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Simulation of the Configuration Geometrical Shape of Submarine Pipelines During Laying

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Abstract

To simulate the shape of submarine pipeline during installation an attempt had been tested in the present paper. The results of OFFPIPE software were used and a statistical regression was the tool followed to reach the best function or curve near the shape of OFFPIPE results by curve fitting. So many functions were tested but they failed. The sigmoid function was the one which gives success and best fit. It is an exponent function which has five parameters a ,b ,c , Xo and y_o*. A charts or curves were prepared to find out these parameters to be substituted in the original sigmoid function. If these parameters are known, sigmoid function can be easily substituted in the nonlinear beam deflection equation to find any unknown displacements and stresses as it was well-known for structural engineers. So many variables which are affecting on pipeline shape were discussed here including water depth , tension applied on pipe ,pipe diameter and pipe thickness. The governed ready curves can be used as data base to solve this complicated problem.*

Introduction

The problem of the unknown shape of the pipeline during installation is really a very complicated problem facing engineers and scientists in the analysis and design of such offshore problems. That is because of the different multiple connected parts mostly having curvilinear shapes. These parts can be divided into four parts as shown in Fig.(1) : 1.Sea bed part that has horizontal straight length depending upon the assumption used to model the seabed soil. This part is represented by the segment between the first touchdown point of the pipe to the sea pipe end.

2.Sag-bend part which is the part between the touchdown point and inflection point before the stinger. The shape of this part is taken to be approximately catenary by so many authors. This part is the most dangerous because it is free of supports and has the longest span.

3.Over-bend part is that part of the submarine pipeline rested on the barge stinger between the inflection point and deck of the barge. The shape of the pipe here takes approximately the shape of the stinger. Silva D.M. et al(1) proposed two numerical models for the analysis of the interaction between pipeline and lay barge on the over-bend region. This analysis includes not only the contact between the pipeline and the launching structure but also the tensioner behavior.

4.Barge part where the pipe is lying on the deck of the barge prepared to be supplied to the stinger then to the sea. The shape here is approximately straight beam rested on side feeder supports

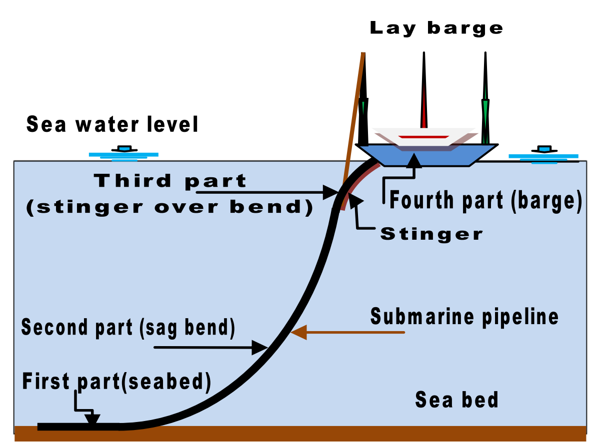


Fig.(1) Submarine pipeline installation by S-lay method.

So the problem is really how to model the pipe in the middle parts namely the sag-bend and over- bend parts because other two end parts are beams supported on certain media. These end parts are the seabed part which can be modeled as beam rested on an elastic foundation and the barge part which is continuous beam supported by so many side feeders or rolling supports. The assumption of the middle two parts; one or two of them, to be catenary is weak because the pipeline is exposed to tension. To overcome this difficulty Dixon & Rutledge(2) assumed that the pipe is stiffened in the two end parts to reach a model that is near the truth and they solved the problem depending on an asymptotic expansion. Since the problem is geometrically nonlinear problem and due to the mentioned difficulties especially large displacements so many workers and researchers had been study this problem to reach a suitable solution(3,4,5,6) .The analysis of pipeline done by those authors focus on an approximate solutions using numerical methods to solve the governed nonlinear beam deflection equation because there is not an exact analytical solution. The present work focuses on a try attempt to use S-lay method in deep water because this method was used in shallow waters limited to maximum depth of 150 m . Above this range of depth another method of laying pipelines is used called J-lay method which can cover depths of up to 3500m (7,8,9).

Malahy(10) proposed a very fantastic software to solve such problem called OFFPIPE which takes into consideration all of the variables affecting on pipe laying technique. These variables include pipe diameter, pipe thickness, coating of the pipe, depth of the water, tension applied on the pipe, forces applied on the pipe including self-forces and all of the environmental forces. This software has the ability of making static and dynamic analysis . The pipeline was treated as a beam which is the ordinary assumption done by most of the authors to solve the problem. OFFPIPE is used nowadays in the analysis and design of the submarine pipelines. In our present work the software OFFPIPE was used to find out the results of the analysis of pipeline. One of the most important results was the configuration shape of the deflected pipeline during installation. This shape cannot be known before the analysis because of the nonlinearity besides the so many variables which the pipe exposed to. If this suspended shape is known the problem becomes too easy to be solved by the nonlinear beam deflection theory.

