRODUCTION

This chapter covers the discussion of results of the third part in which the skew laminated plate with a circular hole at the geometric centre is subjected to a non-linearly varying temperature (NVT) load and to combined uniform pressure and non-linearly varying temperature load.

7.2 ANALYSIS OF LAMINATE WITH STACKING SEQUENCE 1

In the first set of second part, the results are obtained for a five-layered symmetric laminate with the stacking sequence $1^0 (0^0/90^0/0^0/90^0/0^0)$ as shown in Fig. 5.2.1.

Non-linear variation of the temperature across the thickness of the laminate is shown in Fig. 7.2.1. In the first, third and fifth layers the non-linearity in the variation of temperature is less when compared to the variation of temperature in the second and fourth layers indicating that the non-linearity is more in the thicker layers of the laminate.

From the second layer onwards the nonlinearity in temperature variation is observed to be more up to fourth layer. The rate of increase of the temperature with respect to the thickness increases
from bottom layer to top layer. The temperature is observed to be increasing with increase in d/l ratio.

The variation of in-plane normal stresses $\sigma_x$, $\sigma_y$ with respect to skew angle ($\alpha$) are shown in Figs. 7.2.2 and 7.2.3. Variation of the in-plane shear stress $\tau_{xy}$ is shown in Fig. 7.2.4. The effect of skew angle on interlaminar stresses is shown in Figs. 7.2.5 to 7.2.7. The Fig. 7.2.8 illustrates the variation of transverse deflection 'w' with respect to skew angle $\alpha$.

There is no significant variation of in-plane normal stress, $\sigma_x$ (Figs. 7.2.2a, 7.2.2b) with respect to skew angle due to thermal loading. $\sigma_x$ due to pressure loading (pl) and combined loading (cl) decreases with the increase in skew angle.

The in-plane normal stress, $\sigma_y$ (Figs. 7.2.3a, 7.2.3b) decreases with the increase in skew angle for all the load cases and also for all d/l values.

The in-plane shear stress, $\tau_{xy}$ (Figs. 7.2.4a, 7.2.4b) for thermal loading increases up to 30° of $\alpha$ and then decreases for d/l = 0.10 and 0.20. For d/l = 0.3 and 0.4, this stress increases up to $\alpha = 20^\circ$ and then decreases. In case of pressure loading $\tau_{xy}$ increases with increase in $\alpha$ for d/l = 0.1 and 0.2 up to $\alpha = 10^\circ$ and then decreases. This stress
decreases with increase in $\alpha$ for $d/l = 0.3$ and 0.4. In case of combined loading $\tau_{xy}$ decreases with increase in $\alpha$ for all $d/l$ ratios.

The interlaminar normal stress at the free edge of the hole, $\sigma_z$ (Figs. 7.2.5a, 7.2.5b) increases with increase in up to $\alpha = 20^\circ$ and then decreases for all $d/l$ values in thermal loading. In case of pressure loading, there is no significant variation of this stress with respect to $\alpha$. In case of combined loading $\sigma_z$ decreases with increase in skew angle for all $d/l$ ratios.

There is no significant variation of interlaminar shear stress, $\tau_{yz}$ (Figs. 7.2.6a, 7.2.6b) with respect to skew angle due to thermal loading. In case of pressure loading there is no significant variation of this stress with respect to $\alpha$. In case of combined loading $\tau_{yz}$ increases with increase in $\alpha$ for $d/l = 0.1$ and 0.2. For $d/l = 0.3$ this stress increases up to $\alpha = 40^\circ$ and then decreases. For $d/l = 0.4$ this stress increases up to $\alpha = 30^\circ$ and then decreases.

The interlaminar shear stress, $\tau_{xz}$ (Figs. 7.2.7a, 7.2.7b) at the free edge of the hole decreases with increase in $\alpha$ for thermal loading for $d/l = 0.1$. For $d/l = 0.2$ this stress decreases up to $\alpha = 30^\circ$ and then increases. For $d/l = 0.3$ $\tau_{xz}$ decreases up to $\alpha = 20^\circ$ and then increases. For $d/l = 0.4$ this stress increases up to $\alpha = 40^\circ$ and then decreases. In case of pressure loading there is no significant variation of this stress with respect to $\alpha$. In case of combined loading this stress
decreases with increase in $\alpha$ for $d/l = 0.1$. For $d/l = 0.2$ this stress increases up to $\alpha = 10^0$ and then decreases up to $\alpha = 40^0$ and again increases. For $d/l = 0.3$ $\tau_{xx}$ decreases up to $\alpha = 20^0$ and then increases. For $d/l = 0.4$ this stress increases with increase in skew angle up to $\alpha = 40^0$ and then decreases.

