Journal of Engineering and Development, Vol. 15, No. 2, June (2011) **ISSN 1813-7822**

The Effect of Formation a Galloping Motion on the Electric Transmission Cables in the High Voltage Tower

Ali Fahad Fahem
Assist Lecturer
University Of Al-Qadisiya
College Of Engineering
Department Of Mechanical Engineering

Abstract

This research includes a theoretical analysis according to nonlinear Klein- Gordon equation to study the dynamic state of a specimen of an electric translation line in Iraq while it is in a galloping motion that results from: different wind velocity, material type, different tension force as well as the span between towers. This is in addition to knowing the behavior of the specimen under the effect of both the force that results from wind velocity and the altitudes formulated in the string due to the galloping motion. Reducing the effect of the galloping motion and compare it with the numerical method of a model with multi-degree of freedom by using the ANSYS workbench-12.1 is also taken care of in this work.

The theoretical findings of the research have shown that they are very near to those of the numerical method; they have also shown that the material type and the length of the string are very important in determining the altitude of the galloping motion. Moreover, increasing the resistance of the electric network against wind velocity and /or near explosions need to reduce the span between the towers to half is also one of the vital findings of the research.

KEYWORD: galloping motion, string, ANSYS Workbench-v12.1 (FEA), wave equation, translation line, wind forces

---

الخلاصة

تم في هذا البحث اجراء تحليل نظري باستخدام معادلة كلين- جوردان الغير خطية لدراسة الحالة الديناميكية على عينة من خط نقل كهربائي في العراق اثناء حركتة التموجية السريعة تحت تاثير السرع المتغيرة للرياح , ونوع المعدن , وقوى شد مختلفة , وكذلك تاثير تغيير المسافات بين الابراج وذلك لمعرفة سلوك العينة وتاثير القوى الناتجة من سرعة الرياح والارتفاعات المتولدة في السلك نتيجة تشكل الحركة المتموجة وطرق تقليلها ومقارنتها مع التحليل العددي لنموذج ذات درجات متعددة حرية الحركة باستخدام برنامج ANSYS workbench. لقد اظهرت النتائج النظرية تقارباً جيداً مع نتائج التحليل العددي. كما بينت ان نوع المعدن المستخدم وطول السلك مهمان في تحديد مديات الحركة. ان احدى النقاط المهمة لزيادة مقاومة الشبكة الكهربائية الى سرع الرياح او الانفجارات القريبة تحتاج الى تقليل المسافات بين الابراج الى النصف.

Nomenclature

a	**Speed of a wave**
AAAC	**All Aluminum Alloy Conductor**
ACSR	**Aluminum Conductor Steel Reinforced**
A_c	**Reference Area Conductor**
B.C	**Boundary Condition**
C_D	**Drag force coefficient**
F_c	**Wind forces**
L	**Length of conductor**
P_{zc}	**Dynamic wind pressure**
T	**Tension force in connecter**
t	**Time**
$w_{(x,t)}$	**Deflection of conductor**
$y(x,t)$	**Deflection of conductor**
z_1, z_2, z_{min}	**Altitude of conductor(see fig. 2)**
α	**Constant**
β	**Structure damping**
$\propto$	**Span reduction factor**
$\psi(x)$	**Arbitrary function**
θ	**Angle of incidence of the wind**
$\bar{m}$	**Mass per unit length**

1- Introduction

The high-voltage lines and tower of tension structure in the electric energy Transmission Networks in Iraq are subjected to different aerodynamic forces such as wind velocity, or from explosive next to network. Which may cause fatigue in these transmission lines, fretting, and other failure modes acquire in tower under galloping motion of single or multiple conductors. The topic of galloping and wave motions of strings has been studied widely and development in recent research,

Gi Sig Byun et al. [1]. presented the theoretical and numerical method analysis using the describing function methods (DF) to estimates the maximum amplitudes on conductor galloping motion to determine appropriate phase-to-phase clearances of overhead power lines, using a mathematical models of conductor galloping, which include both vertical and torsion motion with various wind speeds. They showed that a good agreement with the maximum amplitude and frequency estimate predicted by the model, also the amplitude estimates obtained by the DF method when torsional motion is included do tend to be smaller than those obtained when only vertical conductor motion is assumed.

H. Wang *et al.* [2]. Presented theoretical and numerical investigation model applying non-linear wave equation and solutions to obtain the general solutions neglecting the curvature and torsional motion, for wind induced galloping of overhead electric power lines. Noted the standing and traveling wave solution are observed depending on the initial data, also showed that galloping solutions can always be damped if a dashpot-type damper of correct stiffness is used at one end of the line.

Y. M. Desai *et al.* [3]. They used the finite element idealization and integral dynamic equilibrium equation with nonlinear damping to analyses galloping for large amplitude vibration of iced, multi-span, electrical transmission line. Support insulator string and remote conductor spans are represented by linear static springs. They developed to obtain the envelope of galloping. Showed that it is necessary to consider a multi rather than were single span for a conservative estimate of the galloping amplitudes to enable sufficient clearances to be designed between adjacent conductors.

O. Chabart *et al.* [4]. Studied the galloping generated during wind tunnel testing with an ice accretion on the conductor. In the first part, the quasi-static aerodynamic coefficients have been measured for different wind speeds. In the second part the same sample has been suspended in the wind tunnel by spring in order to obtain a system as close as possible to on overhead line. Improve from these test make available a full set of data and recording of limit cycles during galloping events. They showed that the system used to simulate galloping on a suspended string model is appropriate and good agreement with the tendencies.

Rong Fong *et al.* [5]. Investigated the qualitative aspects of parametric excitation due to the non-constant traveling velocity of a viscoelastic string, considered is initially stressed viscoelastic string subjected to steady state and harmonic variation of axially traveling motion. Developed the partial differential equation of motion, and then it is reduced to be a set of third order nonlinear ordinary differential equation by applying Galerkin's method. The effect of elastic and viscoelastic parameters, are investigated numerically. They noted that the decreasing value of material properties elastic and viscoelastic leads to a decreasing in the vibration frequencies, and the wave speed ratio increases, the frequency of the transient amplitude will increase.

T. Kalman *et al.* [6]. Presented a numerical model by using nonlinear finite element analysis to calculate the dynamic effect of glaze ice shedding induced by a pulse- type excitation on a single-span overhead line section. Several ice-shedding scenarios are studied with variables including span length and pulse-load characteristics. Showed that the FE model can serves as a basis to study various failure criteria of atmospheric glaze ice in terms of stress-strain relations and strain-rate effects.

Pierre Van *et al.* [7], Presented the experimental method to measure the galloping conducted motion on a high-voltage overhead test line with interphase spacers and D-section over the conductor. One of the results observed that the interphase spaces play an important rate in the behavior of the D-section with respect to galloping amplitudes. Consequently, intend of remaining in a cross flow orientation, the D-section has an initial angle of incidence that varies between 0^{o} and 20^{o}, depending on the perpendicular component of the wind speed.

