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A Comparison between Isotropic and Transversely Isotropic Thermoelastic Solids with Two Temperature and without Energy Dissipation in Frequency Domain Due to Concentrated Force

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Abstract

In the present investigation, a mathematical model of transversely isotropic thermoelastic solids without energy dissipation and with two temperatures has been considered. Fourier transform technique is used to obtain the solution. As an application , a time harmonic concentrated load is taken to show the utility of the solution obtained. The transformed components of displacements, stresses and conductive temperature distribution so obtained are inverted numerically using a numerical inversion technique. A comparison of isotropic and transversely isotropic model has been presented while depicting the effect of frequency.

Keywords: Transversely isotropic thermoelastic, , Fourier transform, concentrated force, two temperature.

1. INTRODUCTION

Thermoelasticity covers a broad field of developments. It consists of the theory of heat transfer and the theory of strains and stresses due to heat flow, when coupling of temperature and strain fields occur.

Green and Naghdi [6] and [7] postulated a new concept in generalized thermoelasticity and proposed three models which are subsequently referred to as GN-I, II, and III models. The linearized version of model-I corresponds to classical Thermoelastic model. In model -II, the internal rate of production entropy is taken to be identically zero implying no dissipation of thermal energy . Model-III includes the previous two models as special cases and admits dissipation of energy in general. In context of Green and Naghdi model many applications have been found. Chandrasekharaiah and Srinath [1] discussed the thermoelastic waves without energy dissipation in an unbounded body with a spherical cavity.

Youssef [18] constructed a new theory of generalized thermoelasticity by taking into account two-temperature generalized thermoelasticity theory for a homogeneous and isotropic body without energy dissipation. Youssef [22] also obtained variational principle of two temperature thermoelasticity without energy dissipation. Chen and Gurtin [2], Chen et al. [3] and [4] have formulated a theory of heat conduction in deformable bodies which depends upon two distinct temperatures, the conductive temperature φ and the thermo dynamical temperature T. For time independent situations, the difference between these two temperatures is proportional to the heat supply, and in absence of heat supply, the two temperatures are identical. For time dependent problems, the two temperatures are different, regardless of the presence of heat supply.

Two temperature problems have been discussed by many as (Warren and Chen [17], Quintanilla [16], Youssef AI-Lehaibi [19] and Youssef AI -Harby [20], Kumar and Deswal [8] ,Kaushal, Kumar and Miglani [9] ,Sharma and Kumar [12], Sharma, Kumar and Ram[13], Kumar and Kansal [10] ,Singh and Bala [14], Kumar, Sharma and Garg [11])

The purpose of the present paper is to determine the expression for components of displacement, normal stress, tangential stress and conductive temperature, when the time -harmonic mechanical or thermal concentrated source is applied, by applying Integral transform techniques. The present model is useful for understanding the behaviour of deformation in isotropic and transversely isotropic thermoelastic solids.

2. BASIC EQUATIONS

Following H.M. Youssef [21] the constitutive relations and field equations are:

$$t_{ij} = C_{ijkl}e_{kl} - \beta_{ij}T \tag{1}$$

$$C_{ijkl}e_{kl,j} - \beta_{ij}T_{,j} + \rho F_i = \rho \ddot{u}_i \tag{2}$$

$$K_{ij}\varphi_{,ij} = \beta_{ij}T_0\ddot{e}_{ij} + \rho C_E\ddot{T} \tag{3}$$

Where

$$T = \varphi - a_{ij}\varphi_{,ij} \tag{4}$$

$$\beta_{ij} = C_{ijkl}\alpha_{ij} \tag{5}$$

$$e_{ij} = u_{i,j} + u_{j,i} \quad i,j = 1,2,3 \tag{6}$$

Here
$C_{ijkl}(C_{ijkl} = C_{klij} = C_{jikl} = C_{ijlk})$ are elastic parameters, β_{ij} is the thermal tensor, T is the temperature, T_0 is the reference temperature, t_{ij} are the components of stress tensor, e_{kl} are the components of strain tensor, u_i are the displacement components, ρ is the density, C_E is the specific heat, K_{ij} is the thermal conductivity, a_{ij} are the two temperature parameters, α_{ij} is the coefficient of linear thermal expansion.