There is no variation in the transverse deflection, ‘$w$’ (Figs. 7.2.8a, 7.2.8b) due to the variation of $\alpha$ for all $d/l$ ratios in case of thermal loading. ‘$w$’ decreases with increase in $\alpha$ for pressure loading and combined loading for all $d/l$ ratios.

The reasons for the variation of the stresses and deflection given in chapter 5 are also valid for the results discussed here.

Fig. 7.2.1 Variation of temperature across thickness on the surface of the hole ($\alpha = 30^0$, $x =$ radius of hole, $y =$0)
Fig. 7.2.2a. Variation of $c_x$ with respect to skew angle for thermal loading (tl)

Fig. 7.2.2b. Variation of $c_x$ with respect to skew angle for pressure loading (pl) and combined loading (cl)
Fig. 7.2.3a. Variation of $\sigma_y$ with respect to skew angle for thermal loading (tl)

Fig. 7.2.3b. Variation of $\sigma_y$ with respect to skew angle for pressure loading (pl) and combined loading (cl)
Fig. 7.2.4a. Variation of $\tau_{xy}$ with respect to skew angle for thermal loading (tl)

Fig. 7.2.4b. Variation of $\tau_{xy}$ with respect to skew angle for pressure loading (pl) and combined loading (cl)
Fig. 7.2.5a. Variation of $\sigma_x$ with respect to skew angle for thermal loading ($t_l$)

Fig. 7.2.5b. Variation of $\sigma_x$ with respect to skew angle for pressure loading ($p_l$) and combined loading ($c_l$)
Fig. 7.2.6a. Variation of $r_{yz}$ with respect to skew angle for thermal loading (tl)

Fig. 7.2.6b. Variation of $r_{yz}$ with respect to skew angle for pressure loading (pl) and combined loading (cl)
Fig. 7.2.7a. Variation of $\tau_{\infty}$ with respect to skew angle for thermal loading (tl)

Fig. 7.2.7b. Variation of $\tau_{\infty}$ with respect to skew angle for pressure loading (pl) and combined loading (cl)
Fig. 7.2.8a. Variation of $w$ with respect to skew angle for thermal loading (tl)

Fig. 7.2.8b. Variation of $w$ with respect to skew angle for pressure loading (pl) and combined loading (cl)
7.3 ANALYSIS OF LAMINATE WITH STACKING SEQUENCE 2

In the second set the fibers in the odd number of layers are taken parallel to the horizontal sides of the plate and the fibers in the even number of layers are arranged parallel to the inclined sides of the skew plate. The Fig 5.3.1 shows the stacking sequence 2 which is taken as $0^0/\alpha/0^0/\alpha/0^0$ where $\alpha$ is the skew angle and this value varies from $0^0$ to $50^0$.

Non-linear variation of the temperature across the thickness of the laminate is shown in Fig. 7.3.1. In the first, third and fifth layers the non-linearity in the variation of temperature is less when compared to the variation of temperature in the second and fourth layers indicating that the non-linearity is more in the thicker layers of the laminate.

The in-plane normal stress, $\sigma_x$ (Figs. 7.3.2a, 7.3.2b) due to thermal loading decreases slightly with increase in skew angle up to $\alpha = 20^0$ and then increases up to $\alpha = 50^0$, for $d/l = 0.1$. For $d/l = 0.2$ and $0.3$ this stress decreases with increase in skew angle up to $\alpha = 30^0$, and then increases up to $\alpha = 40^0$ and again decreases for $\alpha = 50^0$. For $d/l = 0.4$ this stress decreases with increase in skew angle. $\sigma_x$ due to pressure loading and combined loading decreases with increase in skew angle for all $d/l$ values.
The in-plane normal stress, $\sigma_y$ (Figs. 7.3.3a, 7.3.3b) decreases with increase in skew angle $\alpha$ for all the d/l ratios and for all the load cases.

