The Modified Simple Equation Method and Its Application to Solve NLEEs Associated with Engineering Problem

Md. Ashrafuzzaman Khan and M. Ali Akbar

Department of Applied Mathematics, University of Rajshahi, Rajshahi-6205, Bangladesh

.

ABSTRACT

The modified simple equation (MSE) method is an important mathematical tool for searching closed-form solutions to nonlinear evolution equations (NLEEs). Earlier the method cannot be used to NLEEs for higher balance number. Very recently Khan and Akbar developed a technique to fulfill this shortcoming and solved NLEEs for balance number two by the MSE method. In the present paper, by using the MSE method, we derive some impressive solitary wave solutions to NLEES via the strain wave equation in microstructured solids which is a very important equation in the field of engineering. The solutions contain some free parameters and for particulars values of the parameters some known solutions are derived. The solutions exhibit necessity and reliability of the method.

Keywords: Modified simple equation method; balance number; solitary wave solutions; strain wave equation; microstructured solids.

Mathematics Subject Classification: 35C07, 35C08, 35P99.

1. INTRODUCTION

Physical systems are in general explained with nonlinear partial differential equations. The mathematical modeling of microstructured solid materials that change over time depends closely on the study of a variety of systems of ordinary and partial differential equations.

E-mail address: ali_math74@yahoo.com.

Similar models are developed in diverse fields of study, ranging from the natural and physical sciences, population ecology to economics, infectious disease epidemiology, neural networks, biology, mechanics etc. In spite of the eclectic nature of the fields wherein these models are formulated, different groups of them contribute adequate common attributes that make it possible to examine them within a unified theoretical structure. Such study is an area of functional analysis, usually called the theory of evolution equations. Therefore, the investigation of solutions to NLEEs plays a very important role to uncover the obscurity of many phenomena and processes throughout the natural sciences. However, one of the essential problems is to obtain theirs closed-form solutions. For that reason, diverse groups of engineers, physicists, and mathematicians have been working tirelessly to investigate closed-form solutions to NLEEs. Accordingly, in the recent years, they establish several methods to search exact solutions, for instance, the Darboux transformation method [1], the Jacobi elliptic function method [2, 3], the He's homotopy perturbation method [4, 5], the tanh-function method [6, 7], the extended tanh-function method [8, 9], the Lie group symmetry method [10], the variational iteration method [11], the Hirota's bilinear method [12], the Backlund transformation method [13, 14], the inverse scattering transformation method [15], the sine-cosine method [16, 17], the Painleve expansion method [18], the Adomian decomposition method [19, 20], the (G'/G)-expansion method [21-26], the first integration method [27], the F-expansion method [28], the auxiliary equation method [29], the ansatz method [30, 31], the Exp-function method [32, 33], the homogeneous balance method [34], the modified simple equation method [35-39], the $\exp(-\varphi(\eta))$-expansion method [40, 41], the Miura transformation method [42], and others.

Microstructured materials like crystallites, alloys, ceramics, and functionally graded materials have gained broad application. The modeling of wave propagation in such materials should be able to account for various scales of microstructure [43]. In the past years, many authors have studied the strain wave equation in microstructured solids, such as, Alam et al. [43] solved this equation by using the new generalized (G'/G)-expansion method. Pastrone et

E-mail address: ali_math74@yahoo.com.

al. [44], Porubov and Pastrone [45] examined bell-shaped and kink-shaped solutions of this engineering problem. Akbar et al. [46] constructed traveling wave solutions of this equation by using the generalized and improved (G'/G)-expansion method. The above analysis shows that several methods to achieve exact solutions to this equation have been accomplished in the recent years. But, the equation has not been studied by means of the MSE method. If the balance number is two then the method is not directly applicable. In the literature it is found that by using the MSE method only two equations are solved, such as, in Ref. [47], Salam solved the modified Liouville equation (wherein the balance number is two) and set down a solution to this equation. But his attained solution does not satisfy the equation. i.e. this is an incorrect solution. Also in Ref. [48], Zayed and Arnous used the MSE method to solve the KP-BBM equation and they found some solutions to this equation. But there is no guideline in that article, how one can solve other NLEEs for the higher balance number. Very recently, in Ref. [49], Khan and Akbar developed a procedure and remove the shortcoming of the MSE method to solve NLEEs for balance number two. In this article, our aim is, we will apply the MSE method following the technique derived in the Ref. [49] to examine some new and impressive solitary wave solutions to this equation.

The structure of this article is as follows: In section 2, we describe the method. In section 3, we apply the MSE method to the strain wave equation in microstructured solids. In section 4, we provide the physical interpretations of the obtained solutions. Finally, in section 5, conclusions are given.

2. DESCRIPTION OF THE METHOD

Assume the nonlinear evolution equation has the following form

$$P(u, u_t, u_x, u_y, u_z, u_{xx}, u_{tt}, \ldots) = 0, \quad (2.1)$$

where $u = u(x, y, z, t)$ is an unidentified function, P is a polynomial function in $u = u(x, y, z, t)$ and its partial derivatives, wherein nonlinear term of the highest order and the highest order

E-mail address: ali_math74@yahoo.com.

linear terms exist and subscripts indicate partial derivatives. To solve (2.1) by using the MSE method [35-39], we need to perform the subsequent steps:

Step 1: Now, we combine the real variable x and t by a compound variable ξ as follows:

$$u(x,y,z,t)=U(\xi), \qquad \xi = x+y+z \pm \omega\, t\,. \tag{2.2}$$

Here ξ is called the wave variable it allows us to switch Eq. (2.1) into an ordinary differential equation (ODE):

$$Q(U,U',U'',U''',\cdots), \tag{2.3}$$

where Q is a polynomial in $U(\xi)$ and its derivatives, where $U'(\xi)=\frac{dU}{d\xi}$.

Step 2: We assume that Eq. (2.3) has the traveling wave solution in the following form,

$$U(\xi)=\sum_{i=0}^{N} a_i \left(\frac{\psi'(\xi)}{\psi(\xi)}\right)^{i}, \tag{2.4}$$

where a_i, $(i=0,1,2,\cdots,N)$ are arbitrary constants, such that $a_N \neq 0$, and $\psi(\xi)$ is an unidentified function which is to be determined later. In (G'/G)-expansion method, Exp-function method, tanh-function method, sine-cosine method, Jacobi elliptic function method etc., the solutions are initiated through several auxiliary functions which are previously known, but in the MSE method, $\psi(\xi)$ is neither a pre-defined function nor a solution of any pre-defined differential equation. Therefore, it is not possible to speculate from formerly, what kind of solution can be found by this method.

Step 3: We determine the positive integer N, come out in Eq. (2.4) by taking into account the homogeneous balance between the highest order nonlinear terms and the derivatives of the highest order occurring in Eq. (2.3).

Step 4: We calculate the necessary derivatives U', U'', U''', etc., then insert them into Eq. (2.3) and then taken into consideration the function $\psi(\xi)$. As a result of this insertion, we obtain a polynomial in $(\psi'(\xi)/\psi(\xi))$. We equate all the coefficients of $(\psi(\xi))^{i}$,

E-mail address: ali_math74@yahoo.com.

$(i = 0,1,2,...,N)$ to this polynomial to zero. This procedure yields a system of algebraic and differential equations whichever can be solved for getting a_i $(i = 0,1,2,\cdots,N)$, $\psi(\xi)$ and the value of the other parameters.

3. APPLICATION OF THE METHOD

In this section, we will execute the application of the MSE method to extract solitary wave solutions to the strain wave equation in microstructured solids which is a very important equation in the field of engineering. Let us consider the strain wave equation in microstructured solids:

$$u_{tt} - u_{xx} - \varepsilon\,\alpha_1(u^2)_{xx} - \gamma\alpha_2 u_{xxt} + \delta\alpha_3 u_{xxxx} - (\delta\alpha_4 - \gamma^2\alpha_7)u_{xxtt} + \gamma\delta(\alpha_5 u_{xxxxt} + \alpha_6 u_{xxtt}) = 0. \quad (3.1)$$

3.1. THE NON-DISSIPATIVE CASE

The system is non-dissipative, if $\gamma = 0$ and determined by the double dispersive equation (see [44], [45], [50], [51] for details)

$$u_{tt} - u_{xx} - \varepsilon\,\alpha_1(u^2)_{xx} + \delta\alpha_3 u_{xxxx} - \delta\alpha_4 u_{xxtt} = 0. \quad (3.2)$$

The balance between dispersion and nonlinearities happen when $\delta = O(\varepsilon)$. Therefore, (3.2) becomes

$$u_{tt} - u_{xx} - \varepsilon\,\{\alpha_1(u^2)_{xx} - \alpha_3 u_{xxxx} + \alpha_4 u_{xxtt}\} = 0. \quad (3.3)$$

In order to extract solitary wave solutions of the strain wave equation in microstructured solids by using the MSE method, we use the traveling wave variable

$$u(x,t) = U(\xi), \quad \xi = x - \omega\, t. \quad (3.4)$$

The wave transformation (3.4) reduces Eq. (3.3) into the ODE in the following form:

$$(\omega^2 - 1)\,U'' - \varepsilon\{\alpha_1(\,U^2)'' - (\alpha_3 - \omega^2\alpha_4)\,U^{(iv)}\} = 0. \quad (3.5)$$

E-mail address: ali_math74@yahoo.com.

where primes indicate differential coefficients with respect to ξ. Eq. (3.5) is integrable, therefore, integration (3.5) as many time as possible, we obtain the following ODE:

$$(\omega^2-1)\,U-\varepsilon\{\alpha_1U^2-(\alpha_3-\omega^2\alpha_4)\,U''\}=0. \tag{3.6}$$

where the integration constants are set zero, as we are seeking solitary wave solutions. Taking homogeneous balance between the terms U'' and U^2 appearing in Eq. (3.6), we obtain $N=2$. Therefore, the shape of the solution of Eq. (3.6) becomes

$$U(\xi)=a_0+\frac{a_1\psi'}{\psi}+\frac{a_2(\psi')^2}{\psi^2}\,. \tag{3.7}$$

wherein a_0, a_1 and a_2 are constants to be find out afterward such that $a_2\neq 0$, and $\psi(\xi)$ is an unknown function. The derivatives of U are given in the following:

$$U'=-\frac{a_1(\psi')^2}{\psi^2}-\frac{2a_2(\psi')^3}{\psi^3}+\frac{a_1\psi''}{\psi}+\frac{2a_2\psi'\psi''}{\psi^2}. \tag{3.8}$$

$$U''=a_1\left\{\frac{2(\psi')^3}{\psi^3}-\frac{3\psi'\psi''}{\psi^2}+\frac{\psi'''}{\psi}\right\}+2a_2\left\{\frac{(\psi'')^2}{\psi^2}+\frac{\psi'\psi'''}{\psi^2}-\frac{5(\psi')^2\psi''}{\psi^3}+\frac{3(\psi')^4}{\psi^4}\right\}. \tag{3.9}$$

Inserting the values of U, U' and U'' into Eq. (3.6), and setting each coefficient of ψ^j, $j=0,1,2,\cdots$ to zero, we derive, successively

$$a_0(-1+\omega^2-\varepsilon\,a_0\alpha_1)=0. \tag{3.10}$$

$$a_1\{(-1+\omega^2-2\varepsilon a_0\alpha_1)\psi'+\varepsilon(\alpha_3-\omega^2\alpha_4)\psi'''\}=0. \tag{3.11}$$

$$-\varepsilon a_1\psi'\{a_1\alpha_1\psi'+3(\alpha_3-\omega^2\alpha_4)\psi''\}+2a_2\varepsilon(\alpha_3-\omega^2\alpha_4)\psi'\psi''' + a_2\{(-1+\omega^2-2\varepsilon a_0\alpha_1)(\psi')^2+2\varepsilon(\alpha_3-\omega^2\alpha_4)(\psi'')^2\}=0. \tag{3.12}$$

$$-2\varepsilon(\psi')^2\{a_1(a_2\alpha_1-\alpha_3+\omega^2\alpha_4)\psi'+5a_2(\alpha_3-\omega^2\alpha_4)\psi''\}=0. \tag{3.13}$$

$$-\varepsilon a_2(a_2\alpha_1-6\alpha_3+6\omega^2\alpha_4)(\psi')^4=0. \tag{3.14}$$

From Eq. (3.10) and Eq. (3.14), we obtain

$$a_0=0,\ \ \frac{-1+\omega^2}{\varepsilon\alpha_1}\ \text{ and }\ a_2=\frac{6(\alpha_3-\omega^2\alpha_4)}{\alpha_1},\quad \text{scince } a_2\neq 0.$$

Therefore, for the values of a_0, there arise the following cases:

E-mail address: ali_math74@yahoo.com.