applying the transformation

$$x_1' = x_1 cos\theta + x_2 sin\theta, x_2' = -x_1 sin\theta + x_2 cos\theta, x_3' = x_3 \tag{7}$$

where θ is the angle of rotation in $x_1 - x_2$ plane

The basic equations reduce to

$$c_{11}u_{1,11} + c_{12}u_{2,21} + c_{13}u_{3,31} + c_{66}(u_{1,22} + u_{2,12}) + c_{44}(u_{1,33} + u_{3,13}) - \beta_1 \frac{\partial}{\partial x_1}\{\varphi - (a_1\varphi_{,11} + a_2\varphi_{,22} + a_3\varphi_{,33})\} + \rho F_1 = \rho\ddot{u}_1 \tag{8}$$

$$c_{11}(u_{1,12} + u_{2,22}) + c_{66}u_{2,11} + c_{44}u_{2,23} + (c_{13} + c_{44})u_{3,32} - \beta_2 \frac{\partial}{\partial x_2}\{\varphi - (a_1\varphi_{,11} + a_2\varphi_{,22} + a_3\varphi_{,33})\} + \rho F_2 = \rho\ddot{u}_2 \tag{9}$$

$$(c_{13} + c_{44})(u_{1,13} + u_{2,23}) + c_{44}(u_{3,11} + u_{3,22}) + c_{33}u_{3,33} - \beta_3 \frac{\partial}{\partial x_3}\{\varphi - (a_1\varphi_{,11} + a_2\varphi_{,22} + a_3\varphi_{,33})\} + \rho F_3 = \rho\ddot{u}_3 \tag{10}$$

$$k_1\varphi_{,11} + k_2\varphi_{,22} + k_3\varphi_{,33} = T_0(\beta_1\ddot{e}_{11} + \beta_2\ddot{e}_{22} + \beta_3\ddot{e}_{33}) + \rho C_E\{\ddot{\varphi} - (a_1\ddot{\varphi}_{,11} + a_2\ddot{\varphi}_{,22}a_3\ddot{\varphi}_{,33})\} \tag{11}$$

In the above equations we use the contracting subscript notations $(1 \to 11, 2 \to 22, 3 \to 33, 5 \to 23, 4 \to 13, 6 \to 12)$ to relate c_{ijkl} *to* c_{mn}

3. FORMULATION AND SOLUTION OF THE PROBLEM:

We consider a homogeneous, transversely isotropic thermoelastic solid half-space with two temperatures. A rectangular Cartesian co-ordinate $system \quad (x_1, x_2, x_3)$ which has its origin on the surface $x_3 = 0$ with x_3 axis pointing vertically downwards into the medium is introduced. we restrict our analysis in two dimensions subject to plane parallel to $x_1 - x_3$ plane. The displacement vector for two dimensional problems is taken as

$$\boldsymbol{u} = (u_1, 0, u_3) \tag{12}$$

$$(x_1, x_3, 0) = 0 = \dot{\varphi}(x_1, x_3, 0) \qquad \text{For } x_3 \geq 0, \quad -\infty < x_1 < \infty \tag{13}$$

$$u_1(x_1, x_3, t) = u_3(x_1, x_3, t) = \varphi(x_1, x_3, t) = 0 \; for \; t > 0 \; when \; x_3 \to \infty \tag{14}$$

Assuming the harmonic behaviour as

$$(u_1, u_3, \varphi)(x_1, x_3, t) = (u_1, u_3, \varphi)(\, x_1, x_3)e^{i\omega t} \tag{15}$$

where ω is the angular frequency.