The in-plane shear stress, $\tau_{xy}$ (Figs. 7.3.4a, 7.3.4b) for thermal loading increases with increases in skew angle up to $\alpha = 40^\circ$ and then decreases for all the d/l ratios. In case of pressure loading this stress increases with increase in skew angle $\alpha$ up to $30^\circ$ and then decreases for all the d/l ratios. In case of combined loading this stress increases with increase in skew angle up to $\alpha = 40^\circ$ for d/l = 0.1 and 0.2, and then decreases. For d/l = 0.3 and d/l = 0.4 this stress increases up to $\alpha = 30^\circ$ and then decreases.

The interlaminar normal stress, $\sigma_z$ (Figs. 7.3.5a, 7.3.5b) at the free edge of the hole increases with increase in skew angle for d/l = 0.1 and 0.2 for thermal loading. For other two d/l ratios this stress is almost constant with respect to $\alpha$. Incase of pressure loading there is no significant variation in this stress with respect to $\alpha$. In case of combined loading this stress increases up to $\alpha = 40^\circ$ and then decreases for d/l = 0.1 and 0.3. For d/l = 0.2 this stress increases with the increase in skew angle. For d/l = 0.4 this stress increases up to $\alpha = 30^\circ$ and then decreases.
The interlaminar shear stress, $\tau_{yz}$ (Figs. 7.3.6a, 7.3.6b) at the free edge of the hole slightly increases up to $\alpha = 20^\circ$ and then decreases, for all the $d/l$ ratios in case of thermal loading. In case of pressure loading there is no significant variation in this stress with respect to $\alpha$. In case of combined loading this stress increases up to $\alpha = 20^\circ$ and then decreases for $d/l = 0.1, 0.3$ and $0.4$. For $d/l = 0.2$ this stress increases up to $\alpha = 30^\circ$ and then decreases.

The interlaminar shear stress, $\tau_{xx}$ (Figs. 7.3.7a, 7.3.7b) at the free edge of the hole increases with increase in skew angle for $d/l = 0.1$ in case of thermal loading. For $d/l = 0.2, 0.3$ and $0.4$ this stress increases up to $\alpha = 40^\circ$ and then decreases for thermal loading. In case of pressure loading there is no significant variation in this stress with respect to $\alpha$. In case of combined loading this stress increases with increase in skew angle for $d/l = 0.1$ and $0.2$. For $d/l = 0.3$ and $0.4$ this stress increases up to $\alpha = 40^\circ$ and then decreases.

There is no significant variation in the transverse deflection ‘$w$’ (Figs. 7.3.8a, 7.3.8b) due to variation in skew angle for all $d/l$ ratios in case of thermal loading. ‘$w$’ decreases with increase in $\alpha$ for pressure loading and combined loading for all $d/l$ ratios.
The reasons for the variation of the stresses and deflection given in chapter 5 are also valid for the results discussed here.

Fig. 7.3.1 Variation of Temperature across thickness on the surface of the hole ($a = 30^0$, $x =$ radius of hole, $y = 0$)
Fig. 7.3.2a. Variation of $\sigma_t$ with respect to Skew angle for thermal loading (tl)

Fig. 7.3.2b. Variation of $\sigma_t$ with respect to skew angle for pressure loading (pl) and combined loading (cl)
Fig. 7.3.3a. Variation of $\sigma_y$ with respect to Skew angle for thermal loading (tl)

Fig. 7.3.3b. Variation of $\sigma_y$ with respect to Skew angle for pressure loading (pl) and combined loading (cl)
Fig. 7.3.4a. Variation of $\tau_{xy}$ with respect to Skew angle for thermal loading ($tl$)

Fig. 7.3.4b. Variation of $\tau_{xy}$ with respect to Skew angle for pressure loading ($pl$) and combined loading ($cl$)
Fig. 7.3.5a. Variation of $\sigma_z$ with respect to Skew angle for thermal loading (tl)

Fig. 7.3.5b. Variation of $\sigma_z$ with respect to Skew angle for pressure loading (pl) and combined loading (cl)
Fig. 7.3.6a. Variation of $\tau_{yz}$ with respect to Skew angle for thermal loading (tl)