Renato Barbieri *et al.* [8]. Presented mathematical nonlinear models for simulation of the dynamical behavior of transmission line inclined cables. Also using the numerical models is obtained through the finite element method.

The simulated results are compared with experimental data obtained in an automated testing system for overhead line cables. They show in cables with larger sag, Variations can be noticed in the first natural frequencies comparing the linear and nonlinear numerical results. These variations depend on the sag and the applied load. the edition of concentrated mass in straight cable change the dynamic behavior with modal uncoupling near the veering region presenting the same behavior as the one for inclined cable. Fluctuations of the load cable or increase of central sag can change the natural frequencies of the system. Luigi Carassale *et al.* [9]. They used non-linear theory for the description of the mechanical behavior, and of the guast-steady assumption for the description of the aerodynamic forces, the random oscillations of small-sag, small-diameter cable induced by a turbulent wind are investigated through a reduced- order model containing both mechanical and aerodynamic non-linearities. They notice the following main resulting. (1) a good convergence of the discretization is obtained including a quite large number of modes;(2) the modeling of the non-linear direct excitation o turbulent appears fundamental to obtain a correct estimation of the probability distribution;(3) the linear aerodynamic damping does influence the response, particularly when the mean velocity is sufficient high, while the non-linear aerodynamic damping terms do not provide any significantly contribution. The all above aforementioned research, speak and conclusions the list of different parameters, little from it about the using a finite element method and theoretical analyses for galloping motion only[1,2,3,5,6,8,9], other researches using experimental analyses for motion of cable with wind tunnel[4,7]. The aim of this research is to study the effect of Multi parameter on the galloping and vibration motion in the string and method of reducing by using simple model in electric energy transmission network in Iraq.

2- Theoretical Modeling

This part discuss the theories of modeling analysis for string vibration and investigate the effect of the wave velocity on the amplitude of galloping, these steps are , wind force , differential equation of string, and mode shape of string . The properties of the wind, string, and tower structure are listed in **tables (1, 2, and 3)**:

Table (1): Wind Properties [10]

Wind speed (km/h)[11]	**ρ = Air density (kg/ m^3)[13]**	**μ = Dynamic viscosity (N.s/m^2)[13]**
12 – 145 (3.334 - 40.3 m/s)	1.2929	1874.9808e8

Table (2): geometry Properties of 400kv transmission electric lines in Iraq [11]

String material	**Complete coil Diameter(mm)**	**Span of string (m)**	**z_1, z_2, and z_{min} (m).fig.3**	**Tension (N)**
String (AAAC)	35	500 ± 25	$34, 34, 8.25 \pm 3$	$3142\ kg (30.812 kN)$
String (ACSR)	50	500 ± 25	$34, 34, 8.25 \pm 3$	$2977\ kg (29.194\ kN)$

Table (3): String Properties 400kv [12, 13]

String Material	Yield stress (σ_y) MPa.	Ultimate stress ($\sigma_{ult.}$) M Pa.	Modulus of elasticity (E) GPa.	Mass / unit length (kg/m)	(number of wire) x (wire Diameter mm)
1.Aluminum alloy (T.A.A.A.C)	344.737	482.632	73.084	1.516	37 x 4.34
2. Aluminum /steel (ACSR)	344.737 / 330.948	482.632 / 448.159	73.084 / 199.947	2.3089	45 x 4.36 , 7 x 3.4

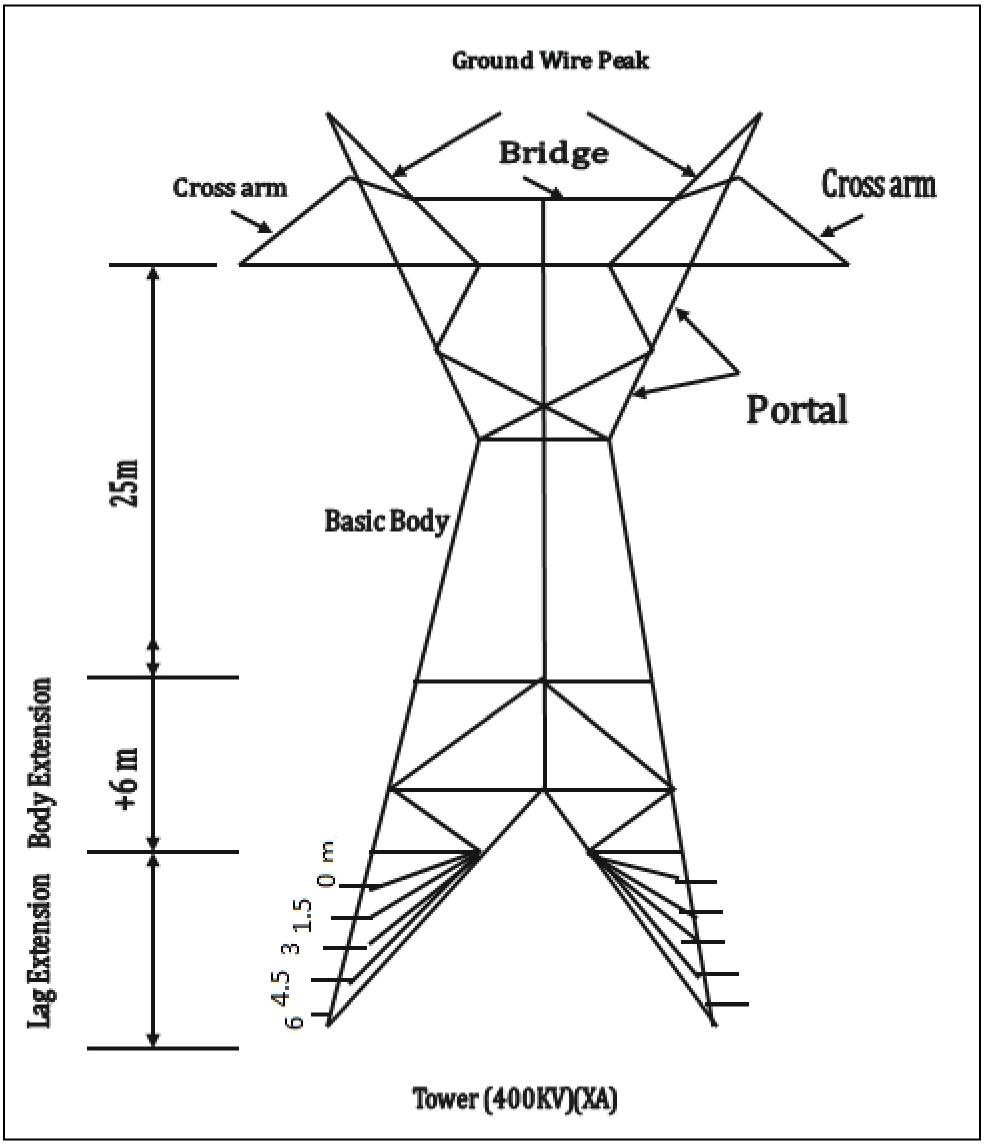


Figure (1): Dimension Of 400kv Tower

2-1 Wind Forces

Theoretical Wind loading competes with seismic loading as the dominant environmental loading for structures. They produce roughly equal amounts of damage over a long time period, although large damaging earthquakes have tended to occur less often than severe windstorms. Almost every day of the year a severe windstorm is happening somewhere on earth – although many storms are low and localized. The nominal wind force acting on a single conductor perpendicular to the span can be taken to be **Eq.1** [14]:

$$F_c = P_{zc}.C_D.A_c.\sin^2\theta.\propto \tag{1}$$

Where

- $P_{zc} = \frac{\rho_{air}\,U_{zc}^2}{2}$ (The free-stream dynamic wind pressure)
- $zc = \frac{0.5(z_1+z_2)+z_{min}}{2}$ (Mean conductor height)
- $C_D = f(Re.) = \frac{24}{Re} + \frac{6}{1+\sqrt{Re}} + 0.4$, (The drag force coefficient for the conductor)[15]
- The Reynolds number is[15] : $Re = \frac{U_{zc}\,d}{\nu}$
- $A_c = S \times b$ (The reference area, S and b are wind span and diameter conductor see **Fig. 1**
- θ Is the horizontal angle of incidence of the wind in relation to the direction of the line
- $\propto = 0.58 + 0.42\,exp\left(\frac{-L}{180}\right)$ Span reduction factor [14]
- The average velocity of wind in Iraq is listed in **table 1**.

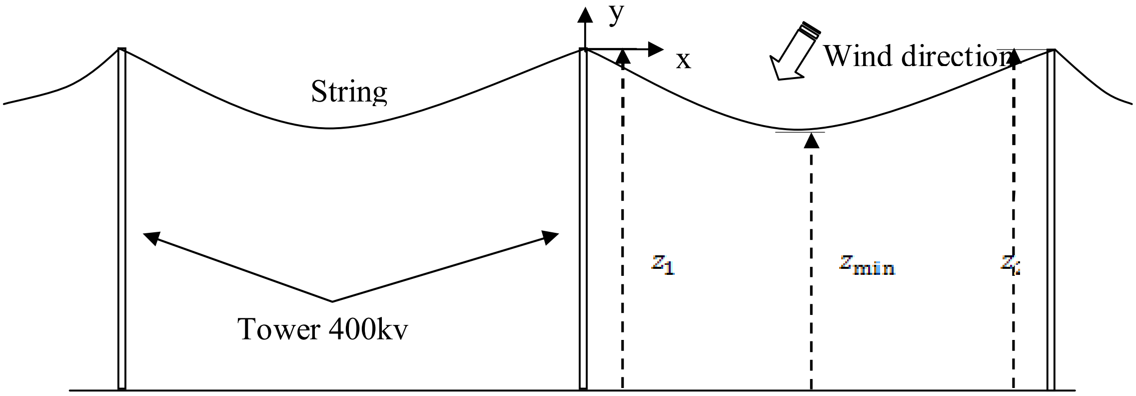


Figure (2): Dimensions Of String Model 400kv

2-2 Vibration of String Model

The high voltage transmission line shown in **Fig.2**, is assumed continuous system. To derive the equation of motion is Newton's second law of motion is applied. When the cable subjected to transverse wind force $f(x,t)$, as shown in **Fig.1**, [16]. Where the transverse displacement $w(x,t)$ in y direction so the equation will be as:

$$\frac{\partial^2 w}{\partial^2 t} - a^2 \frac{\partial^2 w}{\partial^2 x} + \beta \frac{\partial w}{\partial t} = \frac{f_{(x,t)}}{\bar{m}} \tag{2}$$

Where:

$$a = \sqrt{\frac{T}{\bar{m}}} \qquad \text{(velocity of wave moves along string)} \tag{3}$$

$T = tension\ N;\ \bar{m} = mass\ per\ unit\ lenth;\ \beta = structure\ damping = 1.5$[16]

where the boundary conditions are:

$$w_{(x,t)}\Big|_{x=0} = 0 \tag{4}$$

$$w_{(x,t)}\Big|_{x=L} = 0 \tag{5}$$

and the Initial conditions are:

$$w_{(x,t)}\Big|_{t=0} = y(x) = \begin{cases} -\left(\alpha\sqrt{x * 0.1}\right) & 0 < x < 175\ m \\ -\left[\alpha\sqrt{-(x-250) * 0.1}\right] & 175 < x < 350\ m \end{cases} \tag{6}$$

$$\dot{w}_{(x,t)}\Big|_{t=0} = 0 \tag{7}$$

Where $\alpha = \frac{\bar{m}}{2\,T}$

2-3 The Theoretical Model Solutions

The solution of the equation describing the vibration of string by a nonlinear partial differential equation of second order nonhomogeneous **Eq.2** (*nonlinear Klein-Gordon equation)* or called wave equation. For solution the **Eq.2** we need to change the variable $y\ to\ (w + \psi)$ [18, 19], i.e.

$$W(x,t) = Y(x,t) + \psi(x) \tag{8}$$

Sub. **Eq. 8**, in **Eq. 2 ,** we get the new force vibration equation of string

$$\frac{\partial^2 y(x,t)}{\partial t^2} + \beta \frac{\partial y(x,t)}{\partial t} = a^2 \left(\frac{\partial^2 y(x,t)}{\partial x^2} + \frac{\partial^2 \psi}{\partial x^2}\right) + \frac{f(x,t)}{\bar{m}} \tag{9}$$

where

$$\psi(x) = -F_c(x,t)\,\frac{x(L-x)}{2a^2} \tag{10}$$

which is arbitrary function depends on the load, and $y(x,t)$ depends on the location and time.

Now solve the wave equation **Eq.9**, using the special statement from the formal of variable *separation method* with the new boundary and initial condition below **Eqs.11 to 14**.

New boundary conditions are:

$$y_{(x,t)}\Big|_{x=0} = -\psi(0) \tag{11}$$

$$y_{(x,t)}\Big|_{x=L} = -\psi(L) \tag{12}$$

Also the new Initial conditions are:

$$y_{(x,t)}\Big|_{t=0} = y(x) = \begin{cases} -\left(\alpha\sqrt{x * 0.1}\right) - \psi(x) & 0 < x < 175\ m \\ -\left[\alpha\sqrt{-(x-250) * 0.1}\right] - \psi(x) & 175 < x < 350\ m \end{cases} \tag{13}$$

$$\dot{y}_{(x,t)}\big|_{t=0} = 0 \qquad (14)$$

Where $\alpha = \frac{\bar{m}}{2T}$

Substitutes **Eqs.(11, 12, 13, and 14)**, with **Eqs. 9, 10** and Benefit of mathematical program **Maple-13** to finding the new solution of general equation for string under wind force depended on parameter, wind properties and physical properties of string are represented below **Eq. 15**. Its Equation solve for Multi length, wind velocity, physical properties of string.