To facilitate the solution , following dimensionless quantities are introduced:

$$x_1^{'} = \frac{x_1}{L}, \; x_3^{'} = \frac{x_3}{L}, \; u_1^{'} = \frac{\rho c_1^2}{L\beta_1 T_0}u_1, \; u_3^{'} = \frac{\rho c_1^2}{L\beta_1 T_0}u_3, \; T^{'} = \frac{T}{T_0}, t^{'} = \frac{c_1}{L}t \;, t_{33}^{'} = \frac{t_{33}}{\beta_1 T_0},$$

$$t_{31}^{'} = \frac{t_{31}}{\beta_1 T_0}, \varphi^{'} = \frac{\varphi}{T_0}, a_1^{'} = \frac{a_1}{L}, \quad a_3^{'} = \frac{a_3}{L}, \quad F_1^{'} = \frac{F_1}{\beta_1 T_0}, \quad F_2^{'} = \frac{F_2}{T_0} \tag{16}$$

where $c_1^2 = \frac{c_{11}}{\rho}$ and L is a constant of dimension of length.

$$\delta_1 = \frac{c_{44}}{c_{11}}, \; \delta_2 = \frac{c_{13}+c_{44}}{c_{11}}, \delta_4 = \frac{c_{33}}{c_{11}}, p_5 = \frac{\beta_3}{\beta_1}, p_3 = \frac{k_3}{k_1}, \zeta_1 = \frac{T_0\beta_1^2}{k_1\rho}, \zeta_2 = \frac{T_0\beta_3\beta_1}{k_1\rho}, \; \zeta_3 = \frac{C_E c_{11}}{k_1}$$

Using the dimensionless quantities and suppressing the primes and applying Fourier transform defined by

$$\hat{f}(\xi, x_3, \omega) = \int_{-\infty}^{\infty} \bar{f}(x_1, x_3, \omega)e^{i\xi x_1}dx_1 \tag{17}$$

on the resulting equations and then eliminating $\hat{u}_1$, $\hat{u}_3$ and $\hat{\varphi}$ from the resulting expressions,we obtain

$$\left(P\frac{d^6}{dx_3^6} + Q\frac{d^4}{dx_3^4} + R\frac{d^2}{dx_3^2} + S\right)(\hat{u}_1, \hat{u}_3, \hat{\varphi}) = 0 \tag{18}$$

Where $P = \delta_1(-\delta_4\zeta_3 a_3\omega^2 - \delta_4 p_3 + \zeta_2 p_5 a_3\omega^2)$

$Q = (\zeta_3 a_3\omega^2 + p_3)\{(\xi^2+\omega^2)\delta_4 + \delta_1(b_1\xi^2-\omega^2) - \delta_2^2\xi^2\} + \delta_1\delta_4\{\xi^2 + \zeta_3\omega^2 + \xi^2\zeta_3\omega^2 a_1\} - \zeta_2\omega^2\{a_3 p_5(\xi^2-\omega^2) + \delta_1 p_5(a_1\xi^2+1)\} - \xi^2\omega^2\{-\delta_4 a_3(p_5\zeta_1 + \zeta_2 - \zeta_1)\}$

$R = (1+a_1\xi^2)\{(\xi^2+\omega^2)\zeta_2 p_5\omega^2 - \xi^2\omega^2(p_5\zeta_1\delta_2 + \zeta_2\delta_2 - \zeta_1\delta_4)\} + (\delta_1\xi^2 - \omega^2)\{(\xi^2-\omega^2)(-\omega^2\zeta_3 a_3 - p_3) - \delta_1(\xi^2 + \zeta_3\omega^2 + \zeta_3\omega^2 a_1\xi^2) + \xi^2 a_3\zeta_1\omega^2\} + (\xi^2 + \zeta_3\omega^2 + \zeta_3\omega^2\xi^2 a_1)\{-(\xi^2-\omega^2)\delta_4 + \delta_2^2\xi^2\}$

$S = (\delta_1\xi^2 - \omega^2)\{(\xi^2-\omega^2)(\xi^2 + \zeta_3\omega^2 + \zeta_3\omega^2 a_1\xi^2) - \xi^2(1+a_1\xi^2)\xi^2\zeta_1\omega^2\}$