Fig. 7.3.6b. Variation of $\tau_{yz}$ with respect to Skew angle for pressure loading (pl) and combined loading (cl)
Fig. 7.3.7a. Variation of $\tau_{\alpha}$ with respect to Skew angle for thermal loading (tl)

Fig. 7.3.7b. Variation of $\tau_{\alpha}$ with respect to Skew angle for pressure loading (pl) and combined loading (cl)
Fig. 7.3.8a. Variation of 'w' with respect to Skew angle for thermal loading (tl)

Fig. 7.3.8b. Variation of 'w' with respect to Skew angle for pressure loading (pl) and combined loading (cl)
7.4 ANALYSIS OF LAMINATE WITH STACKING SEQUENCE 3

In this case also the skew angle of the plate varies from $0^\circ$ to $50^\circ$ similar to the first and second cases. But the fibers are arranged parallel to the diagonals of the plate as shown in Fig. 5.4.1. The fibers of the odd number of layers are taken parallel to the longer diagonal and in even number of layers the fibers are parallel to the shorter diagonal of the laminate. The sequence is taken as $(45^\circ - \alpha/2) / (135^\circ - \alpha/2) / (45^\circ - \alpha/2) / (135^\circ - \alpha/2) / (45^\circ - \alpha/2)$.

Non-linear variation of the temperature across the thickness of the laminate is shown in Fig. 7.4.1. In the first, third and fifth layers the non-linearity in the variation of temperature is less when compared to the variation of temperature in the second and fourth layers indicating that the non-linearity is more in the thicker layers of the laminate.

The in-plane normal stress, $\sigma_{xx}$ (Figs. 7.4.2a, 7.4.2b) decreases with the increase in the skew angle up to $\alpha = 10^\circ$ and then increases for $d/l = 0.1$ and 0.2 due to thermal loading (tl). For $d/l = 0.3$ this stress increases with increase in $\alpha$. For $d/l = 0.4$ this stress increases up to $\alpha = 40^\circ$ and then decreases with the increase in skew angle. In case of pressure loading (pl) this stress increases up to $\alpha = 20^\circ$ and then decreases with the increase in skew angle for $d/l = 0.1$ and 0.2. For $d/l = 0.3$ and 0.4 this stress increases up to $\alpha = 10^\circ$ and then decreases with the increase in skew angle. In case of combined loading (cl) this stress increases up to $\alpha = 40^\circ$ and then decreases for
d/l = 0.1. For the remaining d/l values this stress increases up to \( \alpha = 30^\circ \) and then decreases.

The in-plane normal stress, \( \sigma_y \) (Figs. 7.4.3a, 7.4.3b) in case of thermal loading increases with increase in skew angle up to \( \alpha = 40^\circ \) and then decreases for d/l = 0.1. For d/l = 0.2 and 0.3 this stress increases up to \( \alpha = 30^\circ \), then decreases. For d/l = 0.4 this stress decreases up to \( \alpha = 10^\circ \) remains almost constant up to 20\(^\circ\) of \( \alpha \) and then decreases. In case of pressure loading \( \sigma_y \) increases with increase in skew angle up to \( \alpha = 30^\circ \) and then decreases for d/l = 0.1. For d/l = 0.2, this stress decreases up to \( \alpha = 10^\circ \), then increases up to \( \alpha = 20^\circ \) and again decreases. For d/l = 0.3 and 0.4, this stress decreases up to \( \alpha = 10^\circ \), then increases up to \( \alpha = 30^\circ \) and again decreases. In case of combined loading this stress increases with increase in \( \alpha \) up to 30\(^\circ\) and then decreases for d/l = 0.1 and 0.2. For d/l = 0.3 and 0.4 this stress increases up to \( \alpha = 20^\circ \) and then decreases.

The in-plane shear stress, \( \tau_{xy} \) (Figs. 7.4.4a, 7.4.4b) increases with increase in skew angle \( \alpha \) up to 10\(^\circ\) and then decreases for all d/l ratios for thermal loading. In case of pressure and combined loading this stress decreases with increase in \( \alpha \) for all d/l ratios.

The Interlaminar normal stress, \( \sigma_z \) (Figs. 7.4.5a, 7.4.5b) at the free edge of the hole decreases with the increase in the skew angle for all
d/l ratios for thermal and combined loading. In case of pressure loading there is no significant variation in this stress with respect to $\alpha$.