Aim of the study

The goal of this work is to achieve the analysis of submarine pipelines through the use of the nonlinear deflected beam theory equation. This cannot be done without the knowledge of the deflected pipeline function. The deflected shape of this beam is primarily unknown, so to reach an equation representing it, this needs a use of an available results. OFFPIPE software results are used to overcome this task work and from which a curve fitting was used to reach the most appropriate function

Formulation of the problem

Most of the researchers assumed that the suspended pipeline is a long beam exposed to large deflections and supported at one end at the sea bed and partially free at the other end. Therefore it is a nonlinear geometric problem exposed to unfamiliar self and environmental loads. If the shape of the deflected beam is reached, so by applying the moment equation of the beam theory Eq.(1) all of the unknown forces can be calculated.

$$M = EI \frac{y''}{\left[1+(y')^2\right]^{1.5}} ----------(1)$$

The first step is to find out the results of the software OFFPIPE and draw them. The governed shape of the results cannot be represented by a one continuous equation because it is an accumulation of four parts as explained earlier. So many trials of curve fitting were done to find the most acceptable suitable continuous equation of the deflected shape. It was found that the equation which gives a very accurate results was the sigmoid with five parameters. If the deflected shape of the pipeline is governed which means an equation of deflection having so many parameters related to the horizontal distance (x) from a specified point had been obtained. If this equation is derived two times ,then Eq.(1) can be used easily by simply using a very simple program to facilitate the calculations of all internal forces and stresses in the pipeline. This methodology is used for the S-lay method and not to J-method which needs more study and is not included in this presented work.

A nonlinear regression analysis was made to know the perfect fit of the equation. The knowledge of the deflections in this indeterminate problem leads to an open window to find out unknown forces and displacements in the pipeline. The most appropriate curve gives fit to the pipeline deflection is the sigmoid equation. This equation is a nonlinear ordinary equation with five parameters as follows:

$$y = y_o + \frac{a}{\left[1+e^{-\frac{(x-x_o)}{b}}\right]^c} -------(2)$$

Results and discussion

To make sure that the aim of this work was fulfilled an example used by Malahy (10) is tested in which the problem taken states that the pipe properties are as follows:

Pipe outside diameter is 40.64 cm ,wall thickness is 1.27cm ,weight /length in air is 2851.32 N/m ,submerged weight/length is 773.85, specific gravity is 1.372 ,elastic modulus is 196500 MPa ,cross sectional area is 157.08 cm^2 *, moment of inertia is 30465.73* cm^4 *,yield stress is 358 MPa ,stress intensity factor is 1 and steel density is 76970* N/m^3 .

The results of one of the OFFPIPE executions between deflection and depth are shown in Fig.(2).This figure also shows the sigmoid curve obtained after so many trials of curve fitting. It is as shown that the best curve gives coincidence of points with the compared curve. The pipeline problem is very complicated due to the effects of so many variables namely:

1.The unknown primarily length of the pipeline during installation.
2. Unknown deflected shape.
3.Unfamiliar loads include self-weight and environmental loads.
4. Sea water depth.
5. Tension applied on the pipe.
6. Pipe diameter.
7. Pipe thickness.

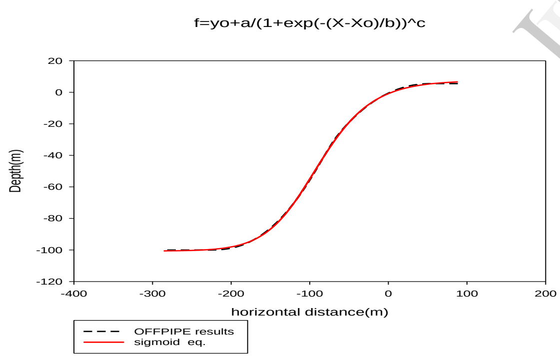


Fig.(2) Submarine pipeline layout compared to sigmoid equation.

So to facilitate the solution of Eq.(1) ,the parameters a ,b ,c ,x_o , and y_o must be determined. The attempts are done here to reach to so many curves or charts to find these variables or parameters which will be inserted directly to the deflection equation to find out deflections.

The variables which will be studied are water depth, tension applied, pipe diameter and pipe thickness. Each of these variables will be taken to study their effects on finding out the five parameters of the sigmoid equation while the other variables are taken to be constants.

Effect of water depth

The configuration of the pipeline gets steeper with increase of laying water depth(11). Steeper configuration of pipeline means larger stresses in pipe will be induced, so higher potential to damage should be adjusted by enhancing the tension of the tensioner. As water depth increased more tension is needed . If the tension is kept constant then there is a maximum limit for the water depth above it the pipe will buckle where OFFPIPE software was pointed out this phenomena. The figures 3,4,5,6 and 7 show the relations between water depth and the parameters of the sigmoid equation a ,b , c ,x_o , and y_o respectively. The water depths taken are starting from 50m up to 225m by an increment of 25m. The tension applied is 200KN and this value kept constant throughout the variation of water depth which reaches maximum limit of 238m above which the pipe buckles. The relation between water depth and parameter "a" seems to be linearly proportional. This is clearly shown in Fig.(3) but this result is especially for a specified value of tension .If the tension applied is now increased an increment in water depth will be observed. Fig.(4) shows the relation between water depth and parameter "b" of the sigmoid equation. The relation is perfectly curvilinear where the range of the values of "b" is less than 36 for a maximum water depth of 225m. As water depth increased the value of this parameter decreased so the relation is an inversely relation to some extent. Fig.(5) shows the variation of (c) parameter with the depth. It seems from the curve that the relation is inversely proportional and maximum registered value is 1.4937. This parameter has less values compared to others but it has noticeable effect on final results. The relation between depth variation and the parameter (X_o) is something like a conical section as shown in Fig.(6). Whole values of this parameter are in negative sign and minimum value as show in the figure is -109.44 and maximum registered value is -71.11 .