$$\begin{aligned}
y(x,t) = e^{-1.5t/2}\frac{2}{L}\sum_{n=1}^{\infty} & \Bigg(\Big[\cos\Big(\frac{n\pi}{2}-1\Big)\Big(\frac{\rho}{2n\pi T}\Big)(4.i833L-1464.155)\Big] \\
& +\Bigg[\frac{\rho}{2T}\Bigg(P_{zc}C_DA_c\alpha\Big(\frac{1}{2}-\frac{\cos(2\theta)}{2}\Big)\Bigg)\Bigg[-\frac{21437500\Big(-2\sin\Big(\frac{n\pi}{2}\Big)+\cos\Big(\frac{n\pi}{2}\Big)n\pi\Big)}{(n\pi)^2} \\
& +\frac{1}{(n\pi)^3}\Bigg(10718750\Bigg(8-8\cos\Big(\frac{n\pi}{2}\Big)+(n\pi)^2\cos\Big(\frac{n\pi}{2}\Big)-4n\pi\sin\Big(\frac{n\pi}{2}\Big)\Bigg)\Bigg)\Bigg]\Bigg)\Bigg] \\
& +\Bigg[\frac{1464.155\rho}{n\pi T}\Bigg(\cos\Big(\frac{n\pi}{2}\Big)-\cos(n\pi)\Bigg)-\frac{\rho}{2T}\Bigg(P_{zc}C_DA_c\alpha\Big(\frac{1}{2}-\frac{\cos(2\theta)}{2}\Big) \\
& \Bigg[\frac{1}{(n\pi)^2}\Bigg(21437500\Bigg(-2\sin\Big(\frac{n\pi}{2}\Big)+\cos\Big(\frac{n\pi}{2}\Big)n\pi+2\sin(n\pi)-2\cos(n\pi)n\pi\Bigg)\Bigg) \\
& -\frac{1}{(n\pi)^3}\Bigg(10718750\Bigg(-8\cos\Big(\frac{n\pi}{2}\Big)+(n\pi)^2\cos\Big(\frac{n\pi}{2}\Big)-4n\pi\sin\Big(\frac{n\pi}{2}\Big)+8\cos(n\pi) \\
& -(2n\pi)^2\cos(n\pi)+8n\pi\sin(n\pi)\Bigg)\Bigg)\Bigg]\Bigg)\Bigg]\Bigg)\sin\Big(\frac{n\pi x}{L}\Big)\ \cos\Bigg(\sqrt{\Big(\frac{n\pi}{L}\Big)^2\frac{T}{\rho}-\Big(\frac{3}{4}\Big)^2}\ t\Bigg) \\
& -\frac{\rho P_{zc}C_DA_c\alpha x(L-x)(1-\cos(2\theta))}{4T} \qquad (15)
\end{aligned}$$

3- FEM Model

ANSYS Workbench-V12 is a general purpose finite element modeling package for numerically solution[20], the vibration analysis of system in this package are passing through three stage (a) static analysis, (b) model analysis (free vibration), and (c) transit vibration (force vibration) **Fig 3**. Simulate the wind velocity effect on the modal of string In this paper is by using the ANSYS Workbench-V12.

The procedure of Create the model an package (ANSYS) have list steps:

- starting from Select the unit system and assign the material properties see **Fig.4**
- create the string geometry in Design Moeller **Fig(5a-b),**
- Mesh the part **Fig.(6)** and **Table 4**.
  No of node = 73425
  No of element = 13590
- Set the Boundary condition in other ends of string – fixed supported1,2 see **fig.7**

- Calculated Applied wind loads from **Eq. 1**, and inserted to the FE model of string **Fig.(7)**
- Solution a FE model under static condition, model condition (free vibration), random vibration (force vibration).
- The final step see a review the results. See simple of result in **Fig (8, 9,10 and 11)**.

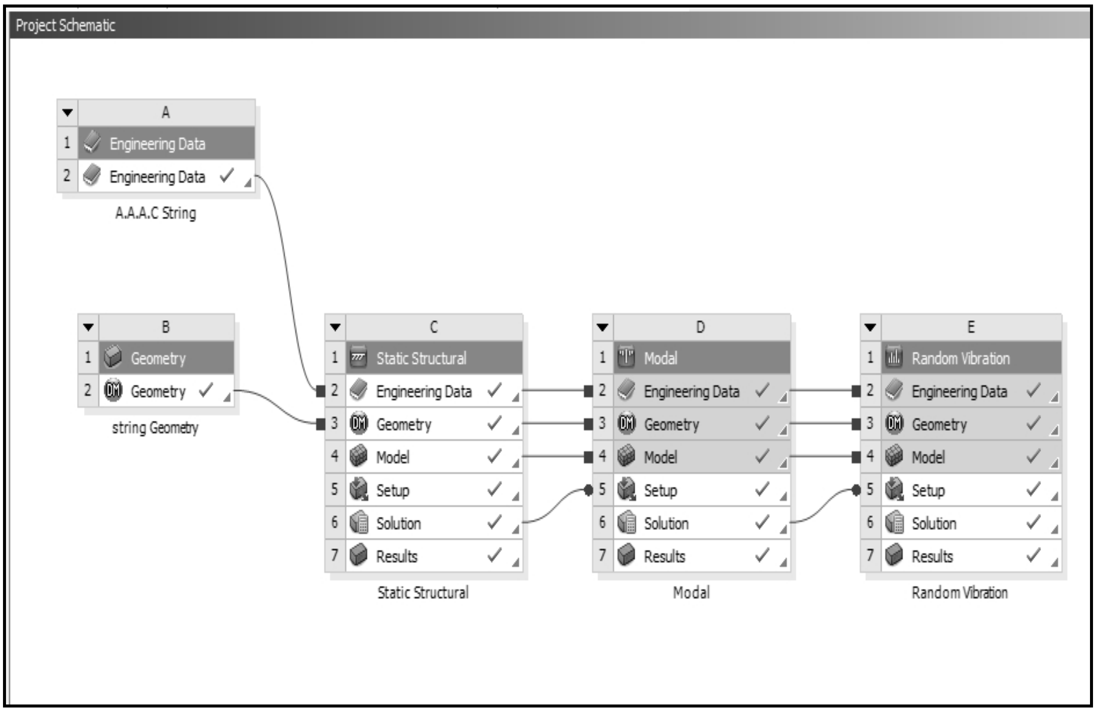
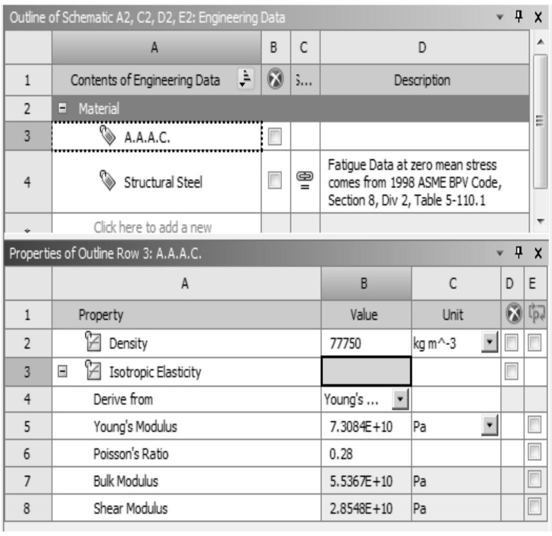


Figure 3: general three stage



Outline of Schematic A2, C2, D2, E2: Engineering Data

	A	B	C	D
1	Contents of Engineering Data		S...	Description
2	Material			
3	A.A.A.C.	☐		
4	Structural Steel	☐		Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1
*	Click here to add a new			

Properties of Outline Row 3: A.A.A.C.