The Interlaminar shear stress, $t_{yz}$ (Figs. 7.4.6a, 7.4.6b) increases with the increase in skew angle $\alpha$ up to $30^\circ$ and then decreases for $d/l = 0.1$ and $0.2$ for thermal loading. For $d/l = 0.3$ this stress increases up to $\alpha = 20^\circ$ and then decreases. For $d/l = 0.4$ this stress increases up to $\alpha = 10^\circ$ and then decreases. In case of pressure loading there is no significant variation in this stress with respect to $\alpha$. In case of combined loading this stress increases with the increase in skew angle for $d/l = 0.1$. for $d/l = 0.2$ this stress increases up to $40^\circ$ of $\alpha$ and then decreases. For $d/l = 0.3$ this stress increases with increase in $\alpha$ up to $30^\circ$ and then decreases. For $d/l = 0.4$ this stress decreases with increase in skew angle.

The Interlaminar shear stress, $t_{zx}$ (Figs. 7.4.7a, 7.4.7b) decreases with the increase in skew angle for thermal and combined loading for all $d/l$ values. In case of pressure loading there is no significant variation in this stress with respect to $\alpha$.

In case of thermal loading there is no significant variation in the transverse deflection ‘$w$’ (Figs. 7.4.8a, 7.4.8b) with respect to $\alpha$. ‘$w$’ decreases with the increase in skew angle for pressure and combined loading for all $d/l$ ratios.
The reasons for the variation of the stresses and deflection given in chapter 5 are also valid for the results discussed here.

Fig. 7.4.1. Variation of temperature across thickness on the surface of the hole ($\alpha = 30^\circ$, $x =$ radius of hole, $y = 0$)
Fig. 7.4.2a. Variation of $\sigma_x$ with respect to skew angle for thermal loading (tl)

Fig. 7.4.2b. Variation of $\sigma_x$ with respect to skew angle for pressure loading (pl) and combined loading (cl)
Fig. 7.4.3a. Variation of $\sigma_y$ with respect to skew angle for thermal loading (tl)

Fig. 7.4.3b. Variation of $\sigma_y$ with respect to skew angle for pressure loading (pl) and combined loading (cl)
Fig. 7.4.4a. Variation of $\tau_{xy}$ with respect to skew angle for thermal loading (tl)

Fig. 7.4.4b. Variation of $\tau_{xy}$ with respect to skew angle for pressure loading (pl) and combined loading (cl)
Fig. 7.4.5a. Variation of $\alpha_x$ with respect to skew angle for thermal loading ($l_t$)

Fig. 7.4.5b. Variation of $\alpha_x$ with respect to skew angle for pressure loading ($p_l$) and combined loading ($c_l$)
Fig. 7.4.6a. Variation of $\tau_{xy}$ with respect to skew angle for thermal loading (tl)

Fig. 7.4.6b. Variation of $\tau_{xy}$ with respect to skew angle for pressure loading (pl) and combined loading (cl)
Fig. 7.4.7a. Variation of $\tau_{\text{ext}}$ with respect to skew angle for thermal loading (tl)

Fig. 7.4.7b. Variation of $\tau_{\text{ext}}$ with respect to skew angle for pressure loading (pl) and combined loading (cl)
Fig. 7.4.8a. Variation of $w'$ with respect to skew angle for thermal loading (tl)

Fig. 7.4.8b. Variation of $w'$ with respect to skew angle for pressure loading (pl) and combined loading (cl)
7.5 ANALYSIS OF LAMINATE WITH STACKING SEQUENCE 4

As in the first set of this part, in this case also fibers in the adjacent layers are perpendicular to each other. But the orientation of the fibers with respect to the horizontal sides of the skew laminate is varied from $0^\circ$ to $90^\circ$. Fig. 5.5.1 shows the laminate stacking sequence 4 which is considered as $\theta/90+\theta/90+\theta/\theta$ where $\theta$ is the angle of the fiber in the lower layer with respect to the horizontal sides of the laminate. The skew angle $\alpha$ is taken as $30^\circ$ for this set of results.