Case 1: When $a_0 = 0$, from Eqs. (3.11)-(3.13), we obtain

$$a_1 = \pm \frac{6\sqrt{1-\omega^2}\sqrt{\alpha_3 - \omega^2\alpha_4}}{\sqrt{\varepsilon}\alpha_1}$$

and

$$\psi(\xi) = c_2 + \frac{\varepsilon c_1(-\alpha_3 + \omega^2\alpha_4)}{-1+\omega^2}\, e^{\mp \frac{\xi\sqrt{1-\omega^2}}{\sqrt{\varepsilon}\sqrt{\alpha_3-\omega^2\alpha_4}}},$$

where c_1 and c_2 are integration constants.

Substituting the values of a_0, a_1, a_2 and $\psi(\xi)$ into Eq. (3.7), we obtain the following exponential form solution:

$$U(\xi) = \frac{6e^{\pm \frac{\xi\sqrt{1-\omega^2}}{\sqrt{\varepsilon}\sqrt{\alpha_3-\omega^2\alpha_4}}}(-1+\omega^2)^2 c_1 c_2(-\alpha_3+\omega^2\alpha_4)}{\alpha_1\left((-1+\omega^2)c_2\, e^{\pm \frac{i\xi\sqrt{-1+\omega^2}}{\sqrt{\varepsilon}\sqrt{\alpha_3-\omega^2\alpha_4}}} + \varepsilon c_1(-\alpha_3+\omega^2\alpha_4)\right)^2}. \qquad (3.15)$$

Simplifying the required solution (3.15), we derive the following close-form solution of the strain wave equation in microstructured solids (3.3):

$$\begin{aligned} u(x,t) = {} & \{6(-1+\omega^2)^2 c_1 c_2(-\alpha_3+\omega^2\alpha_4)\} \\ & / \Big[\alpha_1 \Big\{\pm\, i \sin\big((x-t\omega)\beta\big)\{(-1+\omega^2)c_2 + \varepsilon c_1(\alpha_3 - \omega^2\alpha_4)\} \\ & + \cos\big((x-t\omega)\beta\big)\{(-1+\omega^2)c_2 + \varepsilon c_1(-\alpha_3+\omega^2\alpha_4)\}\Big\}^2\Big] \end{aligned} \qquad (3.16)$$

where $\beta \frac{\sqrt{-1+\omega^2}}{2\sqrt{\varepsilon}\sqrt{\alpha_3-\omega^2\alpha_4}}$. Solution (3.16) is the generalized solitary wave solution of the strain wave equation in microstructured solids. Since c_1 and c_2 are arbitrary constants, one might arbitrarily choose their values. Therefore, if we choose $c_1 = (-1+\omega^2)$ and $c_2 = \varepsilon(-\alpha_3 +$ $\omega 2\alpha 4$ then from (3.16), we obtain the following bell shaped soliton solution:

$$u_1(x,t) = \frac{3(-1+\omega^2)}{2\varepsilon\alpha_1}\,\mathrm{sech}^2\left(\frac{(x-t\omega)\sqrt{-1+\omega^2}}{2\sqrt{\varepsilon}\sqrt{-\alpha_3+\omega^2\alpha_4}}\right). \qquad (3.17)$$

E-mail address: ali_math74@yahoo.com.

Again, if we choose $c_1 = (-1+\omega^2)$ and $c_2 = -\varepsilon(-\alpha_3 + \omega^2\alpha_4)$, then from (3.16), we obtain the following singular soliton:

$$u_2(x,t) = -\frac{3(-1+\omega^2)}{2\varepsilon\alpha_1}\,\operatorname{csch}^2\left(\frac{(x-t\omega)\sqrt{-1+\omega^2}}{2\sqrt{\varepsilon}\sqrt{-\alpha_3+\omega^2\alpha_4}}\right). \qquad (3.18)$$

On the other hand, when $c_1 = (-1+\omega^2)$ and $c_2 = \pm i\,\varepsilon(-\alpha_3 + \omega^2\alpha_4)$, from solution (3.16), we obtain the following trigonometric solution:

$$u_3(x,t) = \frac{3(-1+\omega^2)}{2\varepsilon\alpha_1}\,\sec^2\left[\frac{1}{4}\left\{\pi + \frac{2(x-t\omega)\sqrt{-1+\omega^2}}{\sqrt{\varepsilon}\sqrt{\alpha_3-\omega^2\alpha_4}}\right\}\right]. \qquad (3.19)$$

Again when $c_1 = (-1+\omega^2)$ and $c_2 = \mp i\,\varepsilon(-\alpha_3 + \omega^2\alpha_4)$, then the generalized solitary wave solution (3.16) can be simplified as:

$$u_4(x,t) = \frac{3(-1+\omega^2)}{2\varepsilon\alpha_1}\,\csc^2\left[\frac{1}{4}\left\{\pi + \frac{2(-x+t\omega)\sqrt{-1+\omega^2}}{\sqrt{\varepsilon}\sqrt{\alpha_3-\omega^2\alpha_4}}\right\}\right]. \qquad (3.20)$$

If we choose more different values of c_1 and c_2, we may derive a lot of general solitary wave solutions to the Eq. (3.3) through the MSE method. For succinctness, other solutions have been overlooked.

Case 2: When $a_0 = \dfrac{-1+\omega^2}{\varepsilon\,\alpha_1}$, then Eqs. (3.11)-(3.13) yield

$$a_1 = \pm\frac{6\sqrt{-1+\omega^2}\sqrt{\alpha_3-\omega^2\alpha_4}}{\sqrt{\varepsilon}\alpha_1}$$

And

$$\psi(\xi) = c_2 + \frac{\varepsilon c_1(\alpha_3-\omega^2\alpha_4)}{-1+\omega^2}\, e^{\mp\frac{\xi\sqrt{-1+\omega^2}}{\sqrt{\varepsilon}\sqrt{\alpha_3-\omega^2\alpha_4}}},$$

where c_1 and c_2 are constants of integration.

Now, by means of the values of a_0, a_1, a_2 and $\psi(\xi)$, from Eq. (3.7), we obtain the subsequent solution:

E-mail address: ali_math74@yahoo.com.

$$U(\xi)=\frac{-1+\omega^2}{\varepsilon\alpha_1}+\frac{6(-1+\omega^2)^2c_1c_2(-\alpha_3+\omega^2\alpha_4)e^{\pm\frac{\xi\sqrt{-1+\omega^2}}{\sqrt{\varepsilon}\sqrt{\alpha_3-\omega^2\alpha_4}}}}{\alpha_1\left\{(-1+\omega^2)c_2e^{\pm\frac{\xi\sqrt{-1+\omega^2}}{\sqrt{\varepsilon}\sqrt{\alpha_3-\omega^2\alpha_4}}}+\varepsilon c_1(\alpha_3-\omega^2\alpha_4)\right\}^2}. \qquad (3.21)$$

Now, transforming the required exponential function solution (3.21) into hyperbolic function, we obtain the following solution to the strain wave equation in the microstructured solids:

$$\begin{aligned}u(x,t)=(-1+\omega^2)\big[&(-1+\omega^2)^2\{\cosh(2\rho(x-t\omega))+\sinh(2\rho(x-t\omega))\}c_2^2\\&+\varepsilon^2\{\cosh(2\rho(x-t\omega))-\sinh(2\rho(x-t\omega))\}c_1^2(\alpha_3-\omega^2\alpha_4)^2\\&+4\varepsilon(-1+\omega^2)c_1c_2(-\alpha_3+\omega^2\alpha_4)\big]\\&/\Big(\varepsilon\alpha_1\big[(-1+\omega^2)\{\cosh(\rho(x-t\omega))+\sinh(\rho(x-t\omega))\}c_2\\&+\varepsilon\{\cosh(\rho(x-t\omega))-\sinh(\rho(x-t\omega))\}c_1(\alpha_3-\omega^2\alpha_4)\big]^2\Big). \qquad (3.22)\end{aligned}$$

Thus, we acquire the generalized solitary wave solution (3.22) to the strain wave equation in microstructured solids, where $\rho=\frac{\sqrt{-1+\omega^2}}{2\sqrt{\varepsilon}\sqrt{\alpha_3-\omega^2\alpha_4}}$. Since c_1 and c_2 are integration constants, therefore, somebody might randomly pick their values. So, if we pick $c_1=(-1+\omega^2)$ and $c_2=-\varepsilon(\alpha_3-\omega^2\alpha_4)$, then from (3.22), we obtain the subsequent solitary wave solution:

$$u_5(x,t)=\frac{(-1+\omega^2)}{2\varepsilon\alpha_1}\left\{2+3\,\mathrm{csch}^2\left(\frac{(x-t\omega)\sqrt{-1+\omega^2}}{2\sqrt{\varepsilon}\sqrt{\alpha_3-\omega^2\alpha_4}}\right)\right\}. \qquad (3.23)$$

Again, if we pick $c_1=(-1+\omega^2)$ and $c_2=\varepsilon(\alpha_3-\omega^2\alpha_4)$, then the solitary wave solution (3.22) reduces to:

$$u_6(x,t)=-\frac{(-1+\omega^2)}{2\varepsilon\alpha_1}\left\{-2+3\,\mathrm{sech}^2\left(\frac{(x-t\omega)\sqrt{-1+\omega^2}}{2\sqrt{\varepsilon}\sqrt{\alpha_3-\omega^2\alpha_4}}\right)\right\}. \qquad (3.24)$$

Moreover, if we pick $c_1=(-1+\omega^2)$ and $c_2=\mp i\,\varepsilon(\alpha_3-\omega^2\alpha_4)$, then from (3.22), we derive the following solution:

$$u_7(x,t)=\frac{(-1+\omega^2)}{\varepsilon\alpha_1}\left\{1-\frac{3}{2}\csc^2\left(\frac{\pi}{4}-\frac{1}{2}\frac{(x-t\omega)\sqrt{-1+\omega^2}}{\sqrt{\varepsilon}\sqrt{-\alpha_3+\omega^2\alpha_4}}\right)\right\}. \qquad (3.25)$$

E-mail address: ali_math74@yahoo.com.

Again, if we pick $c_1 = (-1+\omega^2)$ and $c_2 = \pm i\,\varepsilon(\alpha_3 - \omega^2\alpha_4)$, then from (3.22), we obtain the following solution:

$$u_8(x,t) = \frac{(-1+\omega^2)}{\varepsilon\alpha_1}\left\{1 - \frac{3}{2}\csc^2\left(\frac{\pi}{4} + \frac{1}{2}\frac{(x-t\omega)\sqrt{-1+\omega^2}}{\sqrt{\varepsilon}\sqrt{-\alpha_3+\omega^2\alpha_4}}\right)\right\}. \qquad (3.26)$$

Forasmuch as, c_1 and c_2 are arbitrary constants, if we choose more different values of them, we may derive a lot of general solitary wave solutions to the Eq. (3.3) through the MSE method easily. But, we did not write down the other solutions for minimalism.

Remark 1: Solutions (3.17)-(3.20) and (3.23)-(3.26) have been confirmed by inserting them into the main equation and found accurate.

3.2. THE DISSIPATIVE CASE

If $\gamma \neq 0$, then the system is dissipative. Therefore, for $\delta = \gamma = O(\varepsilon)$, the balance should be between nonlinearity, dispersion and dissipation, perturbed by the higher order dissipative terms to the strain wave equation in microstructured solids (see [44], [45], [50], [51] for details),

$$u_{tt} - u_{xx} - \varepsilon\,\{\alpha_1(u^2)_{xx} + \alpha_2 u_{xxt} - \alpha_3 u_{xxxx} + \alpha_4 u_{xxtt}\} = 0. \qquad (3.27)$$

where $\varepsilon \to 0$, so the higher order term are omitted.

The traveling wave transformation (3.4) reduces Eq. (3.27) to the following ODE:

$$(\omega^2-1)\,U'' - \varepsilon\{\alpha_1(\,U^2)'' - \omega\,\alpha_2 U''' - (\alpha_3 - \omega^2\alpha_4)\,U^{(iv)}\} = 0. \qquad (3.28)$$

where prime stands for the differential coefficient. Integrating Eq. (3.28) with respect to ξ, we get

$$(\omega^2-1)\,U - \varepsilon\{\alpha_1 U^2 - \omega\,\alpha_2 U' - (\alpha_3 - \omega^2\alpha_4)\,U''\} = 0. \qquad (3.29)$$

The homogeneous between the highest order nonlinear term and the linear terms of the highest order, we obtain $N = 2$. Thus, the structure of the solution of Eq. (3.29) is one and the same to the form of the solution (3.7).