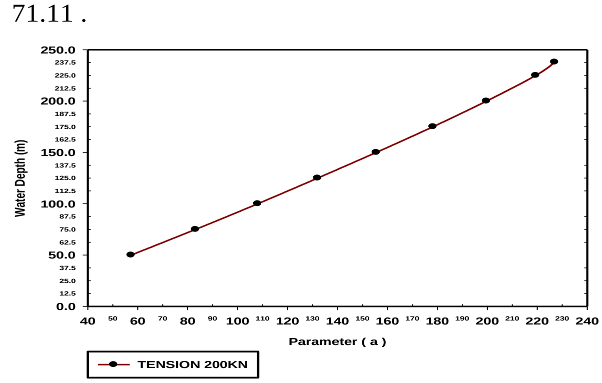


Fig.(3)Relation between water depth and parameter (a).

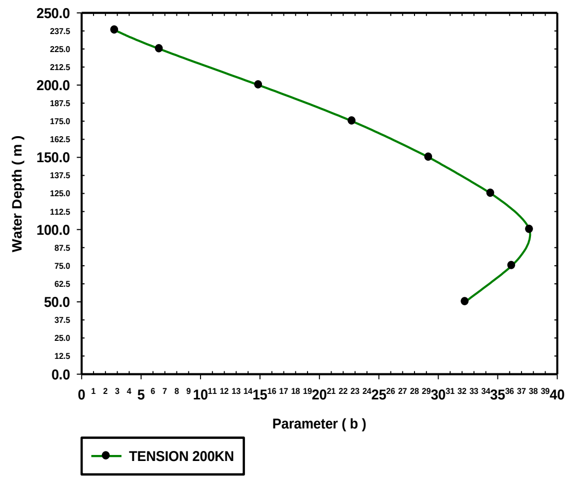


Fig.(4)Relation between water depth and parameter (b).

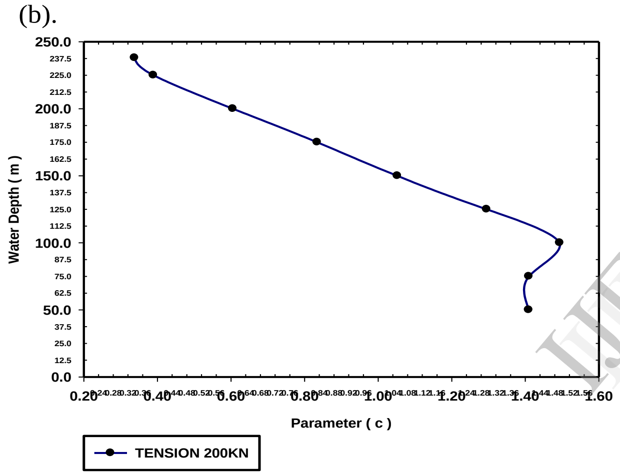


Fig.(5)Relation between water depth and parameter (c).

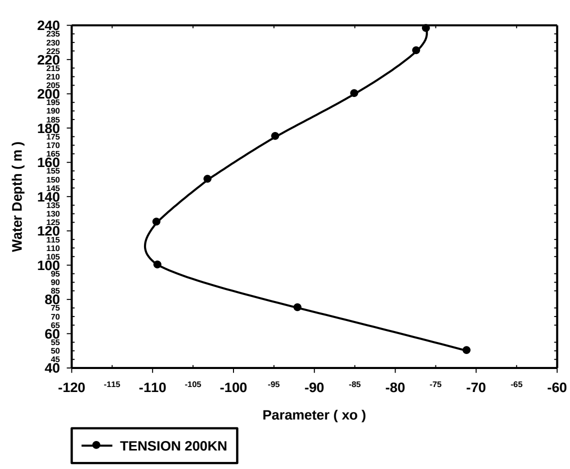


Fig.(6)Relation between water depth and parameter (Xo).

The fifth parameter in sigmoidal equation is (y_o) which is clearly shown in Fig.(7). The relationship between this parameter and water depth seems to be an inverse linearly relation .Another property can be noticed that the relation is approximately an inverse of the relation between water depth and (a) parameter explained in Fig.(3) but in negative values.