Non-linear variation of the temperature across the thickness of the laminate is shown in Fig. 7.5.1. In the first, third and fifth layers the non-linearity in the variation of temperature is less when compared to the variation of temperature in the second and fourth layers indicating that the non-linearity is more in the thicker layers of the laminate.

The In-plane normal stress, $\sigma_x$ (Figs. 7.5.2a, 7.5.2b) decreases with increase in the fiber angle up to $\theta = 45^\circ$ and then increases for thermal loading and combined loading for all the d/l ratios. In case of pressure loading this stress decreases with increases in fiber angle up to $\theta = 45^\circ$ and then increases up to $\theta = 75^\circ$ and again decreases, for all the d/l ratios. In addition to the effect of thermal load as explained in the fifth chapter, in this phase of the results, the pressure load is also influencing the net stresses in the laminate. The reasons for the variation of the stresses with respect to the skew angle have already
been discussed in the fifth chapter. The two varying factors, flexibility and stiffness of the plate are also influenced by the variation of fiber angle. The reason for the minimum stresses at 45° of θ may be due to the domination of stiffness factor.

The in-plane normal stress, $\sigma_y$ (Figs. 7.5.3a, 7.5.3b) decreases with increase in the fiber angle up to $\theta = 45^\circ$ and then increases for all d/l ratios and for all load cases except for d/l = 0.4 for thermal loading where it decreases up to $30^\circ$ and later increases. The reason given for the variation of $\sigma_x$ is valid for $\sigma_y$ also.

The in-plane shear stress, $\tau_{xy}$ (Figs. 7.5.4a, 7.5.4b) increases with increase in fiber angle up to $\theta = 45^\circ$ and then decreases with the increase in fiber angle for all the load cases and for all d/l ratios. In general the in-plane maximum shear stress occurs at an angle of 45° to the direction of maximum in-plane normal stresses.

The interlaminar normal stress, $\sigma_z$ (Figs. 7.5.5a, 7.5.5b) at the free edge of the hole decreases with the increase in the fiber angle θ up to $\theta = 30^\circ$ and then increases with increase in fiber angle for all the d/l ratios for thermal loading and combined loading. In case of pressure loading there is no significant variation in this stress with respect to θ.
The interlaminar shear stress, $\tau_{yz}$ (Figs. 7.5.6a, 7.5.6b) at the free edge of the hole increases up to $\theta = 30^0$ and then decreases for $d/l = 0.1$ and $d/l = 0.2$ in case of thermal loading. For $d/l = 0.3$ and $0.4$ this stress increases up to $\theta = 45^0$ and then decreases. In case of pressure loading there is no significant variation in this stress with respect to $\theta$. This stress increases with the increase in the fiber angle up to $\theta = 30^0$ and then decreases for all the $d/l$ ratios for combined loading.

The interlaminar shear stress, $\tau_{xz}$ (Figs. 7.5.7a, 7.5.7b) increases with the increase in the fiber angle up to $\theta = 60^0$ and then decreases for all the $d/l$ ratios for thermal and combined loading. In case of pressure loading there is no significant variation in this stress with respect to $\theta$.

As there is no significant effect of pressure load on the interlaminar stresses, the reasons given in chapter 5 are also valid for the variation of these stresses.

There is no significant variation in the transverse deflection, ‘$w$’ (Figs. 7.5.8a, 7.5.8b) with the variation in the fiber angle for thermal loading. In case of pressure loading and combined loading the transverse deflection ‘$w$’ increases up to $\theta = 30^0$ and then decreases.
for all the d/l ratio's. The reasons explained in the fifth chapter are valid in these cases also.

Fig. 7.5.1 Variation of temperature across thickness on the surface of the hole ($\theta = 30^\circ$, $x =$ radius of hole, $y = 0$)
Fig. 7.5.2a. Variation of $\alpha_x$ with respect to Fiber angle for thermal loading (tl)

Fig. 7.5.2b. Variation of $\alpha_x$ with respect to Fiber angle for pressure loading (pl) and combined loading (cl)
Fig. 7.5.3a. Variation of $\sigma_y$ with respect to Fiber angle for thermal loading (tl)

Fig. 7.5.3b. Variation of $\sigma_y$ with respect to Fiber angle for pressure loading (pl) and combined loading (cl)
Fig. 7.5.4a. Variation of $\tau_{xy}$ with respect to Fiber angle for thermal loading (tl)