E-mail address: ali_math74@yahoo.com.

Inserting the values of U, U' and U'' into Eq. (3.29) and then setting each coefficient of $\psi^{-j},\ j = 0, 1, 2,\ \cdots$ to zero, we successively obtain

$$a_0(-1 + \omega^2 - \varepsilon a_0 \alpha_1) = 0. \tag{3.30}$$

$$a_1\{(-1 + \omega^2 - 2\varepsilon a_0 \alpha_1)\psi' + \varepsilon\omega\alpha_2\psi'' + \varepsilon(\alpha_3 - \omega^2\alpha_4)\psi'''\} = 0. \tag{3.31}$$

$$-\varepsilon a_1 \psi'\{(a_1\alpha_1 + \omega\alpha_2)\psi' + 3(\alpha_3 - \omega^2\alpha_4)\psi''\} + 2\varepsilon a_2 \psi'\{\omega\alpha_2\psi'' + (\alpha_3 - \omega^2\alpha_4)\psi'''\}$$
$$+ a_2[(-1 + \omega^2 - 2\varepsilon a_0\alpha_1)(\psi')^2 + 2\varepsilon(\alpha_3 - \omega^2\alpha_4)(\psi'')^2] = 0. \tag{3.32}$$

$$-2\varepsilon a_1(a_2\alpha_1 - \alpha_3 + \omega^2\alpha_4)(\psi')^3 - 2\varepsilon a_2\{\omega\alpha_2\psi' + 5(\alpha_3 - \omega^2\alpha_4)\psi''\}(\psi')^2 = 0. \tag{3.33}$$

$$-\varepsilon a_2(a_2\alpha_1 - 6\alpha_3 + 6\omega^2\alpha_4)(\psi')^4 = 0. \tag{3.34}$$

From Eqs. (3.30) and (3.34), we obtain

$$a_0 = 0,\ \ \frac{-1 + \omega^2}{\varepsilon\alpha_1} \ \text{ and } \ a_2 = \frac{6(\alpha_3 - \omega^2\alpha_4)}{\alpha_1}, \quad \text{scince } a_2 \neq 0.$$

Therefore, depending on the values of a_0, the following different cases arise:

Case 1: When $a_0 = 0$, from Eqs. (3.31) - (3.33), we get

$$\psi(\xi) = c_2 + \frac{30c_1(\alpha_3 - \omega^2\alpha_4)}{-5a_1\alpha_1 - 6\omega\alpha_2}\, e^{\frac{\xi(-5a_1\alpha_1 - 6\omega\alpha_2)}{30(\alpha_3 - \omega^2\alpha_4)}},$$

$$a_1 = 0,\ \ \omega = \pm\frac{\sqrt{\frac{6\varepsilon\alpha_2^2 - 25(\alpha_3+\alpha_4) + \sqrt{\{6\varepsilon\alpha_2^2 - 25(\alpha_3+\alpha_4)\}^2 - 2500\alpha_3\alpha_4}}{-\alpha_4}}}{5\sqrt{2}} = \pm\theta,$$

and

$$a_1 = \frac{3\left[3\varepsilon\omega\alpha_1\alpha_2 + 5\sqrt{\varepsilon\alpha_1^2\{\varepsilon\omega^2\alpha_2^2 + 4(-1+\omega^2)(-\alpha_3 + \omega^2\alpha_4)\}}\right]}{5\varepsilon\alpha_1^2},$$

$$\omega = -\frac{\sqrt{25 + \frac{6\varepsilon\alpha_2^2}{\alpha_4} + \frac{25\alpha_3}{\alpha_4} \pm \frac{\sqrt{(-6\varepsilon\alpha_2^2 - 25\alpha_3 - 25\alpha_4)^2 - 2500\alpha_3\alpha_4}}{\alpha_4}}}{5\sqrt{2}},$$

where c_1 and c_2 are integration constants.

Hence for the values of a_1 and ω, there also arise three cases. But when $a_1 \neq 0$ then the shape of the solutions for dissipative case is distorted and the solution size is very long. So we have omitted the other value of a_1 and discussed only for $a_1 = 0$.

E-mail address: ali_math74@yahoo.com.

When $a_1 = 0$ then we get also the solutions to the above mentioned equation depends for the values of ω. Thus,

$$\psi(\xi) = c_2 - \frac{5c_1(\alpha_3 - \omega^2\alpha_4)}{\omega\alpha_2}\, e^{-\frac{\xi\omega\alpha_2}{5(\alpha_3-\omega^2\alpha_4)}}$$

Now, by means of the values of a_0, a_1, a_2 and $\psi(\xi)$ from Eq. (3.7), we achieve the subsequent solution:

$$U(\xi) = -\frac{6\omega^2 c_1^2 \alpha_2^2(-\alpha_3 + \omega^2\alpha_4)}{\alpha_1\left\{\omega c_2 \alpha_2 e^{\frac{\xi\omega\alpha_2}{5\alpha_3 - 5\omega^2\alpha_4}} - 5c_1(\alpha_3 - \omega^2\alpha_4)\right\}^2}. \tag{3.35}$$

Simplifying the required solution (3.35), we derive the following close-form solution of the strain wave equation in microstructured solids for dissipative case (3.27):

$$\begin{aligned} u(x,t) = {} & \left[6\omega^2\{-\cosh\big(2\sigma(x-t\omega)\big) + \sinh\big(2\sigma(x-t\omega)\big)\}c_1^2\alpha_2^2(-\alpha_3+\omega^2\alpha_4)\right] \\ & /\Big(\alpha_1\big[\omega\{\cosh\big(\sigma(x-t\omega)\big) + \sinh\big(\sigma(x-t\omega)\big)\}c_2\alpha_2 \\ & + 5\{-\cosh\big(\sigma(x-t\omega)\big) + \sinh\big(\sigma(x-t\omega)\big)\}c_1(\alpha_3-\omega^2\alpha_4)\big]^2\Big). \end{aligned} \tag{3.36}$$

where $\sigma = \frac{\omega\,\alpha_2}{10(\alpha_3-\omega^2\alpha_4)}$, $\omega = \pm\theta$ or and c_1, c_2 are integrating constants. Since c_1 and c_2 are integration constants, one might arbitrarily select their values. If we choose $c_1 = \alpha_2\omega$ and $c_2 = -5(\alpha_3 - \omega^2\alpha_4)$, then from (3.36), we obtain

$$u_9(x,\ t) = \frac{3\omega^2\alpha_2^2}{50\alpha_1(\alpha_3-\omega^2\alpha_4)}\left\{1 + \tanh\left(\frac{\omega(-x+t\omega)\alpha_2}{10(\alpha_3-\omega^2\alpha_4)}\right)\right\}^2. \tag{3.37}$$

Again if we choose $c_1 = \alpha_2\omega$ and $c_2 = 5(\alpha_3 - \omega^2\alpha_4)$, then from (3.36), we attain the subsequent soliton solution:

$$u_{10}(x,\ t) = \frac{3\omega^2\alpha_2^2}{50\alpha_1(\alpha_3-\omega^2\alpha_4)}\left\{1 + \coth\left(\frac{\omega(-x+t\omega)\alpha_2}{10(\alpha_3-\omega^2\alpha_4)}\right)\right\}^2. \tag{3.38}$$

Case 2: When $a_0 = \dfrac{-1+\omega^2}{\varepsilon\,\alpha_1}$, from Eq.(3.31)-(3.33), we obtain

$$\psi(\xi) = c_2 + \frac{30c_1(\alpha_3-\omega^2\alpha_4)}{-5a_1\alpha_1 - 6\omega\alpha_2}\, e^{\frac{\xi(-5a_1\alpha_1-6\omega\alpha_2)}{30(\alpha_3-\omega^2\alpha_4)}},$$

where c_1 and c_2 are integration constants and

E-mail address: ali_math74@yahoo.com.

$$\left\{ a_1 = 0,\ \ \omega = \left[\begin{array}{l} \pm\dfrac{\sqrt{\dfrac{6\varepsilon\alpha_2^2+25\alpha_3+25\alpha_4-\sqrt{\{6\varepsilon\alpha_2^2+25(\alpha_3+\alpha_4)\}^2-2500\alpha_3\alpha_4}}{\alpha_4}}}{5\sqrt{2}} = \pm\vartheta_1(\text{say}) \\ \pm\dfrac{\sqrt{\dfrac{6\varepsilon\alpha_2^2+25\alpha_3+25\alpha_4+\sqrt{\{6\varepsilon\alpha_2^2+25(\alpha_3+\alpha_4)\}^2-2500\alpha_3\alpha_4}}{\alpha_4}}}{5\sqrt{2}} = \pm\vartheta_2(\text{say}) \end{array} \right. \right\};$$

$$\left\{ a_1 = \frac{3\left[3\varepsilon\omega\alpha_1\alpha_2 + 5\sqrt{\varepsilon\alpha_1^2\{\varepsilon\omega^2\alpha_2^2 + 4(-1+\omega^2)(\alpha_3-\omega^2\alpha_4)\}}\right]}{5\varepsilon\alpha_1^2}, \right.$$

$$\left. \omega = -\frac{\sqrt{\dfrac{-6\varepsilon\alpha_2^2+25\alpha_3+25\alpha_4\pm\sqrt{\{6\varepsilon\alpha_2^2-25(\alpha_3+\alpha_4)\}^2-2500\alpha_3\alpha_4}}{\alpha_4}}}{5\sqrt{2}} \right\};$$

$$\left\{ a_1 = \frac{3\left[3\varepsilon\omega\alpha_1\alpha_2 - 5\sqrt{\varepsilon\alpha_1^2\{\varepsilon\omega^2\alpha_2^2 + 4(-1+\omega^2)(\alpha_3-\omega^2\alpha_4)\}}\right]}{5\varepsilon\alpha_1^2}, \right.$$

$$\left. \omega = \frac{\sqrt{\dfrac{-6\varepsilon\alpha_2^2+25\alpha_3+25\alpha_4\pm\sqrt{\{6\varepsilon\alpha_2^2-25(\alpha_3+\alpha_4)\}^2-2500\alpha_3\alpha_4}}{\alpha_4}}}{5\sqrt{2}} \right\}.$$

Hence for the values of a_1 and ω, there arises also three cases. When $a_1 \neq 0$, then the form of solutions to the strain wave equation in microstructured solids for dissipative case (3.24) indistinct and the solution size is very lengthy. So we omitted the extra value of a_1 and only discuss for $a_1 = 0$.

When $a_1 = 0$ then we find also the solutions to the above revealed equation depends for the values of ω, i.e. $\omega = \pm\vartheta_1$ and $\omega = \pm\vartheta_2$. Therefore,

$$\psi(\xi) = c_2 - \frac{5c_1(\alpha_3 - \omega^2\alpha_4)}{\omega\alpha_2}\, e^{-\frac{\xi\omega\alpha_2}{5(\alpha_3-\omega^2\alpha_4)}}$$

E-mail address: ali_math74@yahoo.com.

where . $\omega = \pm\vartheta_1$ or $\omega = \pm\vartheta_2$, c_1 and c_2 are constants of integration.