The roots of the equation (18) are $\pm\lambda_i$ ($i = 1,2,3$). Making use of the radiation condition that $\hat{u}_1, \hat{u}_3, \hat{\varphi} \to 0$ as $x_3 \to \infty$ the solution of the equation (20) may be written as

$$\hat{u}_1 = A_1 e^{-\lambda_1 x_3} + A_2 e^{-\lambda_2 x_3} + A_3 e^{-\lambda_3 x_3} \tag{19}$$

$$\hat{u}_3 = d_1 A_1 e^{-\lambda_1 x_3} + d_2 A_2 e^{-\lambda_2 x_3} + d_3 A_3 e^{-\lambda_3 x_3} \tag{20}$$

$$\hat{\varphi} = l_1 A_1 e^{-\lambda_1 x_3} + l_2 A_2 e^{-\lambda_2 x_3} + l_3 A_3 e^{-\lambda_3 x_3} \tag{21}$$

where

$$d_i = \frac{-\lambda_i^3 P^* - \lambda_i Q^*}{\lambda_1^4 R^* + \lambda_1^2 S^* + T^*} \;, l_i = \frac{\lambda_i^2 P^{**} + Q^{**}}{\lambda_1^4 R^* + \lambda_1^2 S^* + T^*} \; i = 1,2,3$$

where $P^* = i\xi\{(\zeta_1 p_5 a_3\omega^2 - \delta_2(\zeta_3 a_3\omega^2 + p_3)\}$

$Q^* = \delta_2(\xi^2 + \zeta_3\omega^2 + \zeta_3\omega^2 a_1\xi^2) - p_5\zeta_1(1+a_1\xi^2)\omega^2$

$R^* = \zeta_2 p_5 a_3\omega^2 - \delta_4(\zeta_3 a_3\omega^2 + p_3)$

$S^* = (\xi^2 + \zeta_3\omega^2 + \zeta_3\omega^2 a_1\xi^2)\delta_4 + (\delta_1\xi^2 - \omega^2)(a_3\zeta_3\omega^2 + p_3) - \zeta_2 p_5\omega^2(1+a_1\xi^2)$

$T^* = -(\delta_1\xi^2 - \omega^2)(\xi^2 + \zeta_3\omega^2 + \zeta_3\omega^2 a_1\xi^2)$

$P^{**} = -(\zeta_2\delta_2 - \zeta_1\delta_4)\omega^2 i\xi$

$Q^{**} = -\zeta_1\omega^2(\delta_1\xi^2 - \omega^2)$

4. APPLICATIONS

On the half-space surface($x_3 = 0$) normal point force which is assumed to be time harmonic, is applied. We consider the boundary conditions, as follows

(1) $t_{33}(x_1, x_3, t) = -F_1\psi_1(x)e^{i\omega t}$

(2) $t_{31}(x_1, x_3, t) = 0$

(3) $\frac{\partial\, \varphi(x_1,x_3,t)}{\partial x_3} = 0$ at $x_3 = 0$ (22)

where F_1 is the magnitude of the force applied, $\psi_1(x)$ specify the source distribution function along x_1 axis.

4.1. Green's function

To synthesize the Green's function, i.e. the solution due to concentrated normal force on the half-space is obtained by setting

$$\psi_1(x) = \delta(x) \tag{23}$$

In equations (23) Applying the Fourier transform defined by (17) on the equation (23) gives

$$\hat{\psi}_1(\xi) = 1$$

Making use of (1), (4)-(6), (12),(15)and (16) in B.C. (22) and applying Fourier Transform defined by (17) and substitute the values of $\hat{u}_1$, $\widehat{u_3}$ *and* $\hat{\varphi}$ from (19)-(21) in the resulting equations ,we obtain the components of displacement, normal stress, tangential stress and conductive temperature as

$$\hat{u}_1 = \frac{F_1\hat{\psi}_1(\xi)}{\Delta}\left(-M_{11}e^{-\lambda_1 x_3} + M_{12}e^{-\lambda_2 x_3} - M_{13}e^{-\lambda_3 x_3}\right)e^{i\omega t} \tag{24}$$

$$\widehat{u_3} = \frac{F_1\hat{\psi}_1(\xi)}{\Delta}\left(-d_1M_{11}e^{-\lambda_1 x_3} + d_2M_{12}e^{-\lambda_2 x_3} - d_3M_{13}e^{-\lambda_3 x_3}\right)e^{i\omega t} \tag{25}$$