Fig. 7.5.4b. Variation of $\tau_{xy}$ with respect to Fiber angle for pressure loading (pl) and combined loading (cl)
Fig. 7.5.5a. Variation of $\sigma_z$ with respect to Fiber angle for thermal loading (tl)

Fig. 7.5.5b. Variation of $\sigma_z$ with respect to Fiber angle for pressure loading (pl) and combined loading (cl)
Fig. 7.5.6a. Variation of $\tau_{yz}$ with respect to Fiber angle for thermal loading (tl)

Fig. 7.5.6b. Variation of $\tau_{yz}$ with respect to Fiber angle for pressure loading (pl) and combined loading (cl)
Fig. 7.5.7a. Variation of $\tau_{\text{ex}}$ with respect to Fiber angle for thermal loading (tl)

Fig. 7.5.7b. Variation of $\tau_{\text{ex}}$ with respect to Fiber angle for pressure loading (pl) and combined loading (cl)
Fig. 7.5.8a. Variation of ‘w’ with respect to Fiber angle for thermal loading (tl)

Fig. 7.5.8b. Variation of ‘w’ with Fiber angle for pressure loading (pl) and combined loading (cl)
7.6 STRESS CONTOURS

Figures 7.6.1 to 7.6.3 show the variation of the in-plane stresses in a five layered skew laminated composite plate with a circular cutout at the centre where the fibers are arranged parallel to the diagonals (Stacking sequence \(3 (45^0 - \alpha/2) / (135^0 - \alpha/2) / (45^0 - \alpha/2) / (135^0 - \alpha/2) / (45^0 - \alpha/2)\)) and subjected to uniform transverse pressure and non-linear variation of temperature across the thickness of the plate \((s = 10, \alpha = 50^0, d/l = 0.4)\).

7.6.1 Variation of \(\sigma_x\) (Fig. 7.6.1)

- The distribution of the normal stress \(\sigma_x\) in the skew plate is shown in Fig. 7.6.1a. It can be observed that the maximum stress is occurred at the circumference of the circular hole.
- The variation of \(\sigma_x\) around the hole boundary is shown in Fig. 7.6.1b. Maximum value of \(\sigma_x\) is observed near the \(y\)-axis location.
- Through thickness variation of \(\sigma_x\) can be observed in Fig. 7.6.1c. The maximum stress occurs at the outer surface of the top layer.

7.6.2 Variation of \(\sigma_y\) (Fig. 7.6.2)

- The maximum stress \(\sigma_y\) also occurs at the circumference of the cutout. (Fig. 7.6.2a).
- The maximum value of \(\sigma_y\) can be observed near the \(x\)-axis location. (Fig. 7.6.2b).
The variation of $\sigma_y$ across the thickness is shown in Fig. 7.6.2c. The maximum value of $\sigma_y$ occurs at the interface of the fourth and fifth layers where the layer numbering is measured from bottom to top of the laminate.

### 7.6.3 Variation of $\tau_{xy}$ (Fig. 7.6.3)

- The distribution of the shear stress, $\tau_{xy}$ in the skew plate is shown in Fig. 7.6.3a. It can be observed that the maximum stress is occurred at the circumference of the circular hole.

- The variation of $\tau_{xy}$ around the hole boundary is shown in Fig. 7.6.3b. Maximum value of $\tau_{xy}$ is observed near the $y$-axis location.

- Through thickness variation of $\tau_{xy}$ can be observed in Fig. 7.6.3c. The maximum stress occurs at the outer surface of the top layer.
Fig. 7.6.1a. Variation of $\sigma_x$ (MPa) in skew laminated plate due to combined loading ($s = 10$, $\alpha = 50^0$, $d/l = 0.4$)

Fig. 7.6.1b. Variation of $\sigma_x$ (MPa) around the hole in skew laminated plate due to combined loading ($s = 10$, $\alpha = 50^0$, $d/l = 0.4$)
Fig. 7.6.1c. Variation of $\sigma_z$ (MPa) across the thickness in skew laminated plate due to combined loading ($s = 10$, $\alpha = 50^0$, $d/l = 0.4$)