Substituting the values of a_0, a_1, a_2 and $\psi(\xi)$ into Eq. (3.7), we accomplish the following solution:

$$U(\xi) = \frac{-1+\omega^2}{\varepsilon\alpha_1} - \frac{6\omega^2 c_1^2\alpha_2^2(-\alpha_3+\omega^2\alpha_4)}{\alpha_1\left\{\omega c_2\alpha_2 e^{\frac{\xi\omega\alpha_2}{5\alpha_3-5\omega^2\alpha_4}} - 5c_1(\alpha_3-\omega^2\alpha_4)\right\}^2}. \tag{3.39}$$

Simplifying the required exponential function solution (3.39) into trigonometric function solution, we derive the solution of Eq. (3.27) as follows:

$$\begin{aligned} u(x,t) = \big[&\omega^2(-1+\omega^2)\{\cosh(2\varphi(x-t\omega)) + \sinh(2\varphi(x-t\omega))\}c_2^2\alpha_2^2 \\ &+ \{\cosh(2\varphi(x-t\omega)) - \sinh(2\varphi(x-t\omega))\}c_1^2(\alpha_3-\omega^2\alpha_4)\{6\varepsilon\omega^2\alpha_2^2 \\ &- 25(-1+\omega^2)(-\alpha_3+\omega^2\alpha_4)\} + 10\omega(-1+\omega^2)c_1c_2\alpha_2(-\alpha_3+\omega^2\alpha_4)\big] \\ &/\Big(\varepsilon\alpha_1\big[\omega\{\cosh(\varphi(x-t\omega)) + \sinh(\varphi(x-t\omega))\}c_2\alpha_2 \\ &+ 5\{-\cosh(\varphi(x-t\omega)) + \sinh(\varphi(x-t\omega))\}c_1(\alpha_3-\omega^2\alpha_4)\big]^2\Big). \end{aligned} \tag{3.40}$$

Therefore, we obtain the generalized soliton solution (3.40) to the strain wave equation in microstructured solids for dissipative case, where $\varphi = \frac{\omega\,\alpha_2}{10(\alpha_3-\omega^2\alpha_4)}$ and . $\omega = \pm\vartheta_1$ or $\omega = \pm\vartheta_2$. But, since c_1 and c_2 are arbitrary constants, someone may arbitrarily choose their values. So, if we choose $c_1 = \alpha_2\omega$ and $c_2 = 5(\alpha_3-\omega^2\alpha_4)$, from (3.20), we get the subsequent soliton solutions:

$$u_{11}(x,\ t) = \frac{(-1+\omega^2)}{\alpha_1\varepsilon} - \frac{3\omega^2\alpha_2^2}{50\alpha_1(-\alpha_3+\omega^2\alpha_4)}\left\{-1+\coth\left(\frac{\omega(x-t\omega)\alpha_2}{10(\alpha_3-\omega^2\alpha_4)}\right)\right\}^2. \tag{3.41}$$

Again, if we choose $c_1 = \alpha_2\omega$ and $c_2 = -5(\alpha_3-\omega^2\alpha_4)$, the solitary wave solution (3.40) becomes

$$u_{12}(x,\ t) = \frac{(-1+\omega^2)}{\varepsilon\alpha_1} + \frac{3\varepsilon\omega^2\alpha_2^2}{50\varepsilon\alpha_1(\alpha_3-\omega^2\alpha_4)}\left\{-1+\tanh\left(\frac{\omega(x-t\omega)\alpha_2}{10(\alpha_3-\omega^2\alpha_4)}\right)\right\}^2. \tag{3.42}$$

E-mail address: ali_math74@yahoo.com.

As c_1 and c_2 are arbitrary constants, one may pick many other values of them and each of this selection construct new solution. But for minimalism, we have not recorded these solutions.

Remark 2: The solutions (3.37)-(3.38), where $\omega = \pm\theta_1$ or $\omega = \pm\theta_2$ and the solutions (3.41)-(3.42) $\omega = \pm\vartheta_1$ or $\omega = \pm\vartheta_2$ have been confirmed by satisfying the original equation.

4. PHYSICAL INTERPRETATIONS OF THE SOLUTIONS

In this sub-section, we draw the graph of the derived solutions and explain the effect of the parameters on the solutions for both non-dissipative and dissipative cases. The solution u_1 in (3.17) depends on the physical parameters $\alpha_1, \alpha_3, \alpha_4, \varepsilon$ and the group velocity ω . Now, we will discuss all the possible physical significances for $-2 \le \alpha_1, \alpha_3, \alpha_4, \varepsilon \le 2$, and soliton exists for $|\omega| > 1$ and $|\omega| < 1$. For the value of parameters $\alpha_1, \alpha_3, \alpha_4, \varepsilon < 0$ and $|\omega| > 1$, the solution u_1 in (3.17) represents the bell shape soliton and when $|\omega| < 1$ then the solution u_1 represents the anti-bell shape soliton. It is shown in Fig. 1. Also if the values of the parameters are $\alpha_1 > 0,\ \alpha_3, \alpha_4, \varepsilon < 0$ and $|\omega| > 1$, then the solution u_1 represents the anti-bell shape soliton and when $|\omega| < 1$, then the solution u_1 represents the bell shape soliton. It is shown the Fig. 2. Again, for $\alpha_1, \alpha_3, \alpha_4 < 0, \varepsilon > 0$ and $|\omega| < 1$, the solution $u_1$in (3.17) represents the multi-soliton and when $|\omega| > 1$, the solution u_1 represents the anti-bell shape soliton. It is plotted in Fig. 3. Again, if the values of the physical parameters are $\alpha_1 > 0,\ \alpha_3, \alpha_4 < 0, \varepsilon > 0$ and $|\omega| > 1$, then the solution u_1 represents the anti-bell shape soliton and when $|\omega| < 1$ then the solution u_1 represents the bell shape soliton. It is shown in Fig. 4. We can sketch the other figures of the solution u_1 for different values of the

E-mail address: ali_math74@yahoo.com.

parameters. But for page limitation in this article we have omitted these figures. So, for other cases we do not draw the figures but we discuss for other cases with the following table:

$\varepsilon > 0$	$\lvert\omega\rvert > 1$	$\alpha_1 < 0,\ \alpha_3 < 0,\ \alpha_4 < 0$	Anti-bell shape soliton
		$\alpha_1 > 0,\ \alpha_3 < 0,\ \alpha_4 < 0$	Bell shape soliton
		$\alpha_1 > 0,\ \alpha_3 > 0,\ \alpha_4 < 0$	Bell shape soliton
		$\alpha_1 > 0,\ \alpha_3 > 0,\ \alpha_4 > 0$	Bell shape soliton
		$\alpha_1 > 0,\ \alpha_3 < 0,\ \alpha_4 > 0$	Bell shape soliton
		$\alpha_1 < 0,\ \alpha_3 > 0,\ \alpha_4 < 0$	Anti-bell shape soliton
		$\alpha_1 < 0,\ \alpha_3 > 0,\ \alpha_4 > 0$	Anti-bell shape soliton
		$\alpha_1 < 0,\ \alpha_3 < 0,\ \alpha_4 > 0$	Anti-bell shape soliton
	$\lvert\omega\rvert < 1$	$\alpha_1 < 0,\ \alpha_3 < 0,\ \alpha_4 < 0$	Bell shape soliton
		$\alpha_1 > 0,\ \alpha_3 < 0,\ \alpha_4 < 0$	Anti-bell shape soliton
		$\alpha_1 > 0,\ \alpha_3 > 0,\ \alpha_4 < 0$	Anti-bell shape soliton
		$\alpha_1 > 0,\ \alpha_3 > 0,\ \alpha_4 > 0$	Anti-bell shape soliton
		$\alpha_1 > 0,\ \alpha_3 < 0,\ \alpha_4 > 0$	Anti-bell shape soliton
		$\alpha_1 < 0,\ \alpha_3 > 0,\ \alpha_4 < 0$	Bell shape soliton
		$\alpha_1 < 0,\ \alpha_3 > 0,\ \alpha_4 > 0$	Bell shape soliton
		$\alpha_1 < 0,\ \alpha_3 < 0,\ \alpha_4 > 0$	Periodic bell shape solution
$\varepsilon < 0$	$\lvert\omega\rvert > 1$	$\alpha_1 < 0,\ \alpha_3 < 0,\ \alpha_4 < 0$	Bell shape or Periodic bell shape solution
		$\alpha_1 > 0,\ \alpha_3 < 0,\ \alpha_4 < 0$	Anti-bell shape soliton or Periodic anti-bell shape solution
		$\alpha_1 > 0,\ \alpha_3 > 0,\ \alpha_4 < 0$	Anti-bell shape soliton
		$\alpha_1 > 0,\ \alpha_3 > 0,\ \alpha_4 > 0$	Periodic anti-bell shape solution
		$\alpha_1 > 0,\ \alpha_3 < 0,\ \alpha_4 > 0$	Periodic anti-bell shape solution
		$\alpha_1 < 0,\ \alpha_3 > 0,\ \alpha_4 < 0$	Bell shape soliton
		$\alpha_1 < 0,\ \alpha_3 > 0,\ \alpha_4 > 0$	Periodic bell shape solution
		$\alpha_1 < 0,\ \alpha_3 < 0,\ \alpha_4 > 0$	Periodic bell shape solution
	$\lvert\omega\rvert < 1$	$\alpha_1 < 0,\ \alpha_3 < 0,\ \alpha_4 < 0$	Anti-bell shape soliton or Periodic anti-bell shape solution
		$\alpha_1 > 0,\ \alpha_3 < 0,\ \alpha_4 < 0$	Bell shape or Periodic bell shape solution
		$\alpha_1 > 0,\ \alpha_3 > 0,\ \alpha_4 < 0$	Periodic bell shape solution
		$\alpha_1 > 0,\ \alpha_3 > 0,\ \alpha_4 > 0$	Bell shape or Periodic bell shape solution
		$\alpha_1 > 0,\ \alpha_3 < 0,\ \alpha_4 > 0$	Bell shape soliton
		$\alpha_1 < 0,\ \alpha_3 > 0,\ \alpha_4 < 0$	Periodic anti-bell shape solution
		$\alpha_1 < 0,\ \alpha_3 > 0,\ \alpha_4 > 0$	Anti-bell shape soliton or Periodic anti-bell shape solution
		$\alpha_1 < 0,\ \alpha_3 < 0,\ \alpha_4 > 0$	Anti-bell shape soliton

E-mail address: ali_math74@yahoo.com.

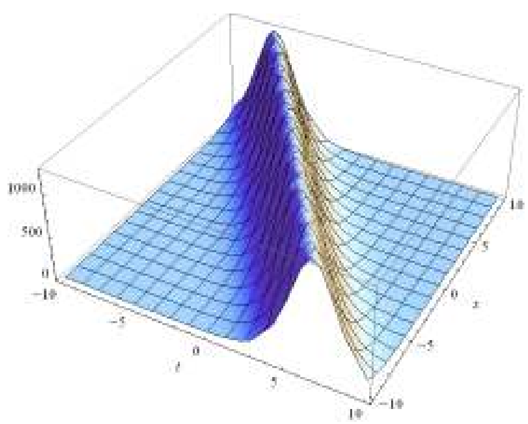
Also the soliton u_2 in (3.18) depends on the parameters $\alpha_1, \alpha_3, \alpha_4, \varepsilon$ and ω. Now, we will discuss all the possible physical significances for $-2 \le \alpha_1, \alpha_3, \alpha_4, \varepsilon \le 2$, and soliton exists for $|\omega| > 1$ and $|\omega| < 1$. For the value of parameters contains $\alpha_1, \alpha_3, \alpha_4, \varepsilon > 0$ and $|\omega| > 1$, then the solution u_2 in (3.18) represents the singular anti-bell shape soliton and when $|\omega| < 1$ then the solution u_2 represents the singular bell shape soliton. It is shown in Fig. 5. Also, for $\alpha_1, \alpha_3, \alpha_4 < 0, \varepsilon > 0$ and $|\omega| > 1$, then the solution u_2 in (3.18) represents the periodic singular anti-bell shape solution and when $|\omega| < 1$ then the solution u_2 represents the periodic singular bell shape solution. It is plotted of the Fig. 6. On the other hand, the solutions u_3 in (3.19) and u_4 in (3.20) exist for $(\alpha_3 - \alpha_4\,\omega^2) > 0,\ \varepsilon < 0$ or $(\alpha_3 - \alpha_4\,\omega^2) < 0,\ \varepsilon > 0$ when $|\omega| > 1$ or $|\omega| > 1$. For the value of the parameters are $\alpha_1 = -1.25, \alpha_3 = -0.1, \alpha_4 = -2, \varepsilon = -1$, when $\omega = 0.96$, the solution u_3 in (3.19) represents the anti-bell shape soliton and $\alpha_1 = -1.5, \alpha_3 = -0.1,\ \alpha_4 = 2, \varepsilon = -1$, when $\omega = 1.5$, the solution u_4 represents the periodic solution. It is shown in Fig. 7. Again, the travelling wave solution u_5 in (3.23) represents the bell shape singular solitons for $\alpha_1 = -1 = \alpha_3,\ \alpha_4 = 1,$ $\varepsilon = 0.5$, $\omega = -1.5$ and $\omega = 0.5$ respectively, in Fig. 8 and Fig. 9 from u_6 in (3.24) represents the bell shape soliton, when $\omega = 1.5$ and the anti-bell shape soliton, when $\omega = -0.75$. In Fig. 10, we have plotted of the periodic bell shape and anti-bell shape solution for $\alpha_1 = \alpha_3 = -1.25$, $\alpha_4 = 1,$ $\varepsilon = 0.7$, $\omega = -1.2$ and $\alpha_1 = \alpha_3 = -1.25$, $\alpha_4 = 1,$ $\varepsilon = -0.7$, $\omega = 0.25$ respectively to the solution of u_7 in (3.25) and Fig. 11 plotted the periodic anti-bell shape solution and bell shape solution for $\alpha_1 = 1.25,$ $\alpha_3 = -1.25$, $\alpha_4 = 1,$ $\varepsilon = 0.7$, $\omega = -1.2$ and $\alpha_1 = \alpha_3 = -1.25$, $\alpha_4 = 1,$ $\varepsilon = -0.7$, $\omega = -0.25$ respectively to the solution of u_8 in (3.26). Fig. 12 and 13 represent the kink shape solutions u_9 given in (3.37) are respectively, for $\alpha_1 = 1,$ $\alpha_2 = 1,$ $\alpha_3 = -1.5,$ $\alpha_4 = -1$ and $\alpha_1 = -1,$ $\alpha_2 = 1,$ $\alpha_3 = -1.5,$ $\alpha_4 = -1$ respectively, when $\omega = \pm\mu_1$ and for $\alpha_1 = 1,$ $\alpha_2 = 1,$ $\alpha_3 = -1.5,$ $\alpha_4 = -1$ and $\alpha_1 = -1,$

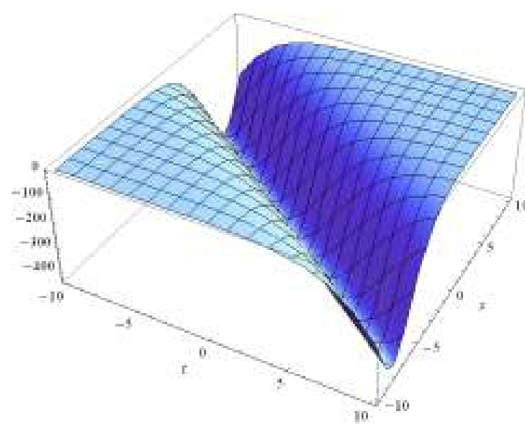
E-mail address: ali_math74@yahoo.com.