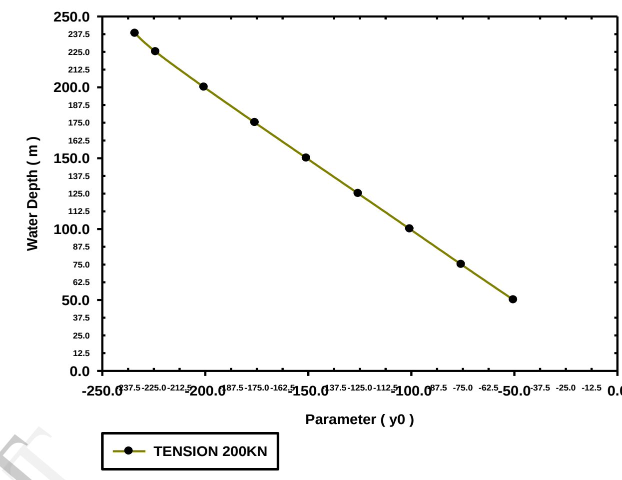
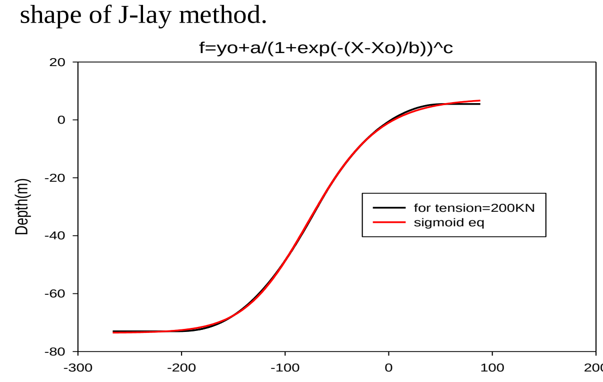
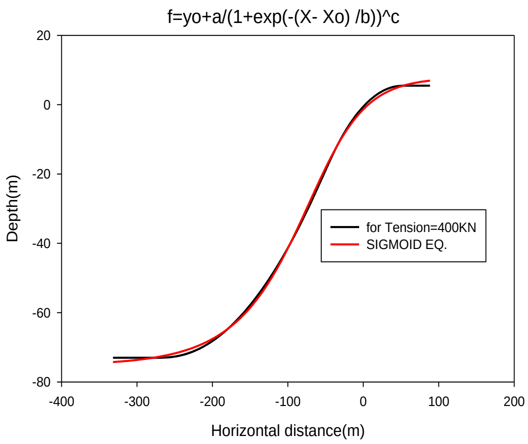


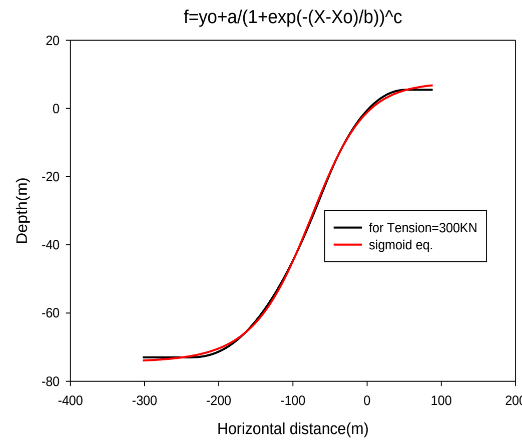
Fig.(7)Relation between water depth and parameter (y_o).

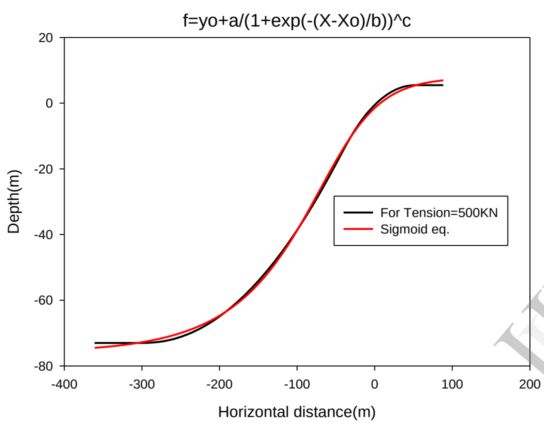
Effect of tension applied

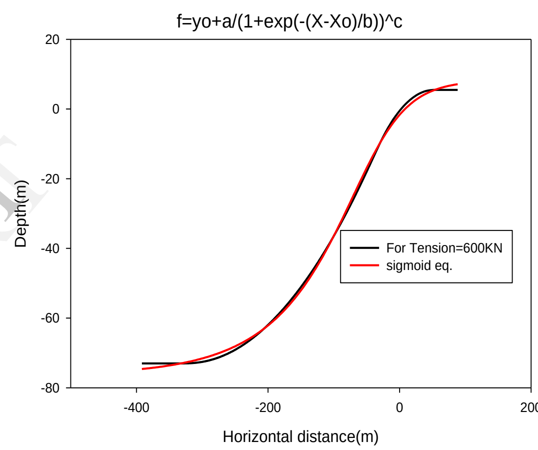
As water depth increases the shape of the pipeline laid gets more steeper due to the induced stresses generated from the accumulation of heavy loads applied on the pipe. Same effect appears when the depth kept constant but the tension applied is varied in descending manner. This can be seen in the nine curves shown in Fig.(8) where the tension is increased from 200 KN to 1000 KN by an increment of 100 KN and a depth of 73m. The truth that the curves get steeper as tension decreased is that there is no huge pull force on the pipe due to tension applied ,so the pipe will settle due to its own weight tending to get catenary shape where the new profile takes the shape of J-lay method.