Fig. 7.6.2a. Variation of $\sigma_y$ (MPa) in skew laminated plate due to combined loading ($s = 10$, $\alpha = 50^0$, $d/l = 0.4$)
Fig. 7.6.2b. Variation of $\sigma_y$ (MPa) around the hole in skew laminated plate due to combined loading ($s = 10$, $\alpha = 50^0$, $d/l = 0.4$)

Fig. 7.6.2c. Variation of $\sigma_y$ (MPa) across the thickness in skew laminated plate due to combined loading ($s = 10$, $\alpha = 50^0$, $d/l = 0.4$)
Fig. 7.6.3a. Variation of $\tau_{xy}$ (MPa) in skew laminated plate due to combined loading ($s = 10$, $a = 50^0$, $d/l = 0.4$)

Fig. 7.6.3b. Variation of $\tau_{xy}$ (MPa) around the hole in skew laminated plate due to combined loading ($s = 10$, $a = 50^0$, $d/l = 0.4$)
Fig. 7.6.3c. Variation of $\tau_{xy}$ (MPa) across the thickness in skew laminated plate due to combined loading ($s = 10$, $\alpha = 50^\circ$, $d/l = 0.4$)
7.7 CONCLUSIONS

In the third phase of the results the pressure load is taken as uniform and the thermal load is taken as non-linearly varying temperature. The results obtained by varying the skew angle are presented in the sections 7.2, 7.3 and 7.4. The following observations are made from these sections.

- The in-plane stresses due to combined temperature and pressure loads are observed to be minimum for higher values of skew angle and d/l ratios except for the case where fibers are parallel to the sides of the skew plate, in which \( t_{xy} \) is minimum at \( \alpha = 0 \).

- The interlaminar stresses due to combined load at the free edge of the hole \( \sigma_z \) and \( t_{yz} \) are observed to be less for smaller d/l ratio and their variation is negligible with respect to \( \alpha \).

- The interlaminar stress due to combined load, \( t_{xx} \) is also minimum for lower d/l values and its variation is negligible with respect to \( \alpha \) for the laminate with stacking sequence 1. In case where the fibers are parallel to sides this stress increases with \( \alpha \). When the fibers are parallel to the diagonals this stress decreases with increase in \( \alpha \).

- The transverse deflection due to combined loading is minimum for higher values of skew angle and d/l ratio for all the cases.

- The magnitude of deflection where it is minimum with respect to skew angle and d/l ratio is almost same for the skew plates with
the Stacking sequence 1 and 3 indicating that these two plates are equally good in the stiffness point of view.

- The skew plate with fibers parallel to the diagonals and $\alpha = 50^\circ$, $d/l = 0.4$ is observed to be good in the in-plane normal and shear strength point of view. Though its $\sigma_y$ value is slightly higher than its value for the skew plate with fibers parallel to sides and $\tau_{xy}$ higher than its value for skew plate with stacking sequence 1, the major stress $\sigma_x$ is far less when compared to these two cases.

- The skew plate with fibers parallel to diagonals and $\alpha = 50^\circ$, $d/l = 0.1$ is observed to be good in the interlaminar strength point of view.

- In the first three sets of results of this phase, the skew plate with the fibers in the alternate layers parallel to one of the diagonals (Stacking sequence 3) is observed to be good in overall strength point of view. However the selection of $d/l$ depends up on the design requirement. If the design is based on in-plane strength, the $d/l$ value should be more. The lesser value of $d/l$ may be preferred when the laminates are designed for interlaminar strength.

The results obtained by varying the fiber angle are presented in the section 7.5. As it is observed that at higher skew angle ($\approx 50^\circ$), the higher value of $d/l$ ($=0.4$) gives smaller stresses in the first three configurations, for the fourth configuration also the variation of
stresses for d/l equal to 0.4 are compared. The following observations are made from this section.

- For the configuration 4, in case of combined loading, the values of $\sigma_x$ and $\sigma_y$ are minimum when the fiber angle $\theta = 45^0$ (Figs. 7.5.2b and 7.5.2b).

- When the skew plates with configurations 3 and 4 are compared, it is observed that the skew plate with stacking sequence 3 is good in overall strength and stiffness point of view.

For further investigation of the problem, the results of the skew plate with configuration 4 may be obtained for other skew angles and compared with the present results.