$\alpha_2 = 1,\ \alpha_3 = -1.5,\ \alpha_4 = -1$ respectively, when $\omega = \pm\mu_2$. Also sketch the figures 14 and 15, singular bell shape solutions u_{10} in (3.38) for $\alpha_1 = 1,\ \alpha_2 = 1,\ \alpha_3 = -1.5,\ \alpha_4 = -1$ and $\alpha_1 = -1,\ \alpha_2 = 1,\ \alpha_3 = -1.5,\ \alpha_4 = -1$ respectively, when $\omega = \pm\mu_1$ and for $\alpha_1 = 1,\ \alpha_2 = 1,$ $\alpha_3 = -1.5,\ \alpha_4 = -1$ and $\alpha_1 = -1,\ \alpha_2 = 1,\ \alpha_3 = -1.5,\ \alpha_4 = -1$ respectively, when $\omega = \pm\mu_2$. On the other hand, Fig. 16 and 17 are singular bell and singular anti-bell shape soliton solitons u_{11} in (3.41) for $\alpha_1 = 1,\ \alpha_2 = 1,\ \alpha_3 = 1,\ \alpha_4 = 1,\ \varepsilon = 0.5$ and $\alpha_1 = -1,\ \alpha_2 = 1,\ \alpha_3 = 1,$ $\alpha_4 = 1,\ \varepsilon = 0.5$ respectively, when $\omega = \pm\theta_1$ and for $\alpha_1 = 1,\ \alpha_2 = 1,\ \alpha_3 = 1,\ \alpha_4 = 1,\ \varepsilon = 0.5$ and $\alpha_1 = -1,\ \alpha_2 = 1,\ \alpha_3 = 1,\ \alpha_4 = 1,\ \varepsilon = 0.5$ respectively, when $\omega = \pm\theta_2$. Also, draw the Figures 18 and 19 are kink shape solitons u_{12} in (3.42) for $\alpha_1 = 1,\ \alpha_2 = 1,\ \alpha_3 = 1,\ \alpha_4 = 1,$ $\varepsilon = 0.5$ and $\alpha_1 = -1,\ \alpha_2 = 1,\ \alpha_3 = 1,\ \alpha_4 = 1,\ \varepsilon = 0.5$ respectively, when $\omega = \pm\theta_1$ and for $\alpha_1 = 1,\ \alpha_2 = 1,\ \alpha_3 = 1,\ \alpha_4 = 1,\ \varepsilon = 0.5$ and $\alpha_1 = -1,\ \alpha_2 = 1,\ \alpha_3 = 1,\ \alpha_4 = 1,\ \varepsilon = 0.5$ respectively, when $\omega = \pm\theta_2$. All figures are drawn within $-10 \le x,\ t \le 10$.

There is another kind of solution which is not a kink, antikink, dark or bell-shape soliton, known as Love wave [52, 53]. A Love wave is define to be a surface wave having a horizontal motion that is transverse or perpendicular to the direction the wave is traveling.

We can discuss the solutions u_2 to u_{12} for other values of the parameters. But for page limitation in this article we have omitted these figures in details.





E-mail address: ali_math74@yahoo.com.

Fig. 1: Sketch of the solution u_1 for $\alpha_1 = -0.001,\ \alpha_3 = \alpha_4 = \varepsilon = \omega = -1.5$ and $\alpha_1 = -0.001,\ \alpha_3 = \alpha_4 = \varepsilon = \omega = -0.75$ respectively.

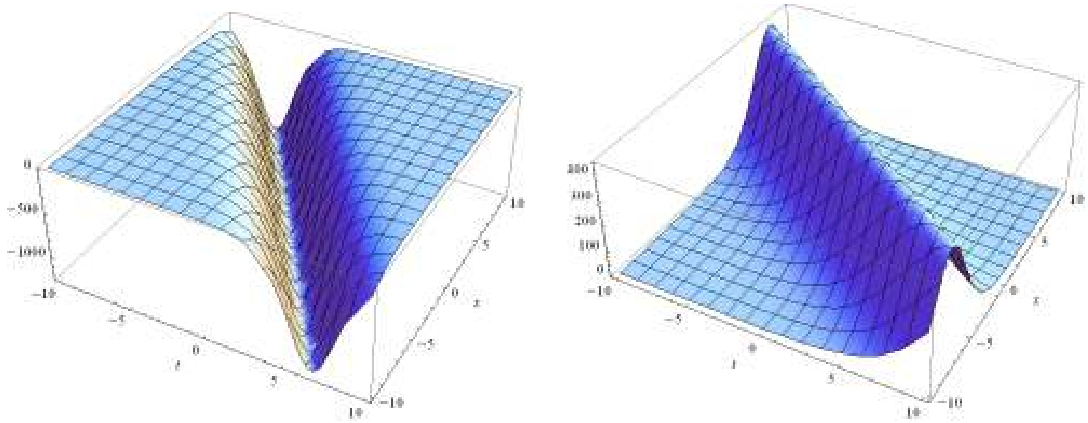


Fig. 2: Plot of the solution u_1 for $\alpha_1 = 0.001,\ \alpha_3 = \alpha_4 = \varepsilon = \omega = -1.5$ and $\alpha_1 = 0.001,\ \alpha_3 = \alpha_4 = \varepsilon = \omega = -0.75$ respectively.

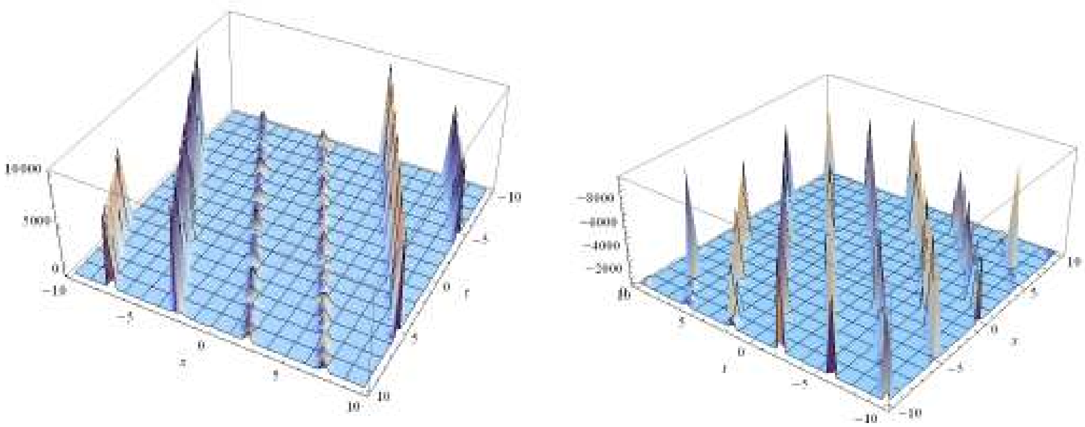


Fig. 3: Sketch of the solution u_1 for $\alpha_1 = \alpha_3 = \alpha_4 = -1.2,\ \varepsilon = \omega = 0.5$ and $\alpha_1 = \alpha_3 = \alpha_4 = -1.2,\ \varepsilon = 0.5,\ \omega = 1.25$ respectively.

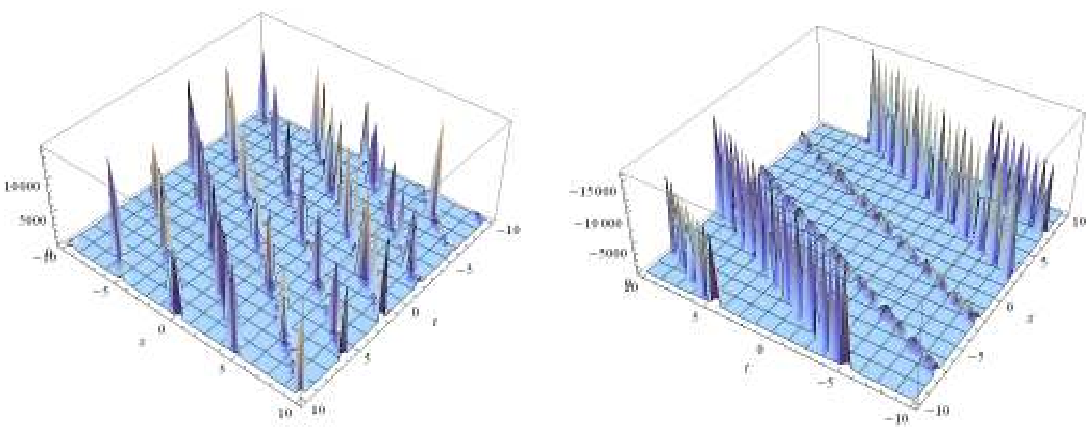


Fig. 4: Sketch of the solution u_1 for $\alpha_1 = 0.75,\ \alpha_3 = \alpha_4 = -1.2,\ \varepsilon = 0.5,\ \omega = 1.25$ and $\alpha_1 = 0.75,\ \alpha_3 = \alpha_4 = -1.2,\ \varepsilon = 0.5,\ \omega = 0.5$ respectively.

E-mail address: ali_math74@yahoo.com.

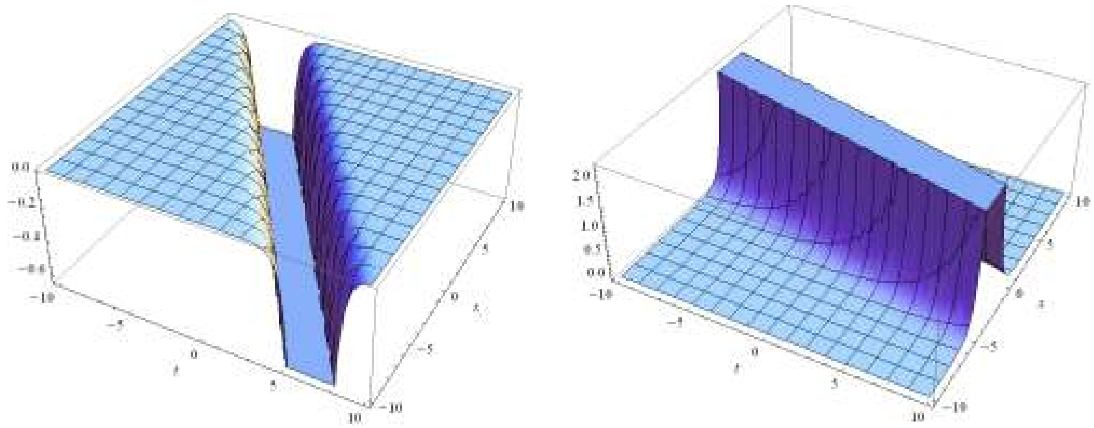


Fig. 5: Sketch of the singular dark and singular bell shape soliton u_2 for $\alpha_1 = \alpha_3 = \alpha_4 = 0.5$, $\varepsilon = 0.75$, $\omega = -1.5$ and $\alpha_1 = \alpha_3 = \alpha_4 = 0.5$, $\varepsilon = 0.75$, $\omega = -0.25$ respectively.