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	77750	kg m^-3	☐	☐
3	Isotropic Elasticity			☐	
4	Derive from	Young's ...			
5	Young's Modulus	7.3084E+10	Pa		☐
6	Poisson's Ratio	0.28			☐
7	Bulk Modulus	5.5367E+10	Pa		☐
8	Shear Modulus	2.8548E+10	Pa		☐

Figure (4): Model Properties

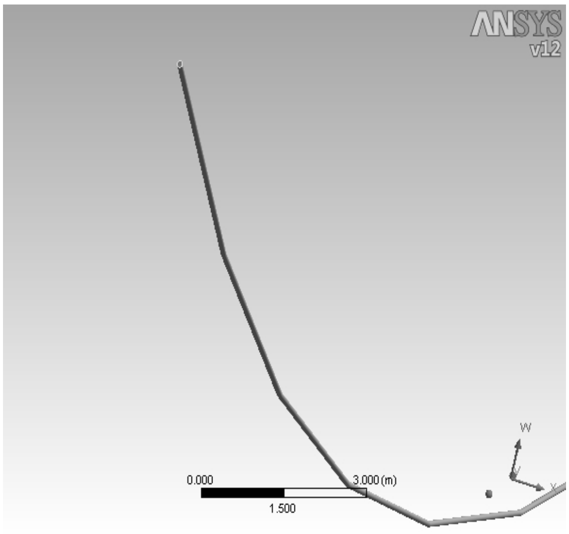
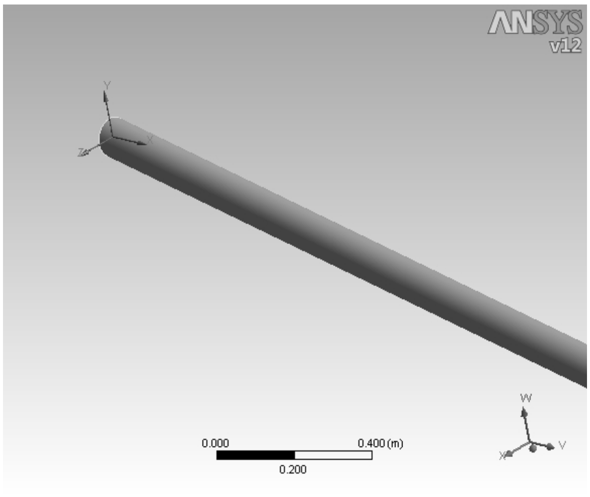


Figure (5a): Model Geometry



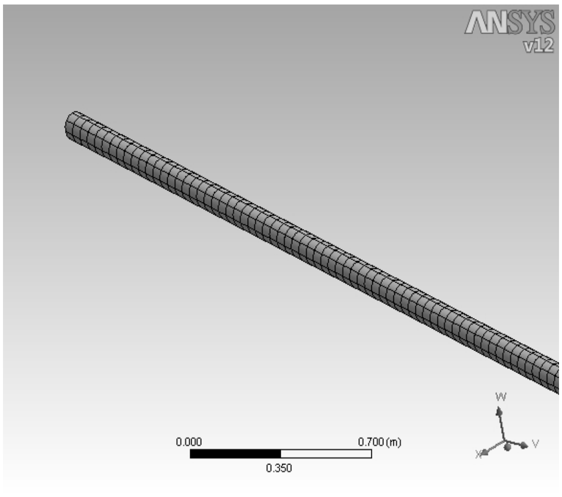
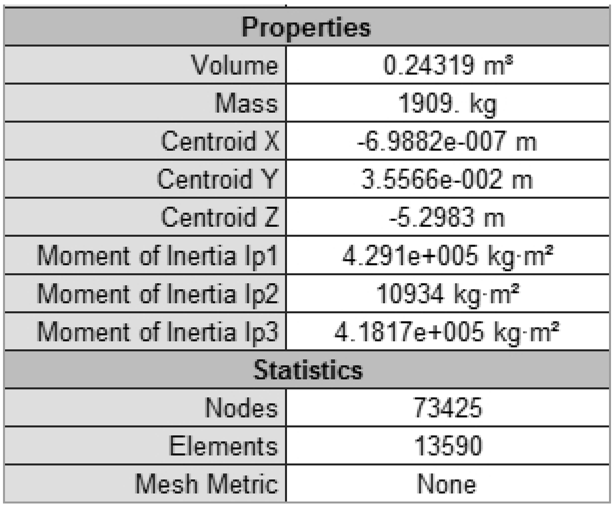
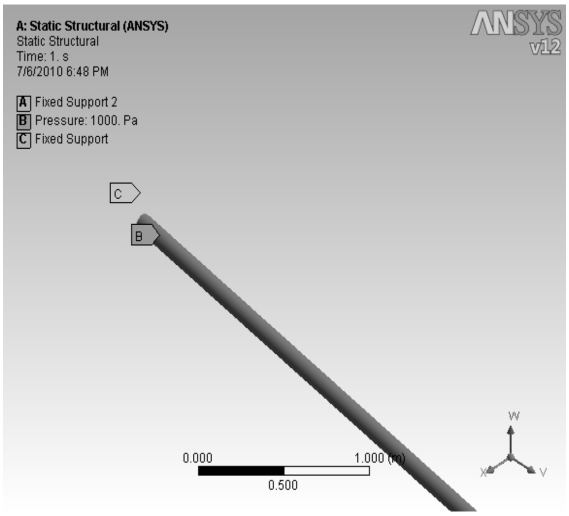


Figure (5b): Geometry With Figure (6): Mesh Distribute
Coordinate System

Table 4: Geometry And Mesh Statistics(Ansys Output)



Properties	
Volume	0.24319 m³
Mass	1909. kg
Centroid X	-6.9882e-007 m
Centroid Y	3.5566e-002 m
Centroid Z	-5.2983 m
Moment of Inertia Ip1	4.291e+005 kg·m²
Moment of Inertia Ip2	10934 kg·m²
Moment of Inertia Ip3	4.1817e+005 kg·m²
Statistics	
Nodes	73425
Elements	13590
Mesh Metric	None