$$\hat{\hat{\varphi}} = \frac{F_1\hat{\psi}_1(\xi)}{\Delta}\left(-l_1M_{11}e^{-\lambda_1 x_3} + l_2M_{12}e^{-\lambda_2 x_3} - l_3M_{13}e^{-\lambda_3 x_3}\right)e^{i\omega t} \tag{26}$$

$$\widehat{t_{33}} = \frac{F_1\hat{\psi}_1(\xi)}{\Delta}\left(-h_1M_{11}e^{-\lambda_1 x_3} + h_2M_{12}e^{-\lambda_2 x_3} - h_3M_{13}e^{-\lambda_3 x_3}\right)e^{i\omega t} \tag{27}$$

$$\widehat{t_{31}} = \frac{F_1\hat{\psi}_1(\xi)}{\Delta}\left(-h'_1 M_{11}e^{-\lambda_1 x_3} + h'_2 M_{12}e^{-\lambda_2 x_3} - h'_3 M_{13}e^{-\lambda_3 x_3}\right)e^{i\omega t} \qquad (28)$$

where

$$M_{11} = \Delta_{22}\Delta_{33} - \Delta_{32}\Delta_{23}\ ,\ M_{12} = \Delta_{21}\Delta_{33} - \Delta_{23}\Delta_{31},\quad M_{13} = \Delta_{21}\Delta_{32} - \Delta_{22}\Delta_{31}$$

$$M_{21} = \Delta_{12}\Delta_{33} - \Delta_{13}\Delta_{22},\ M_{22} = \Delta_{11}\Delta_{33} - \Delta_{13}\Delta_{31},\quad M_{23} = \Delta_{11}\Delta_{32} - \Delta_{12}\Delta_{31}$$

$$\Delta_{1i} = \frac{c_{31}}{\rho c_1^2} i\xi - \frac{c_{33}}{\rho c_1^2} d_i\lambda_i - \frac{\beta_3}{\beta_1} l_i + \frac{\beta_3}{\beta_1 T_0} l_i\lambda_i{}^2 \quad i = 1,2,3$$

$$\Delta_{2i} = -\frac{c_{44}}{\rho c_1^2}\lambda_i + \frac{c_{44}}{\rho c_1^2} i\xi d_i \quad i = 1,2,3$$

$$\Delta_{3i} = l_i\,\lambda_i \ \ i = 1,2,3$$

$$\Delta = \Delta_{11}M_{11} - \Delta_{12}M_{12} + \Delta_{13}M_{13}$$

$$h_i = \frac{c_{31}}{\rho c_1^2} i\xi - \frac{c_{33}}{\rho c_1^2} d_i\lambda_i - \frac{\beta_3}{\beta_1} l_i + \frac{\beta_3}{\beta_1 T_0} l_i\lambda_i{}^2 \quad i = 1,2,3$$

$$h_i' = -\frac{c_{44}}{\rho c_1^2}\lambda_i + \frac{c_{44}}{\rho c_1^2} i\xi d_i \quad i = 1,2,3$$

7. INVERSION OF THE TRANSFORMATION

To obtain the solution of the problem in physical domain, we must invert the transforms in equations (24)-(28) . Here the displacement components , normal and tangential stresses and conductive temperature are functions of x_3 and the parameters of Fourier transforms ξ and hence are of the form $f\,(\xi,\ x_3\,)$. To obtain the function $f(x_1, x_3)$ in the physical domain, we first invert the Fourier transform using

$$f(x_1,x_3) = \frac{1}{2\pi}\int_{-\infty}^{\infty} e^{-i\xi x_1}\hat{f}(\xi,x_3)d\xi = \frac{1}{2\pi}\int_{-\infty}^{\infty}|\cos(\xi x_1)\,f_e - i\sin(\xi x_1)\mathrm{f_o}|\,d\xi$$

Where f_e *and* f_o are respectively the even and odd parts of $\hat{f}\ (\xi, x_3)$. The method for evaluating this integral is described in Press et al. [15] . It involves the use of Romberg's integration with adaptive step size. This also uses the results from successive refinements of the extended trapezoidal rule followed by extrapolation of the results to the limit when the step size tends to zero.