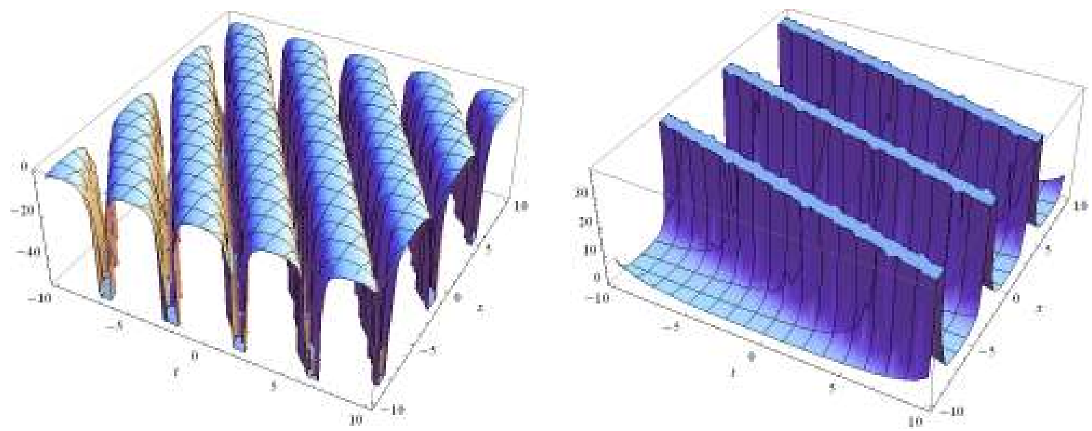


Fig. 6: Sketch of the periodic singular solution u_2 for $\alpha_1 = \alpha_3 = \alpha_4 = -1.5$, $\varepsilon = 0.75$, $\omega = -1.5$ and $\alpha_1 = \alpha_3 = \alpha_4 = -1.5$, $\varepsilon = 0.75$, $\omega = -0.25$ respectively.

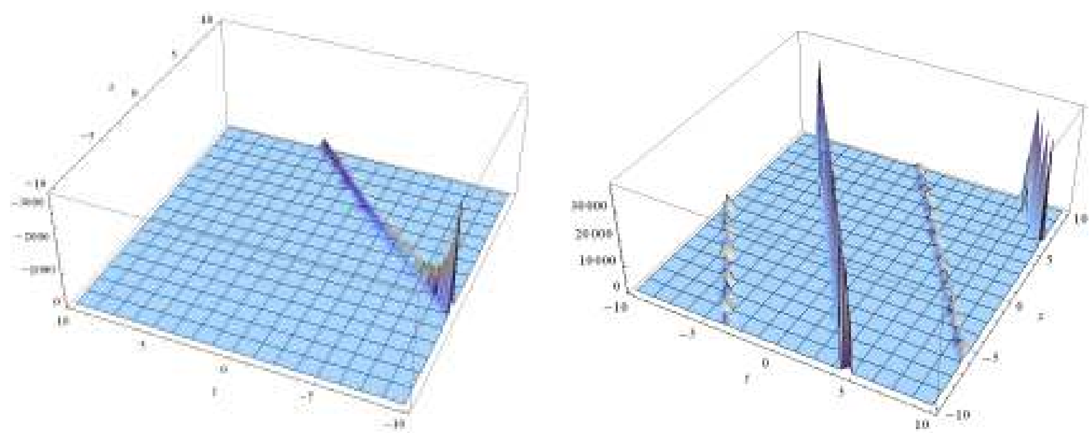


Fig. 7: Sketch of the solution u_3 and the solution u_4 for $\alpha_1 = -1.25$, $\alpha_3 = -0.1$, $\alpha_4 = -2$, $\varepsilon = -1$, $\omega = 0.96$ and $\alpha_1 = -1.5$, $\alpha_3 = -0.1$, $\alpha_4 = 2$, $\varepsilon = -1$, $\omega = 1.5$ respectively.

E-mail address: ali_math74@yahoo.com.

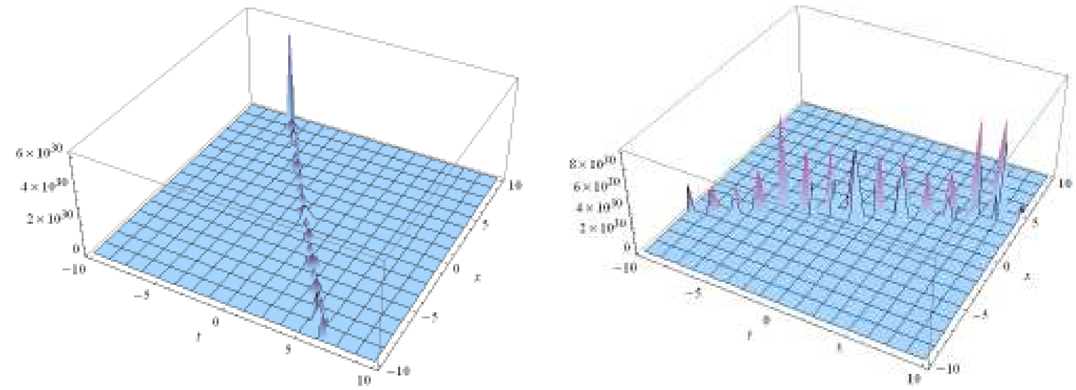


Fig. 8: Sketch of the solutions u_5 for $\alpha_1 = -1 = \alpha_3, \quad \alpha_4 = 1, \ \varepsilon = 0.5, \ \omega = -1.5$ and $\omega = 0.5$ respectively.

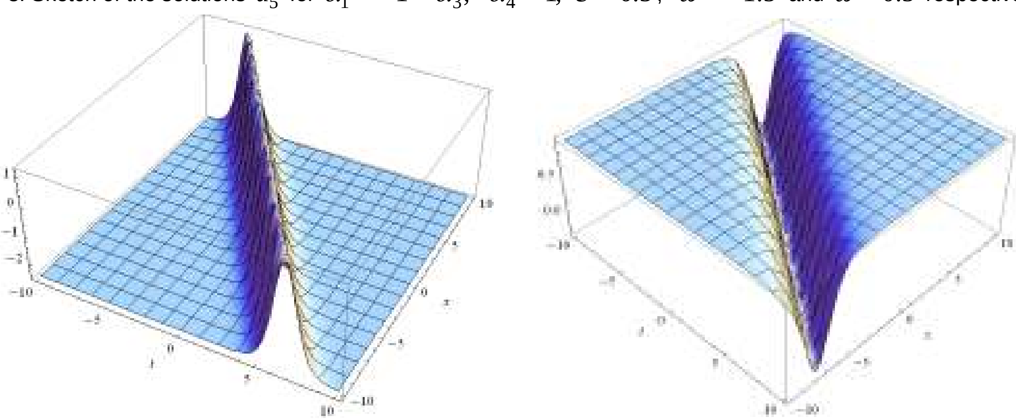


Fig. 9: Sketch of the bell shape soliton and anti-bell shape soliton u_6 for $\alpha_1 = \alpha_3 = \alpha_4 = -1, \quad \varepsilon = 0.5$, $\omega = 1.5$ and $\omega = -0.75$ respectively.

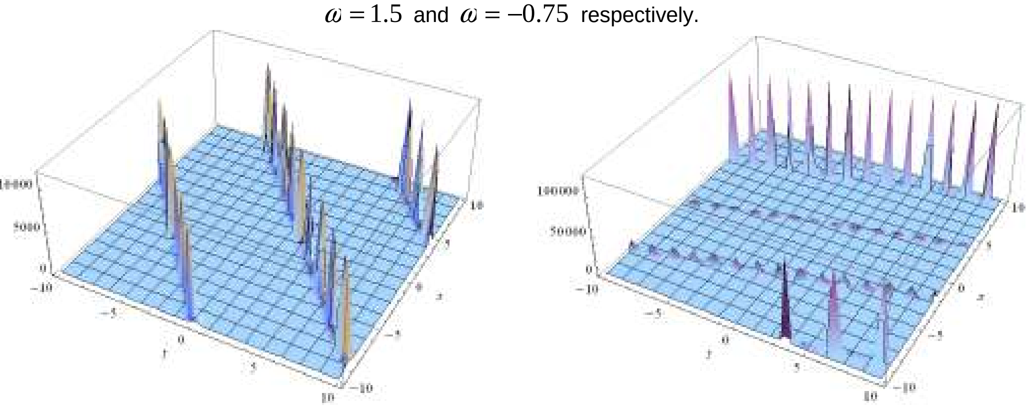


Fig. 10: Sketch of the solutions u_7 for $\alpha_1 = \alpha_3 = -1.25$, $\alpha_4 = 1, \quad \varepsilon = 0.7, \quad \omega = -1.2$ and $\alpha_1 = \alpha_3 = -1.25$, $\alpha_4 = 1, \quad \varepsilon = -0.7$, $\omega = 0.25$ respectively.

E-mail address: ali_math74@yahoo.com.

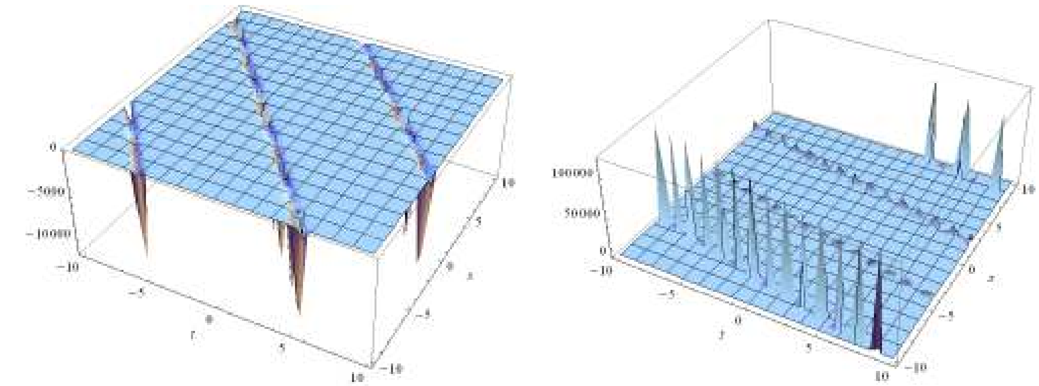


Fig. 11: Sketch of the solutions u_8 for $\alpha_1 = 1.25$, $\alpha_3 = -1.25$, $\alpha_4 = 1$, $\varepsilon = 0.7$, $\omega = -1.2$ and $\alpha_1 = \alpha_3 = -1.25$, $\alpha_4 = 1$, $\varepsilon = -0.7$, $\omega = -0.25$ respectively.

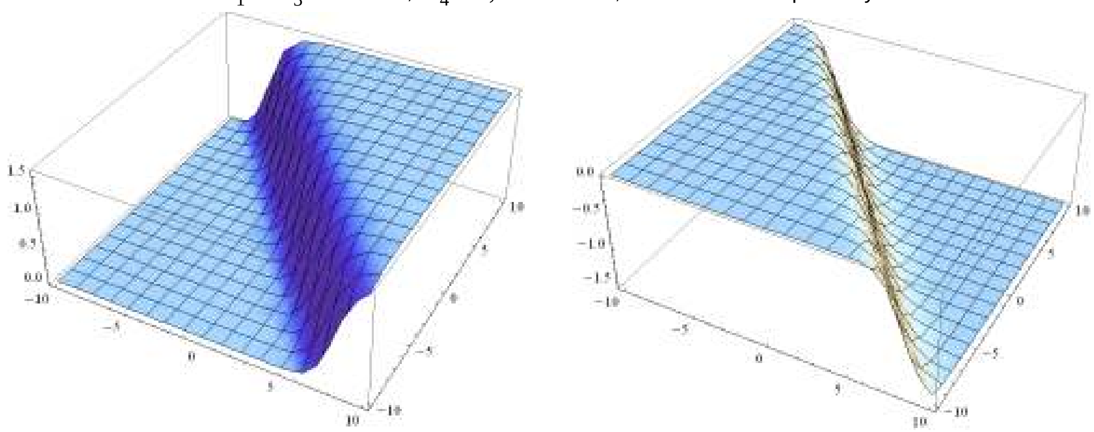


Fig. 12: Kink shape soliton obtained from u_9 for $\alpha_1 = 1$, $\alpha_2 = 1$, $\alpha_3 = -1.5$, $\alpha_4 = -1$, $\varepsilon = 0.5$ and $\alpha_1 = -1$, $\alpha_2 = 1$, $\alpha_3 = -1.5$, $\alpha_4 = -1$, $\varepsilon = 0.5$ respectively, when $\omega = \pm\mu_1$.