A: Static Structural (ANSYS)
Static Structural
Time: 1. s
7/6/2010 6:48 PM

A Fixed Support 2
B Pressure: 1000. Pa
C Fixed Support

Figure (7): B.C. And Applied The Load

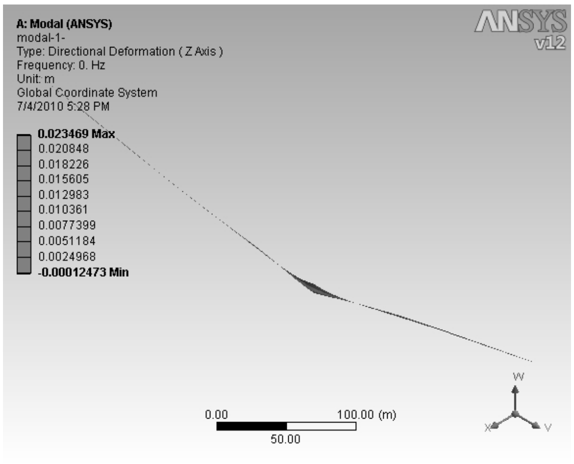


Figure (8): Mode Shape-One

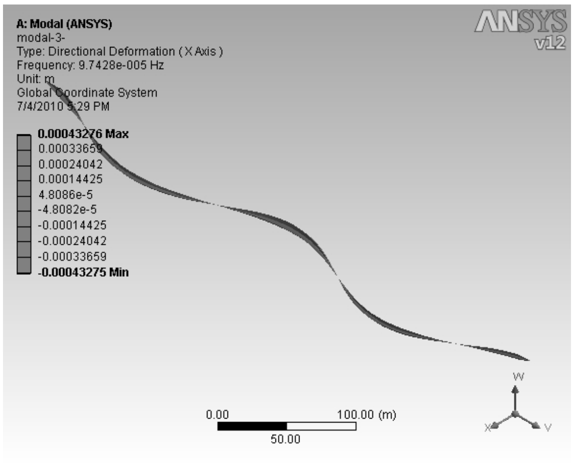


Figure (9): Mode Shape-Two

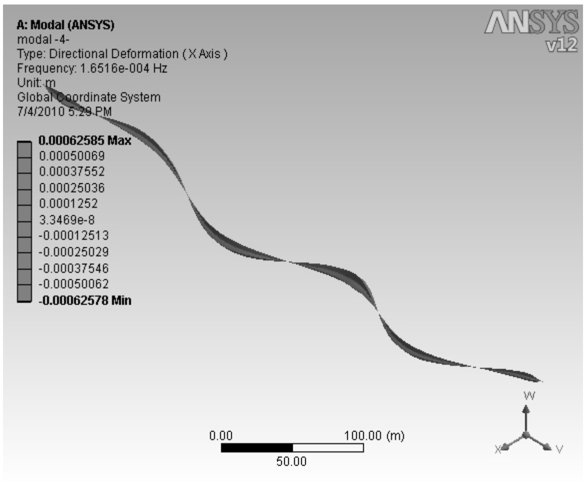


Figure (10): Mode Shape-Three

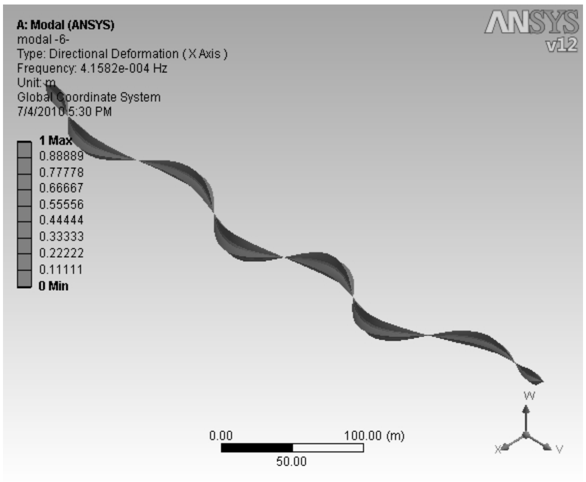


Figure (11): Mode Shape-Six

4- Result

4-1 Wind Velocity Result

The wind velocity effect at the height of conductors center of gravity is shown on **Fig.12, and 13.** the velocity assumes are 2, 5, 10, 20, 40 m/s and substitute in Eq.1, and15 for: a) **AAAC** material , notice the galloping occurs when the velocity are large than 10 m/s (36 km/h) were the altitude is larger than 3.07 m see fig.12. b) when using the **ACSR** material the galloping occurs at velocity is large than 15 m/s (54 km/h) **Fig.13**.the deferent in magnitude between this two materials are because different in modulus of elasticity and because the effect of steel core an **ACSR** string.