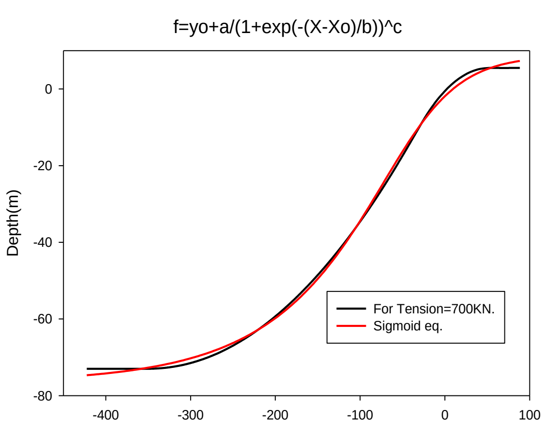


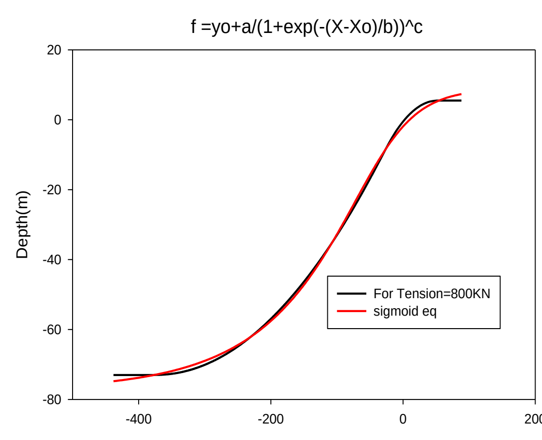

f=yo+a/(1+exp(-(X- Xo) /b))^c
Depth(m)
Horizontal distance(m)
for Tension=400KN
SIGMOID EQ.


f=yo+a/(1+exp(-(X-Xo)/b))^c
Depth(m)
Horizontal distance(m)
for Tension=300KN
sigmoid eq.


f=yo+a/(1+exp(-(X-Xo)/b))^c
Depth(m)
Horizontal distance(m)
For Tension=500KN
Sigmoid eq.


f=yo+a/(1+exp(-(X-Xo)/b))^c
Depth(m)
Horizontal distance(m)
For Tension=600KN
sigmoid eq.


f=yo+a/(1+exp(-(X-Xo)/b))^c
Depth(m)
Horizontal distance(m)
For Tension=700KN.
Sigmoid eq.


f =yo+a/(1+exp(-(X-Xo)/b))^c
Depth(m)
Horizontal distance(m)
For Tension=800KN
sigmoid eq

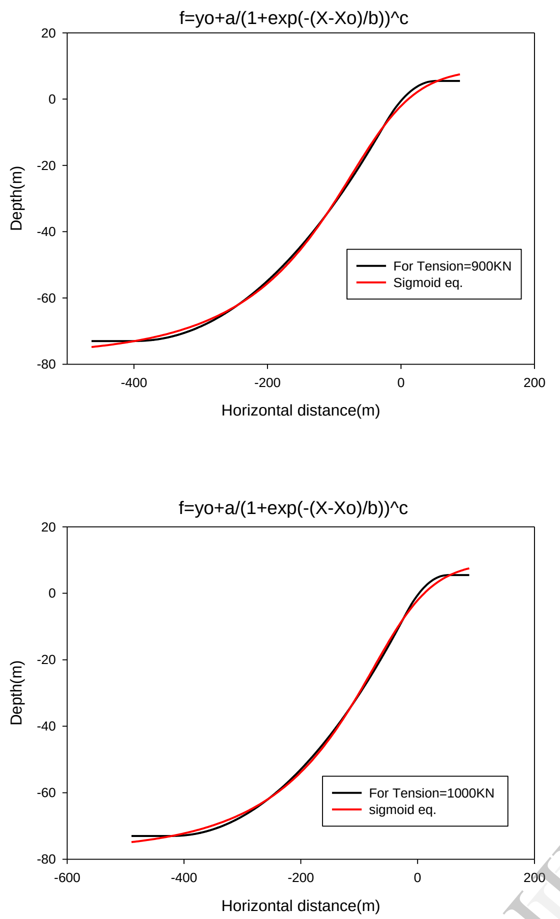


Fig.(8) Curves showing the coincidence between OFFPIPE results and sigmoid equation results for so many values of tension applied and constant depth.

The figures started from 9 to 13 shows the effect of increasing the applied tension on the pipeline when the depth was kept constant. As it was well-known from the literature that as the tension increased, more stresses are induced in the pipeline. If a simple look to figure 9 is taken into consideration ,which represents the relation between tension and parameter (a) ,the shape of this relation is an ascending relation. That means the parameter (a) will maximize the results of deflection as the tension increased. The parameters (b) and (c) behave as an inverse effect of that effect of parameter (a) as shown in figures 10 and 11 respectively but its final effect is also maximizing the deflection as done by parameter (a) because their positions in Eq.(2) were in the denominator. The effect of increasing tension on the parameters (X_O and y_o) can be seen in figures 12 and 13 where the relation seems to be an inverse with y_o and turbulent in opposite to that with X_O .Other turbulent relation is that appeared in Fig.(10) between tension and parameter (b). It is very difficult to reach a fitted equation represents the relation between these parameters and tension applied because of their huge effect on the results of sigmoid equation.

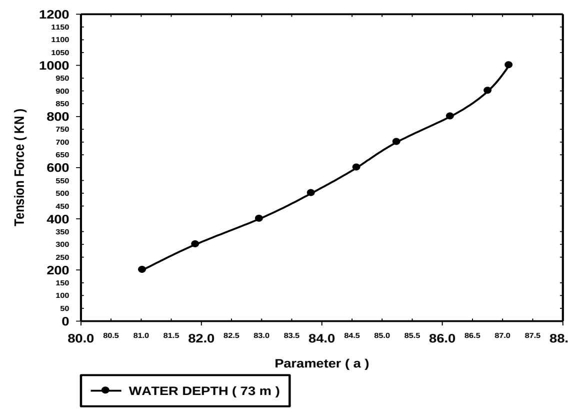


Fig.(9)Relation between Tension applied and parameter (a).