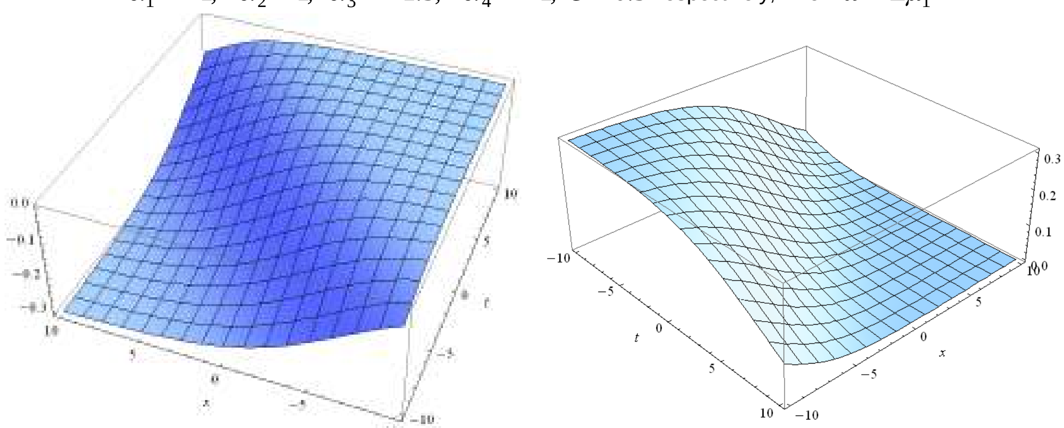


Fig. 13: Kink shape soliton obtained from u_9 for $\alpha_1 = 1$, $\alpha_2 = 1$, $\alpha_3 = -1.5$, $\alpha_4 = -1$, $\varepsilon = 0.5$ and $\alpha_1 = -1$, $\alpha_2 = 1$, $\alpha_3 = -1.5$, $\alpha_4 = -1$, $\varepsilon = 0.5$ respectively, when $\omega = \pm\mu_2$.

E-mail address: ali_math74@yahoo.com.

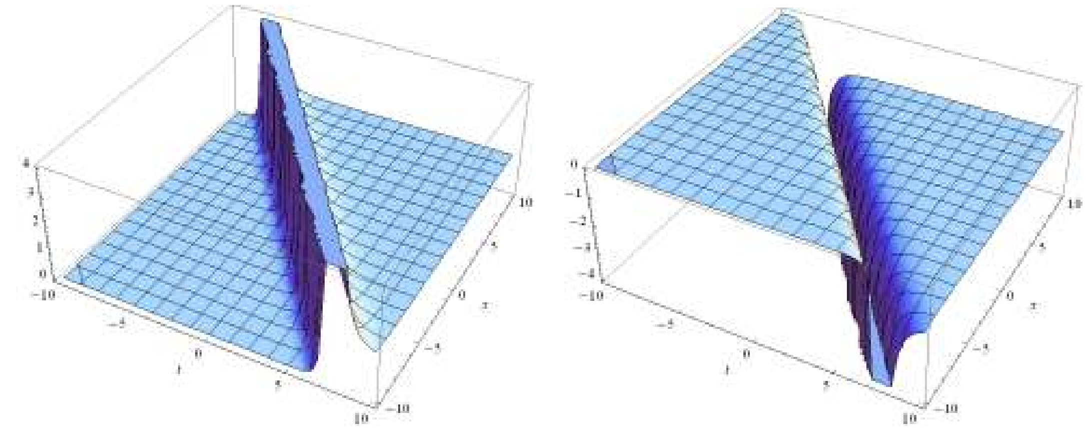


Fig. 14: Singular bell shape and anti-bell shape soliton u_{10} for $\alpha_1 = 1, \quad \alpha_2 = 1, \ \alpha_3 = -1.5, \quad \alpha_4 = -1,$ $\varepsilon = 0.5$ and $\alpha_1 = -1, \quad \alpha_2 = 1, \ \alpha_3 = -1.5, \quad \alpha_4 = -1, \ \varepsilon = 0.5$ respectively, when $\omega = \pm\mu_1$.

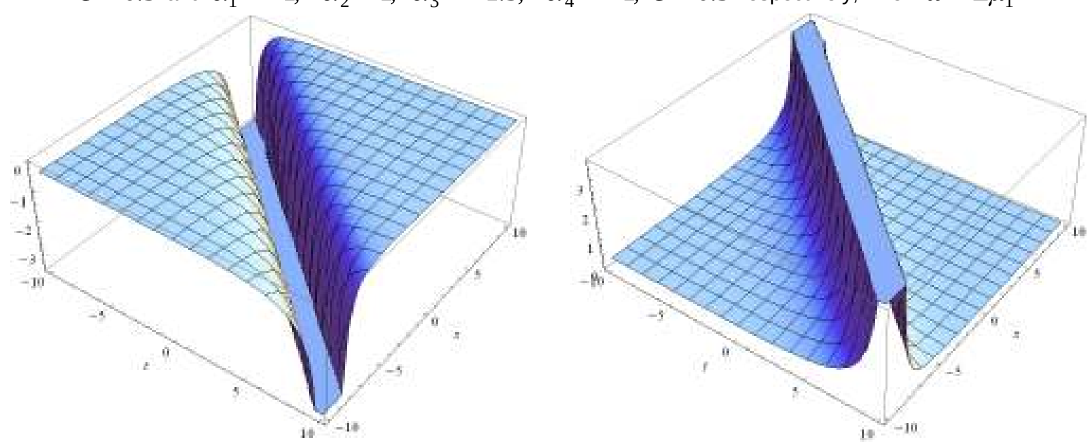


Fig. 15: Singular anti-bell shape and bell shape soliton u_{10} in (3.38) for $\alpha_1 = 1, \quad \alpha_2 = 1, \ \alpha_3 = -1.5,$ $\alpha_4 = -1, \ \varepsilon = 0.5$ and $\alpha_1 = -1, \quad \alpha_2 = 1, \ \alpha_3 = -1.5, \quad \alpha_4 = -1, \ \varepsilon = 0.5$ respectively, when $\omega = \pm\mu_2$.

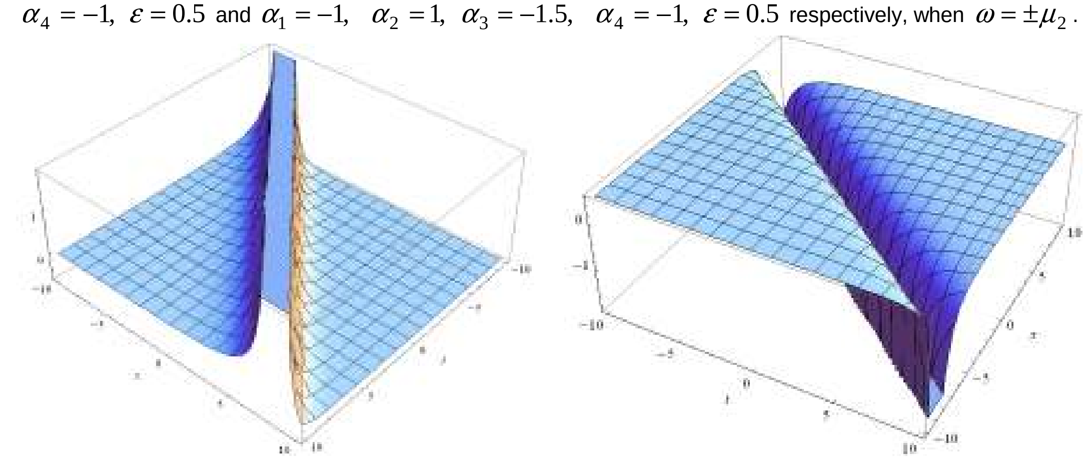


Fig. 16: Sketch the singular bell type and anti-bell soliton u_{11} for $\alpha_1 = 1, \quad \alpha_2 = 1, \ \alpha_3 = 1, \ \alpha_4 = 1, \ \varepsilon = 0.5$ and $\alpha_1 = -1, \quad \alpha_2 = 1, \ \alpha_3 = 1, \ \alpha_4 = 1, \ \varepsilon = 0.5$ respectively, when $\omega = \pm\theta_1$.

E-mail address: ali_math74@yahoo.com.

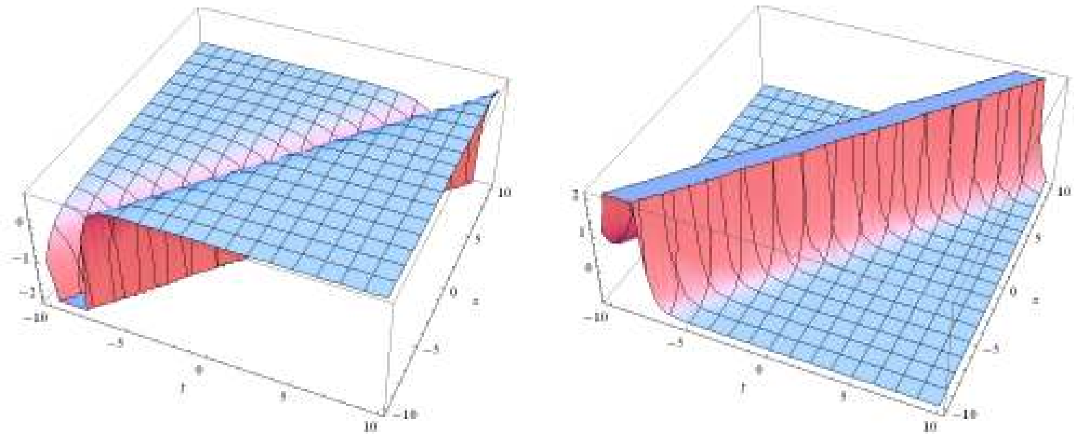


Fig. 17: Singular anti-bell shape and bell shape soliton u_{11} for $\alpha_1 = 1, \quad \alpha_2 = 1, \; \alpha_3 = 1, \; \alpha_4 = 1, \; \varepsilon = 0.5$ and $\alpha_1 = -1, \quad \alpha_2 = 1, \; \alpha_3 = 1, \; \alpha_4 = 1, \; \varepsilon = 0.5$ respectively, when $\omega = \pm\theta_2$.

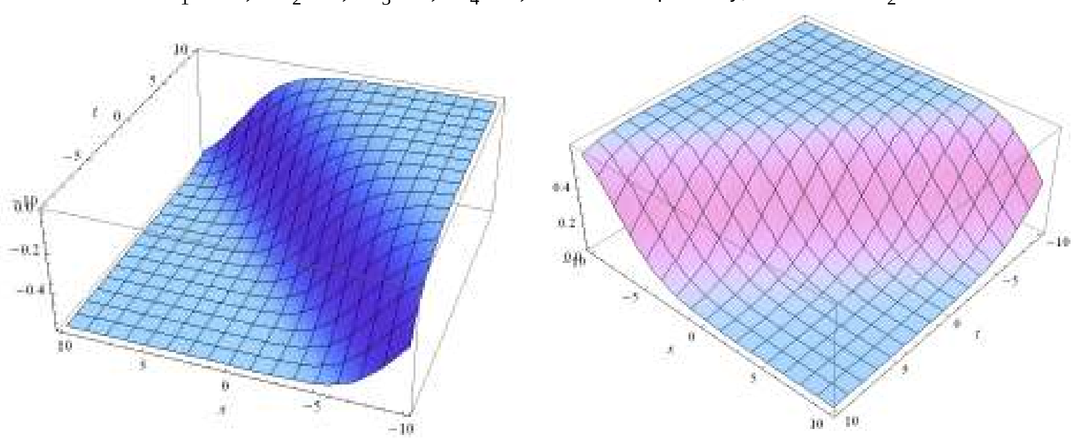


Fig. 18: Kink shape soliton u_{12} for $\alpha_1 = 1, \quad \alpha_2 = 1, \; \alpha_3 = 1, \; \alpha_4 = 1, \; \varepsilon = 0.5$ and $\alpha_1 = -1, \quad \alpha_2 = 1,$ $\alpha_3 = 1, \; \alpha_4 = 1, \; \varepsilon = 0.5$ respectively, when $\omega = \pm\theta_1$.