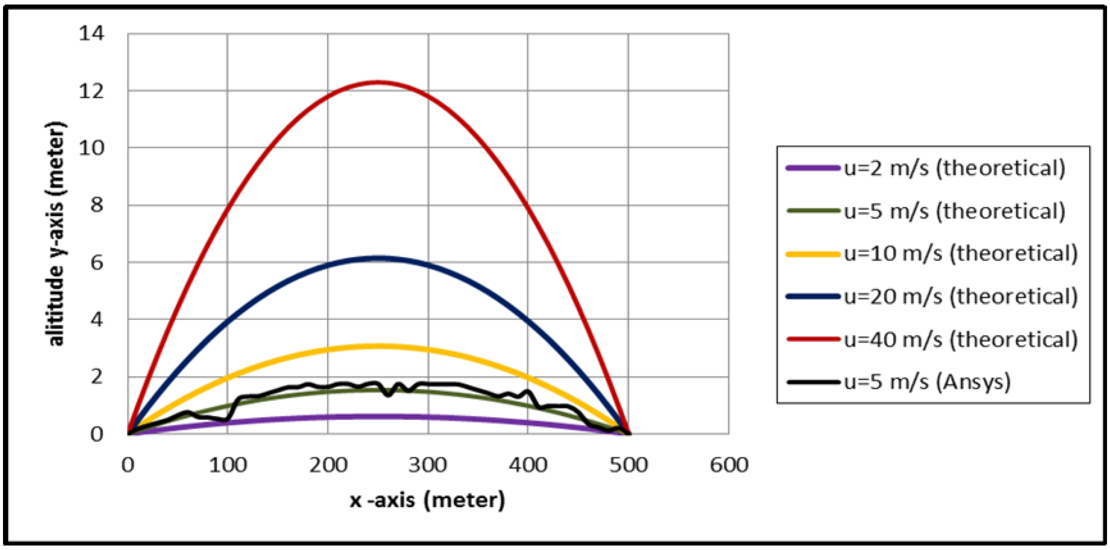


Figure (12): AAAC Type at L=500; T=29KN

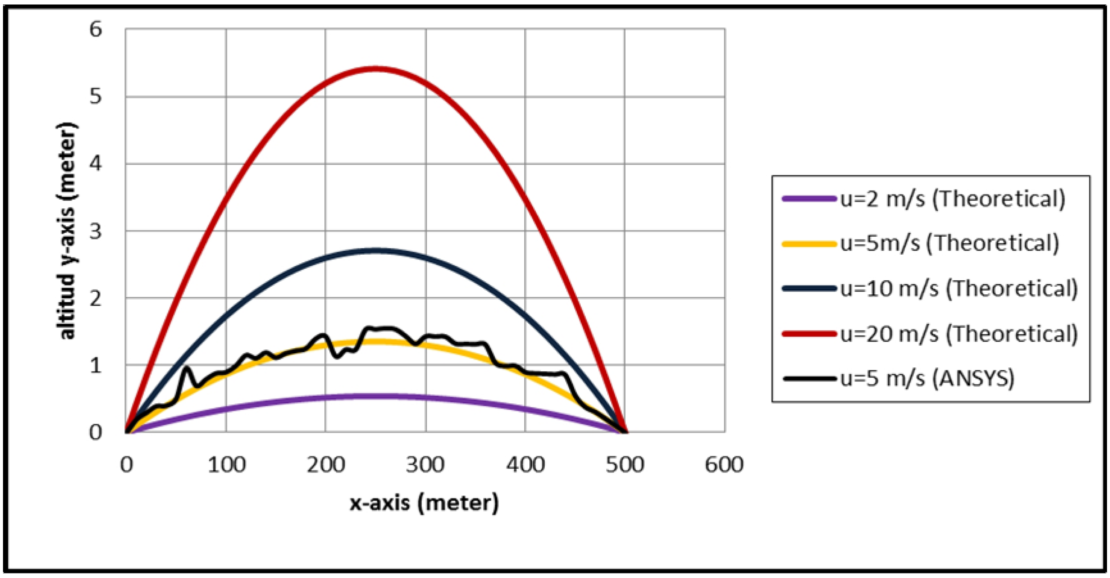
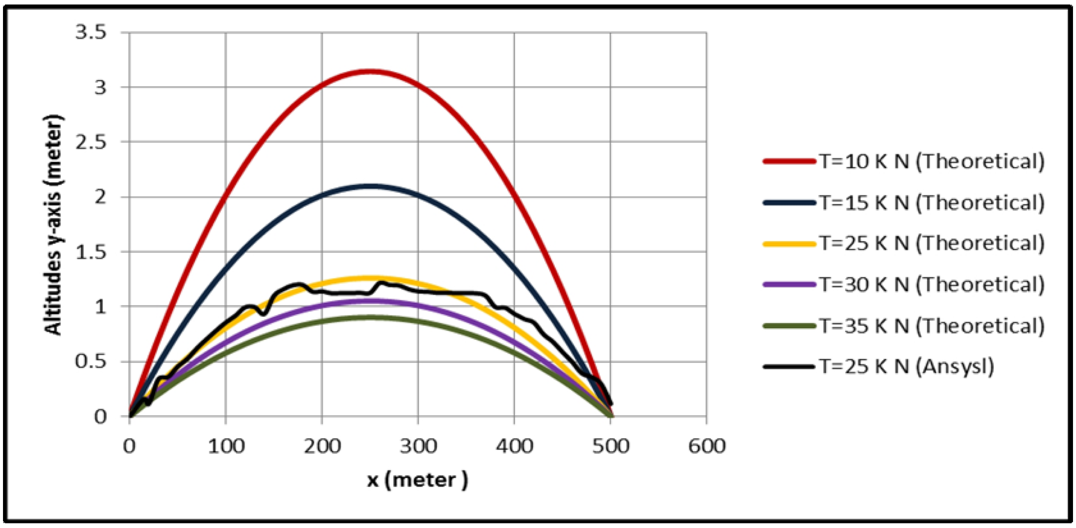


Figure (13): ACSR Type L=500; T=31 KN

4-2 Tension of String Result

Fig. 14 and **Fig. 15** show in the same format the results obtained in the case of tests with deferent tension force applied to the string. Show the galloping motion is unformed when the tension force are increasing, also we notes the better tension are approximated 25 KN, and 30 KN, for **AAAC**, and **ACSR** material respectively. From this result show, can be controller on the galloping altitude by the tension force, put because the ultimate tension force for any materiel have limited, using the composite string to improvement the behavior of conductors.



Figure(14): AAAC Type at L=500 M; u=3.334 m/sec.

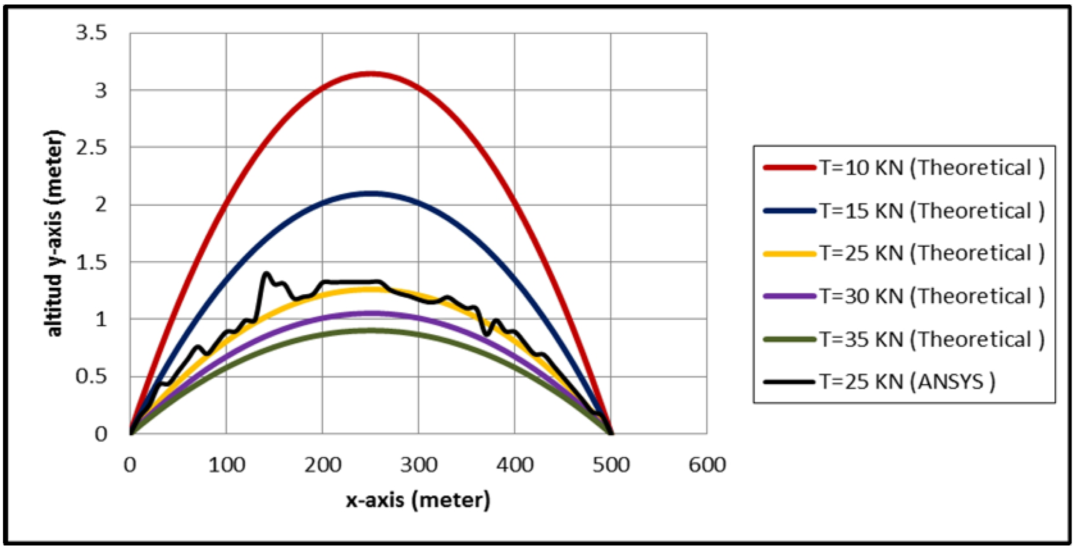


Figure (15): ACSR type L=500M; U=3.334m/sec.

4-3 Span String Result

Fig. 16, and **17** show that the length effect of string on the galloping shape for tow type of material, we Notes a distance between any tow tours are very important to control of galloping motion. Put this parameter depended on the cost. **Fig.16,** for **AAAC** material the altitude are decreasing when the destines decreasing at any velocity of wind, i.e. at x=125 m, the altitude y=1.5m, when the span L=250 m. put for ACSR material y=1.3 m see **Fig.17**. We Notec the deferent in altitude magnitude of string because the mass per unit length of conductor are variable between aluminum and steel.