8. NUMERICAL RESULTS AND DISCUSSION

Copper material is chosen for the purpose of numerical calculation which is transversely isotropic

$c_{11} = 18.78 \times 10^{10}\ Kgm^{-1}s^{-2}$, $c_{12} = 8.76 \times 10^{10}\ Kgm^{-1}s^{-2}$, $c_{13} = 8.0 \times 10^{10}\ Kgm^{-1}s^{-2}$ $c_{33} = 17.2 \times 10^{10}\ Kgm^{-1}s^{-2}$, $c_{44} = 5.06 \times 10^{10}\ Kgm^{-1}s^{-2}$ $C_E = 0.6331 \times 10^{3} JKg^{-1}K^{-1}$ $\alpha_1 = 2.98 \times 10^{-5}K^{-1}$, $\alpha_3 = 2.4 \times 10^{-5}K^{-1}$, $a = 2.4 \times 10^{4}m^2s^{-2}$, $\rho = 8.954 \times 10^{3}Kgm^{-3}$, $K_1 = 0.433 \times 10^{3}Wm^{-1}K^{-1}$, $K_3 = 0.450 \times 10^{3}Wm^{-1}K^{-1}$

Following Dhaliwal and Singh [5] , magnesium crystal is chosen for the purpose of numerical calculation(isotropic solid). In case of magnesium crystal like material for numerical calculations, the physical constants used are

$\lambda = 2.17 \times 10^{10}Nm^2$, $\mu = 3.278 \times 10^{10}Nm^2$, $K = 1.7 \times 10^{2}Wm^{-1}deg^{-1}$

$\omega_1 = 3.58 \times 10^{11}S^{-1}$ $\beta = 2.68 \times 10^{6}\ Nm^{-2}deg^{-1}$, $\rho = 1.74 \times 10^{3}Kgm^{-3}$

$T_0 = 298$K, $C_E = 1.04 \times 10^{3}Jkg^{-1}deg^{-1}$

and two temperature parameter is taken as $a = 0.104$

The values of normal displacement u_3, normal force stress t_{33} , tangential stress t_{31} and conductive temperature φ for a transversely isotropic thermoelastic solid (TIT) and for isotropic thermoelastic solid (IT) are presented graphically for the non-dimensional frequencies ω=.25, ω=.5 and ω=.75

1). The solid line, long dashed line and small dashed line, respectively corresponds to isotropic solid with frequencies ω=.25, ω=.5 and ω=.75 respectively.

2). The solid line with centre symbol circle , the long dashed line with centre symbol diamond and the small dashed line with centre symbol triangle respectively correspond to transversely isotropic solid with frequencies ω=.25, ω=.5 and ω=.75 respectively.

Fig.1 shows the variations of the normal displacement u_3 , in case of TIT decreases sharply in $0 \leq x \leq 2$, smoothly decreases in $7 \leq x \leq 9$ and increases in the rest.Also for IT , u_3 decreases in $0 \leq x \leq 6$ and increases in $6 \leq x \leq 10$. In $0 \leq x \leq 6$ the values of u_3 for TIT are smaller than IT but trend is opposite in the remaining range.Fig.2 depicts the values of normal stress t_{33} . Here for TIT, t_{33} decreases in $0 \leq x \leq 3$, $7 \leq x \leq 8$ and increases in the remaining range whereas in case of IT , it increases in $0 \leq x \leq 3$, decreases in $7 \leq x \leq 10$. Whereas in remaining range neither increases nor decreases .The values of t_{33} for TIT are less than those of IT only in the range $2 \leq x \leq 7$. Fig.3 describes tangential stress t_{31} , for both the cases i.e. IT and TIT , the trend of curves are similar with difference in their magnitudes. For both mediums t_{31} decreases sharply in $0 \leq x \leq 2$ and oscillatory in the rest of the range. Fig.4 interprets the variations of conductive temperature φ .The values of φ are in descending oscillations for TIT in $2 \leq x \leq 10$ and increase sharply in $0 \leq x \leq 2$ whereas for IT, φ decreases in $0 \leq x \leq 1$ and $6 \leq x \leq 10$ and increases in the remaining range.