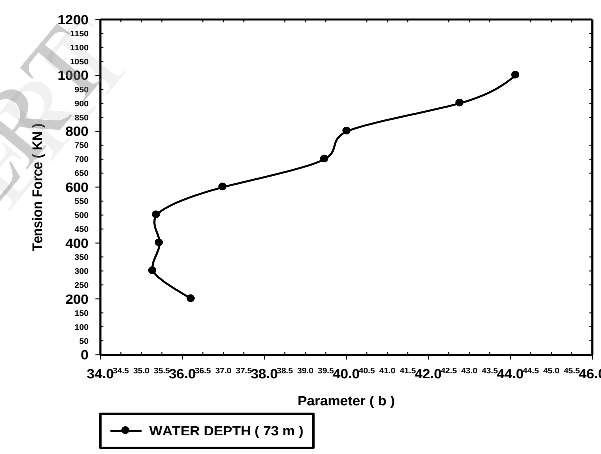


Fig.(10)Relation between Tension applied and parameter (b).

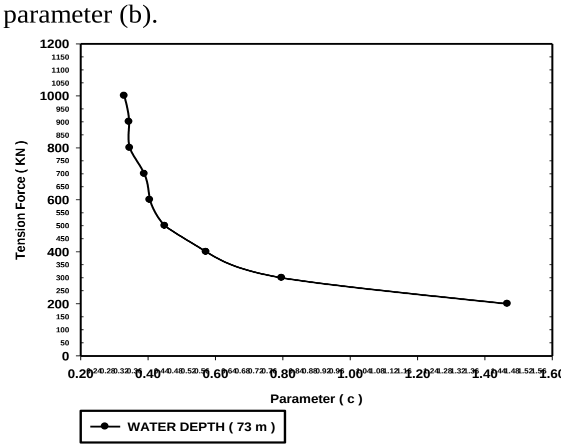


Fig.(11)Relation between Tension applied and parameter (c).

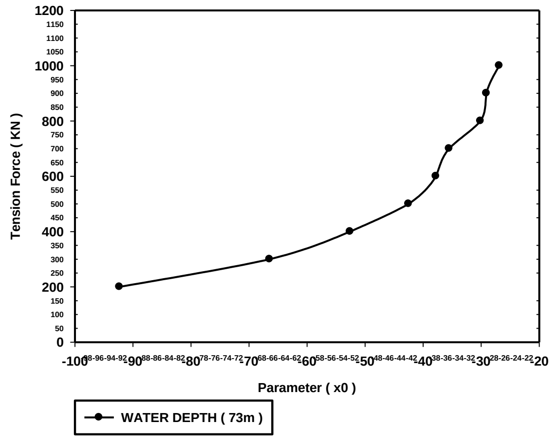


Fig.(12)Relation between Tension applied and parameter (x_o).

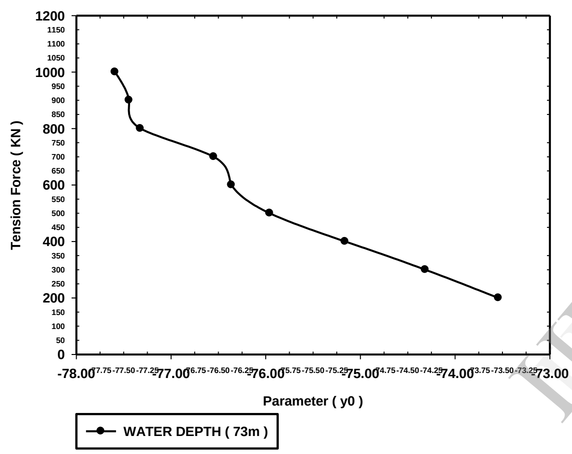


Fig.(13)Relation between Tension applied and parameter (y_o).

Effect of pipe diameter

The ranges of pipe diameter were taken from 40cm to 100cm by an increment of 10 cm. When the depth and tension are assumed to be constants as in the state of laying pipeline in sea regions have same bed horizontal profile, the effect of diameter variation on sigmoid parameters (a ,b ,c ,X_O and y_o) can be seen in figures 14,15,16,17 and 18 respectively .The five curves have some turbulence in shapes especially at higher diameter values . Li, Z.G. et al(11) recommended in their work on pipelines installed in deepwater using S-lay technique that the configuration depends on the inclination angle at the lower end of stinger rather than the pipe diameter. In spite of that conclusion the present work study the effect of changing the diameter to get ready charts for workers to use it easily .

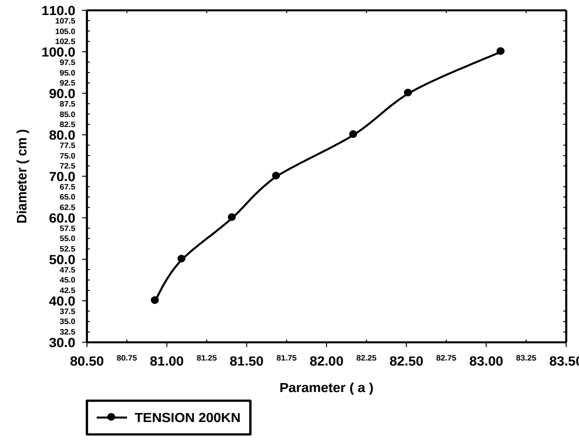


Fig.(14)Relation between Pipe diameter and parameter (a).