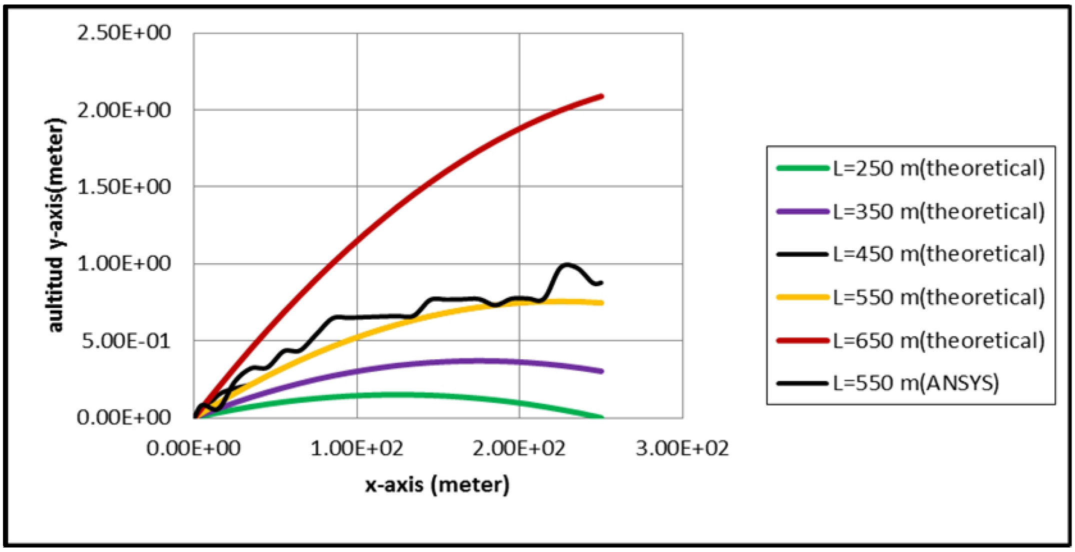


Figure (16): AAAC Type at T=29 kN; U=3.33 m/sec.

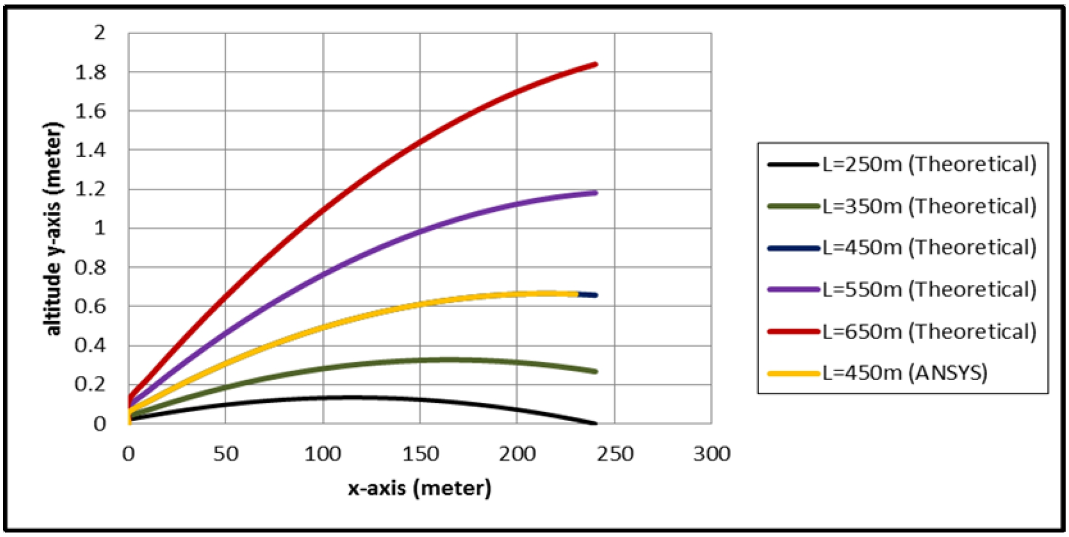


Figure (17): ACSR type; T=31kN; U=3.334 m/sec.

5- Conclusion

The paper presents the using of the nonlinear Klein-Gordon theory to analysis Equation of motion the electric line under wind force. Show the span and material properties played an important role in the galloping motion and amplitude of wave. For a control on this parameter and improved the network electric in Iraq, can using the span is not large than 250 m between any two towers, and use *ACSR materiel* for all string application. Also the high amplitude of galloping motion an account of failure the tower structure, string electric line or together because the residual stress in string and/or translations from string to tower. The tension force effect in ether materiel are fellow, put when increasing the tensing force decreasing the amplitude of galloping , then the ACSR material can by applied for widely ring of force because high ultimate tensile stress compare with AAAC and mass per unit length is increasing. Also the ANSYS software package takes a good resulting with number of command and application tools.

6- References

1. GI Sig Byun and Robert I. Egbert," *Two- Degree-Of- Freedom Analysis Of Power Line Galloping by Describing Function Methods",* Electrical Engineering Systems Research NO.21, 1991.
2. H. Wang and A. R. Elcrat," *Modelling And Boundary Control Of Conductor Galloping"* Journal of Sound and Vibration No.161 (2), 1993.
3. Y. M. Desai , P. Yu, N. Popplewell and A. H. Shah*," Finite Element Modelling Of Transmission Line Galloping",* Pergamum, Computers and Structures Vol.57 No.3, 1995.
4. O. Chabart and J. L. Lilien," *Galloping of Electrical Lines in Wind Tunnel Facilities"* Elsevier, Journal of Wind Engineering and Industrial Aerodynamics, 1998.
5. Rong-Fong Fung *,Jeng-Sheng Huang, Ying-Chang Chen, Chin-Min Yao," Nonlinear Dynamic Analysis Of The Viscoelastic String With A Harmonically Varying Transport Speed"* Pergamon, Computers and Structures Vol.66 No.6, 1998.
6. T. Kalman, M. Farzaneh, G. McClure*." Numerical Analysis Of The Dynamic Effect Of Shock-Load-Induced Ice Shedding on Overhead Ground Wires", ScienceDirect, 2007.*
7. Pierre Van Dyke and Andre Laneville," *Galloping Of A Single Conductor Covered With A D-Section On A High-Voltage Overhead Test Line*", Elsevier, Journal of Wind Engineering and Industrial Aerodynamics 96, 2008.
8. Renato Barbieri, Nilson Barbieri, Oswaldo Honorato*," Dynamical Analysis of Transmission Line Cables"* ScienceDirect, Mechanical System and Signal Processing, 2008.
9. Luigi Carassale and Giuseppe Piccardo," *Non-linear Discrete Models For The Stochastic Analysis Of Cables In Turbulent Wind",* Journal of Non-linear Mechanics 45, 2010.
10. Iraqi Meteorological organization and seismology - http://www.imos-tm.com
11. SL. Bhatia, "handbook of electrical engineering" Khanna, 1983.
12. Marks," *Standard Handbook for Mechanical Engineers"*, McGraw-Hill, Tenth edition, 1996.
13. Iraqi ministry of electricity- training and development office-Baghdad electricity training center.
14. John D. Holmes," *Wind Loading Of Structures",* Spon Press, 2001.
15. Bruce R. Munson, Donald F. Young, Theodore H. Okllshl," *fundamentals of Fluid Mechanics",* John Wiley & Sons, Inc., 2005.
16. Singiresu S. Rao," *Mechanical Vibration",* Pearson Hall, 2005.
17. Zaiyun Zhang," *New Exact Traveling Wave Solutions for the Nonlinear Klein-Gordon Equation"* Turk J Phys, 2008.
18. Richard Haberman," *Elementary Applied Partial Differential Equations",* Prentice-Hall, 1987.
19. Morry R. Sbejel," applied differential equation", John Wiley,1980.
20. ANSYS Workbench version 12.0.1, 2009 SAS IP, Inc.