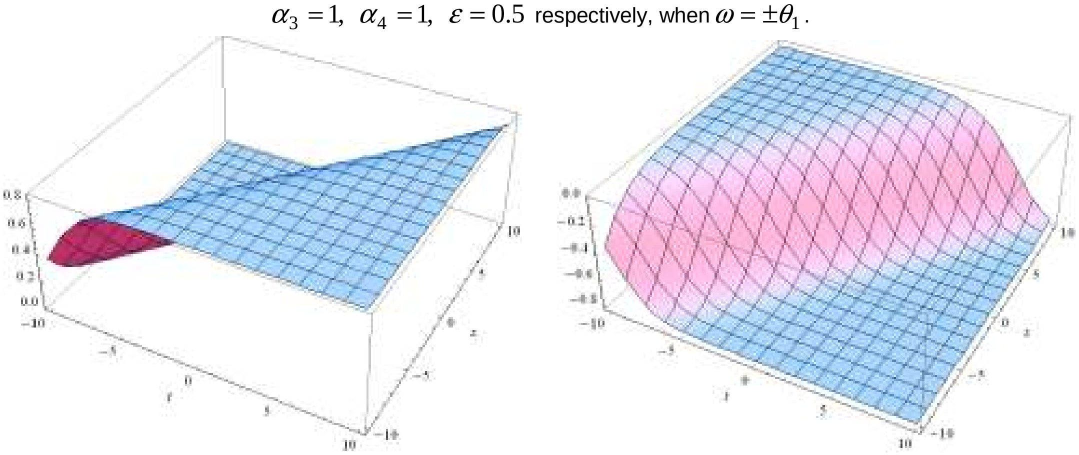


Fig. 19: Kink shape soliton u_{12} for $\alpha_1 = 1, \quad \alpha_2 = 1, \; \alpha_3 = 1, \; \alpha_4 = 1, \; \varepsilon = 0.5$ and $\alpha_1 = -1,$ $\alpha_2 = 1, \; \alpha_3 = 1, \; \alpha_4 = 1, \; \varepsilon = 0.5$ respectively, when $\omega = \pm\theta_2$.

E-mail address: ali_math74@yahoo.com.

5. CONCLUSION

In this article, we have implemented the MSE method to obtain soliton solutions to the strain wave equation in microstructured solids for both non-dissipative and dissipative cases. In fact, we have derived general solitary wave solutions to this equation associated with arbitrary constants, and for particular values of these constants solitons are originated from the general solitary wave solutions. We have illustrated the solitary wave properties of the solutions for various values of the free parameters by means of the graphs. This work shows that the MSE method is competent and more powerful and can be used for many other equations NLEEs applied mathematics and engineering.

REFERENCES

1. V.B. Matveev and M.A. Salle, Darboux transformation and solitons, Springer, Berlin, 1991.
2. G. Xu, An elliptic equation method and its applications in nonlinear evolution equations, Chaos, Solitons Fract., 29 (2006) 942-947.
3. E. Yusufoglu and A. Bekir, Exact solution of coupled nonlinear evolution equations, Chaos, solitons Fract., 37 (2008) 842-848.
4. D.D. Ganji, The application of He's homotopy perturbation method to nonlinear equations arising in heat transfer, Phys. Lett. A, 355 (2006) 137-141.
5. D.D. Ganji, G.A. Afrouzi and R.A. Talarposhti, Application of variational iteration method and homotopy perturbation method for nonlinear heat diffusion and heat transfer equations, Phys. Lett. A, 368 (2007) 450-457.
6. W. Malfliet and W. Hereman, The tanh method II: Perturbation technique for conservative systems, Phys. Scr., 54 (1996) 563-569.
7. H.A. Nassar, M.A. Abdel-Razek and A.K. Seddeek, Expanding the tanh-function method for solving nonlinear equations, Appl. Math., 2 (2011) 1096-1104.

8. A.J.M. Jawad, M.D. Petkovic, P. Laketa and A. Biswas, Dynamics of shallow water waves with Boussinesq equation, Scientia Iranica, Trans. B: Mech. Engr., 20(1) (2013) 179-184.

9. M.A. Abdou, The extended tanh method and its applications for solving nonlinear physical models, Appl. Math. Comput., 190 (1) (2007) 988-996.

10. A.L. Guo and J. Lin, Exact solutions of (2+1)-dimensional HNLS equation, Commun. Theor. Phys., 54 (2010) 401-406.

11. S.T. Mohyud-Din, , M.A. Noor and K.I. Noor, Modified Variational Iteration Method for Solving Sine-Gordon Equations, World Appl. Sci. J., 6 (7) (2009) 999-1004.

12. R. Hirota, The direct method in soliton theory, Cambridge University Press, Cambridge, 2004.

13. C. Rogers and W.F. Shadwick, Backlund transformations and their applications, Vol. 161 of Mathematics in Science and Engineering, Academic Press, New York, USA, 1982.

14. L. Jianming, D. Jie and Y. Wenjun, Backlund transformation and new exact solutions of the Sharma-Tasso-Olver equation, Abstract and Appl. Analysis, 2011 (2011) Article ID 935710, 8 pages.

15. M.J. Ablowitz and P.A. Clarkson, Soliton, nonlinear evolution equations and inverse scattering, Cambridge University Press, New York, 1991.

16. A.M. Wazwaz, A sine-cosine method for handle nonlinear wave equations, Appl. Math. Comput. Modeling, 40 (2004) 499-508.

17. E. Yusufoglu, and A. Bekir, Solitons and periodic solutions of coupled nonlinear evolution equations by using Sine-Cosine method, Int. J. Comput. Math., 83 (12) (2006) 915-924.

18. J. Weiss, M. Tabor and G. Carnevale, The Painlevé property for partial differential equations, J. Math. Phys., 24 (1982) 522-526.

E-mail address: ali_math74@yahoo.com.

19. A.M. Wazwaz, Partial Differential equations: Method and Applications, Taylor and Francis, 2002.

20. M.A. Helal and M.S. Mehana, A comparison between two different methods for solving Boussinesq-Burgers equation, Chaos, Solitons Fract., 28 (2006) 320-326.

21. M. Wang, X. Li and J. Zhang, The (G'/G)-expansion method and traveling wave solutions of nonlinear evolution equations in mathematical physics, Phys. Lett. A, 372 (2008) 417-423.

22. J. Zhang, F. Jiang and X. Zhao, An improved (G'/G)-expansion method for solving nonlinear evolution equations, Inter. J. Comput. Math., 87 (8) (2010) 1716-1725.

23. J. Feng, W. Li and Q. Wan, Using (G'/G)-expansion method to seek the traveling wave solution of Kolmogorov-Petrovskii-Piskunov equation, Appl. Math. Comput., 217 (2011) 5860-5865.

24. M.A. Akbar, N.H.M. Ali and E.M.E. Zayed, Abundant exact traveling wave solutions of the generalized Bretherton equation via (G'/G)-expansion method, Commun. Theor. Phys., 57 (2012) 173-178.

25. R. Abazari, The (G'/G)-expansion method for Tziteica type nonlinear evolution equations, Math. Comput. Modelling, 52 (2010) 1834-1845.

26. M.A. Akbar, N.H.M. Ali and S.T. Mohyud-Din, Further exact traveling wave solutions to the (2+1)-dimensional Boussinesq and Kadomtsev-Petviashvili equation, J. Comput. Analysis Appl., 15 (3) (2013) 557-571.

27. N. Taghizadeh and M. Mirzazadeh, The first integral method to some complex nonlinear partial differential equations, J. Comput. Appl. Math., 235 (2011) 4871-4877.

28. M.L. Wang and X.Z. Li, Extended F-expansion method and periodic wave solutions for the generalized Zakharov equations, Phys. Lett. A, 343 (2005) 48-54.

E-mail address: ali_math74@yahoo.com.

29. Sirendaoreji, Auxiliary equation method and new solutions of Klein-Gordon equations, Chaos, Solitions Fract., 31 (2007) 943-950.

30. H. Triki, A. Chowdhury and A. Biswas, Solitary wave and shock wave solutions of the variants of Boussinesq equation, U.P.B. Sci. Bull., Series A, 75(4) (2013) 39-52.

31. H. Triki, A.H. Kara and A. Biswas, Domain walls to Boussinesq type equations in (2+1)-dimensions, Indian J. Phys., 88(7) (2014) 751-755.

32. J.H. He and X.H. Wu, Exp-function method for nonlinear wave equations, Chaos, Solitons Fract., 30 (2006) 700-708.

33. H. Naher, A.F. Abdullah and M.A. Akbar, New traveling wave solutions of the higher dimensional nonlinear partial differential equation by the Exp-function method, J. Appl. Math., 2012 (2012) Article ID 575387, 14 pages.

34. M. Wang, Solitary wave solutions for variant Boussinesq equations, Phy. Lett. A, 199 (1995) 169-172.

35. A.J.M. Jawad, M.D. Petkovic and A. Biswas, Modified simple equation method for nonlinear evolution equations, Appl. Math. Comput., 217 (2010) 869-877.

36. E.M.E. Zayed and S.A.H. Ibrahim, Exact solutions of nonlinear evolution equations in mathematical physics using the modified simple equation method, Chin. Phys. Lett., 29(6) (2012) 060201.

37. K. Khan, M.A. Akbar and M.N. Alam, Traveling wave solutions of the nonlinear Drinfel'd-Sokolov-Wilson equation and modified Benjamin-Bona-Mahony equations, J. Egyptian Math. Soc., 21 (2013) 233-240.

38. K. Khan and M. Ali Akbar, Exact and solitary wave solutions for the Tzitzeica-Dodd-Bullough and the modified Boussinesq-Zakharov-Kuznetsov equations using the modified simple equation method, Ain Shams Engr. J., 4 (2013) 903-909.

E-mail address: ali_math74@yahoo.com.

39. K. Khan and M.A. Akbar, Traveling wave solutions of some coupled nonlinear evolution equations, ISRN Math. Phys., 2013 (2013) Art. ID 685736, 8 pages.

40. K. Khan and M.A. Akbar, Application of $\exp(-\varphi(\xi))$-expansion method to find the exact solutions of modified Benjamin-Bona-Mahony equation, World Appl. Sci. J., 24(10) (2013) 1373-1377.

41. M.G. Hafez, M.N. Alam and M.A. Akbar, Traveling wave solutions for some important coupled nonlinear physical models via the coupled Higgs equation and the Maccari system, J. King Saud Univ.-Sci., (2014), doi: 10.1016/j.jksus.2014.09.001 (in press).

42. T.L. Bock and M.D. Kruskal, A two-parameter Miura transformation of the Benjamin-One equation, Phys. Lett. A, 74 (1979) 173-176.

43. M.N. Alam, M.A. Akbar, S. T. Mohyud-Din, General traveling wave solutions of the strain wave equation in microstructured solids via the new approach of generalized (G'/G)-expansion method, Alexandria Engr. J., 53 (2014) 233-241.

44. F. Pastrone, P. Cermelli and A. Porubov, Nonlinear waves in 1-D solids with microstructure, Mater. Phys. Mech., 7 (2004) 9-16

45. A.V. Porubov and F. Pastrone, Non-linear bell-shaped and kink-shaped strain waves in microstructured solids, Int. J. Nonlinear Mech., 39(8) (2004) 1289-1299.

46. M.A. Akbar, N.H.M. Ali and E.M.E. Zayed, A generalized and improved (G'/G)-expansion method for nonlinear evolution equations, Math. Prob. Engr., Vol. 2012, Article ID 459879, 22 pages, DOI:10.1155/2012/459879.

47. M.A. Salam, Traveling wave solution of modified Liouville equation by means of modified simple equation method, ISRN Appl. Math., Vol. 2012, Article ID 565247, 4 pages.

E-mail address: ali_math74@yahoo.com.

48. E.M.E. Zayed and A.H. Arnous, Exact traveling wave solutions of nonlinear PDEs in mathematical physics using the modified simple equation method, Appl. Appl. Math.: An Int. J., 8(2) (2013) 553-572.

49. M.A. Khan and M.A. Akbar, Exact and solitary wave solutions to the generalized fifth-order KdV equation by using the modified simple equation method, Appl. Comput. Math., 4(3) (2015) 122-129.

50. A.M. Samsonov, Strain Solitons and How to Construct Them, Chapman and Hall/CRC, Boca Raton, Fla, USA, 2001.

51. F. Pastrone, F. Hierarchy of Nonlinear waves in complex microstructured solids, Int. Con. Com. Of nonlinear waves, (2009) 5-7.

52. A. A. Zakharenko, Analytical studying the group velocity of three-partial Love (type) waves in both isotropic and anisotropic media, Nondestructive Testing and Evaluation, 20(4), Dec. 2005, 237-254.

53. A. A. Zakharenko, Slow acoustic waves with the anti-plane polarization in layered systems, Int. J. of Modern Phys. B, 24(4) (2010) 515-536.

E-mail address: ali_math74@yahoo.com.