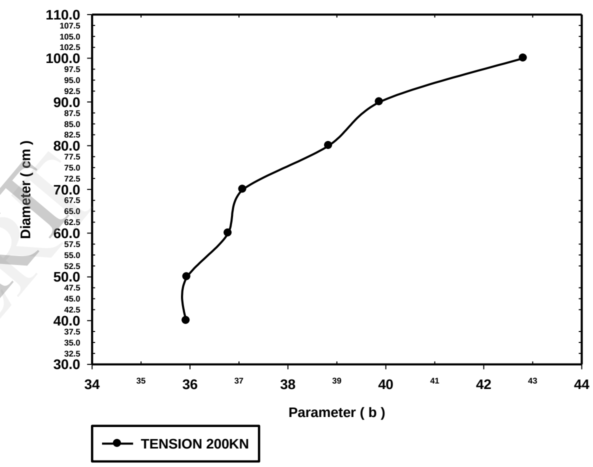


Fig.(15)Relation between Pipe diameter and parameter (b).

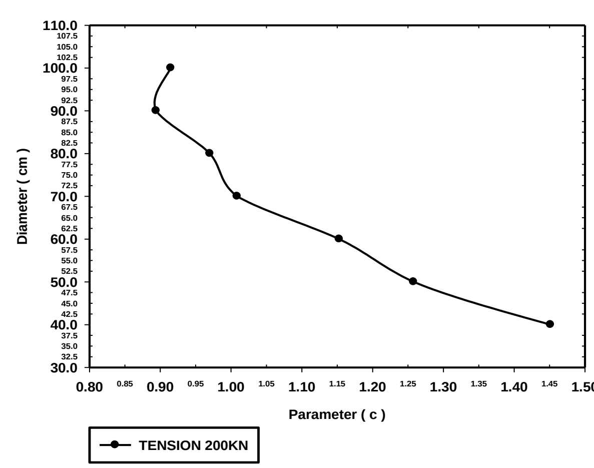


Fig.(16)Relation between Pipe diameter and parameter (c).

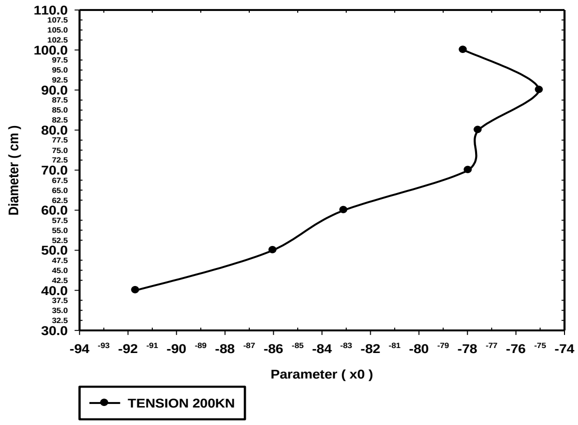


Fig.(17)Relation between Pipe diameter and parameter (X_o).

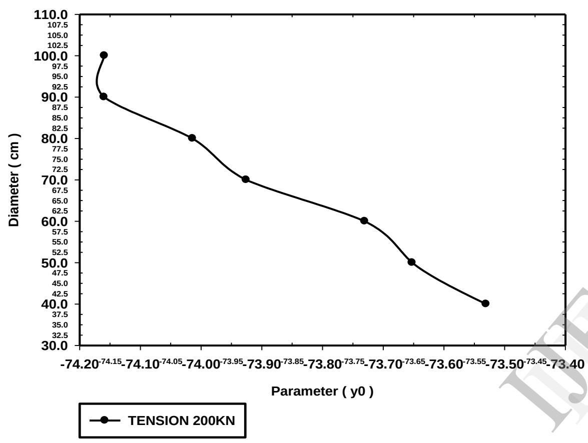


Fig.(18)Relation between Pipe diameter and parameter (y_o).

Effect of pipe thickness

So many trials were done to see the effect of changing the thickness of the pipeline including the concrete coating on the configuration of the pipeline. It was noted from so many runs of the software OFFPIPE that variation of the thickness has little effect on pipe configuration. This result was one of the important recommendation registered by(Li ,Z.G. et al(11)) who mentioned that the change of thickness of the concrete weighted coating layer has little effect on the pipe-laying configuration. It is probably because the increase of the thickness layer results in not only the augment of the pipe unit submerged weight but also the increase of the horizontal tension under the certain control strain required. The figures which gave the values of the sigmoid parameters (a ,b ,c ,X_O and y_o) according to the variation of pipe thickness can be seen in figures 19,20,21,22 and 23 respectively . These curves are studied to know their effect in the fixity of water depth ,diameter, and tension applied .If a certain value of thickness is used when the previous variables are taken to be constants then sigmoid parameters can be taken directly from these curves or charts to be used directly in eq.(2).