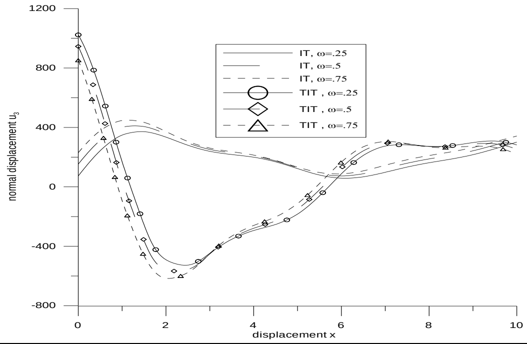

Fig.1. Variation of normal displacement u_3 with distance *x* (concentrated force)

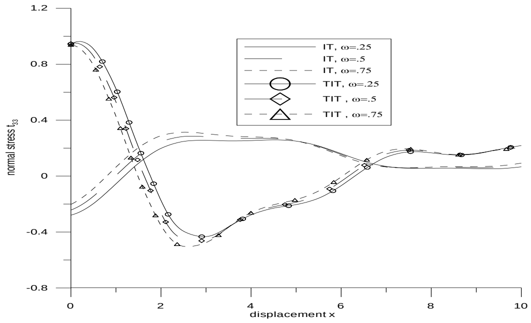

Fig.2. Variation of normal stress t_{33} with distance *x* (concentrated force)

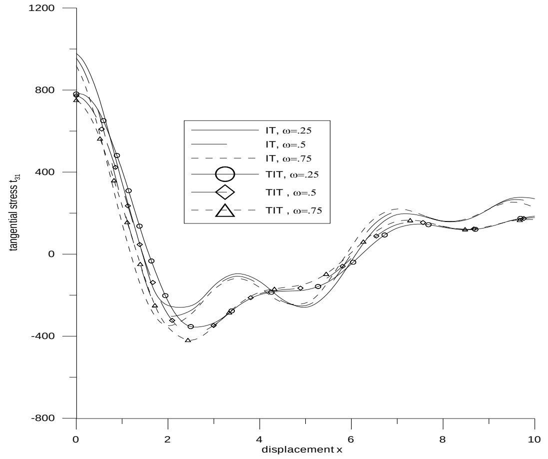

Fig.3. Variation of tangential stress t_{31} with distance x (concentrated force)

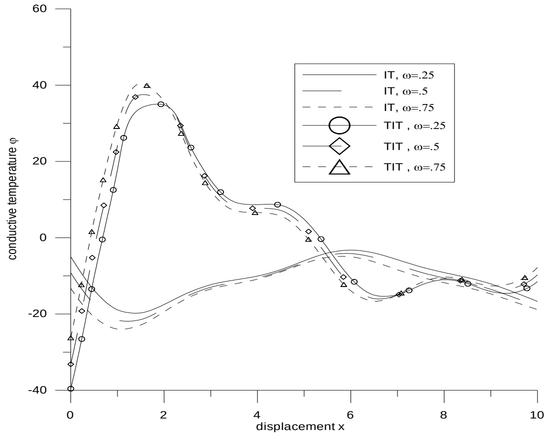

Fig.4. Variation of conductive temperature φ with distance x (concentrated force)

9. CONCLUSION

Effect of anisotropy plays important role in the deformation of the body. As disturbance travels through the constituents of the medium, it suffers sudden changes resulting in an inconsistent / non uniform pattern of graphs. Anisotropy has significant impact on components of normal displacement , normal stress, tangential stress and conductive temperature. It is observed from the figures that the trends in the variations of the characteristics mentioned are similar with difference in their magnitude when the mechanical forces are applied . The trend of curves exhibits the properties of the medium and satisfies requisite condition of the problem. It can also contribute to the theoretical considerations of the seismic and volcanic sources since it can account for deformation fields in the entire volume surrounding the source region.

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