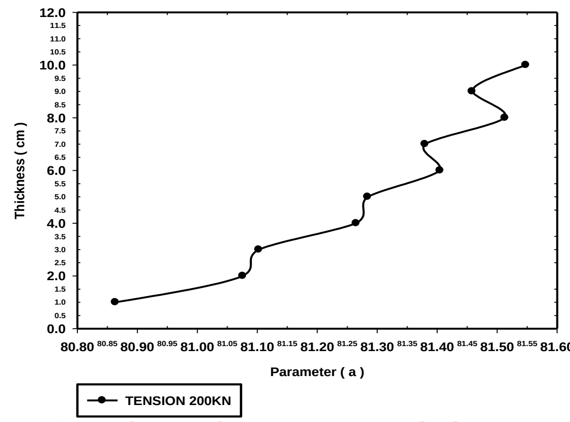


Fig.(19)Relation between Pipe thickness and parameter (a).

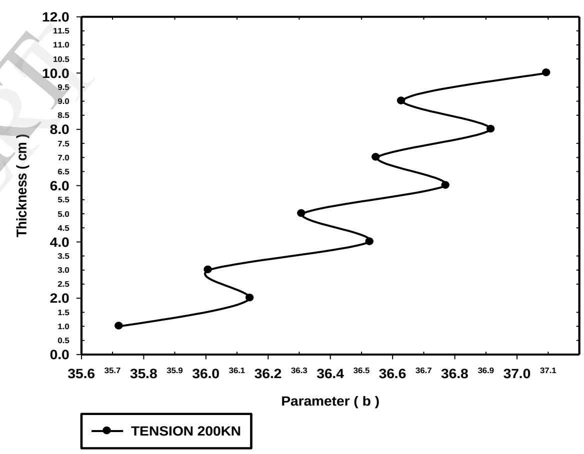


Fig.(20)Relation between Pipe thickness and parameter (b)

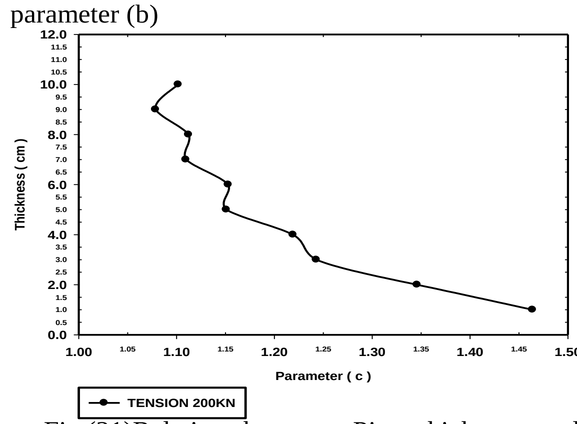


Fig.(21)Relation between Pipe thickness and parameter (c).

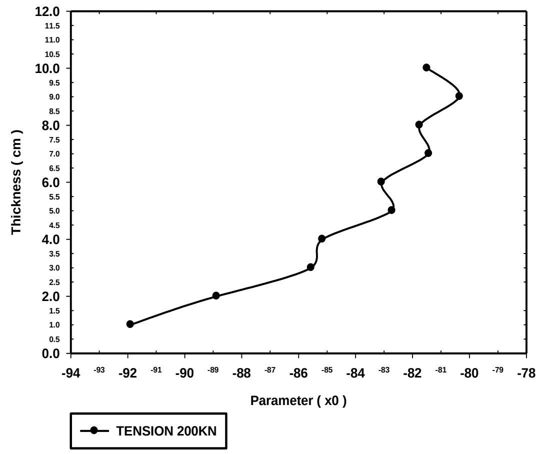


Fig.(22)Relation between Pipe thickness and parameter (X_o).

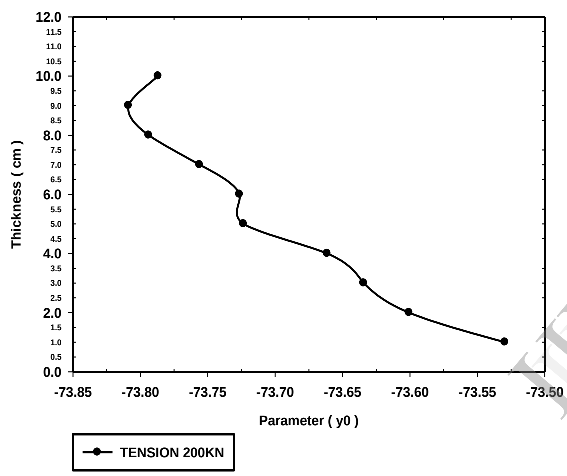


Fig.(23)Relation between Pipe thickness and parameter (y_o).

Conclusions and recommendations

The presented attempt to reach the most convenient and suitable shape of pipeline profile was succeeded through the sigmoid function. The following points can be recorded and concluded in this work:

1-The shape of pipeline during installation takes the shape of catenary if there is no tension. When the pipe is exposed to tension it takes the shape of sigmoid function.

2- The sigmoid function gives an excellent results of fit compared to OFFPIPE results in the first two parts of the pipe(sea bed part and sag bend part).

3-There is a measurable deviation in the shape of pipeline in the second two parts namely stinger part and barge part.

4- The parameters of the sigmoid function were drawn with the most effective variables affecting on pipeline stresses. These drawings can be used directly by analysits in this region.

5- It was noted that most of these sigmoid parameters are maximizing the value of deflection except the parameter © due to their position in the mathematical form of the function.

A future work is needed in the following regions:

a- Three dimensional charts represent the most effective pipeline laying variables drawn with sigmoid function parameters.

b-More study is needed in the upper two parts of the pipelie (stinger and barge parts).

c-Comparison study between OFFPIPE stress results and sigmoid function results.

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