Effect Of Material Nonlinearity On Submarine Pipeline During Laying

Dr. Hakim Saeed Muhammed, Dr. Karim Radhi Obead, Anwar Sabah Abd Alameer

Abstract: The main causes of nonlinearity are the large deformations attained to a structural member which is related to the geometrical shape of that member. This is called geometric nonlinearity whilst the other nonlinearity is due to material behavior under load application. In this study a submarine pipelines are taken into considerately. The two mentioned nonlinearities are facing workers in structural pipeline analysis. The present paper focuses on the effect of material nonlinearity. It was tested though the use of OFFPIPE famous software. The effect of material nonlinearity was studied through the obtained bending moments, deflections and stresses when the pipe exposed to depth variation, diameter variation, tension variation and thickness variation. It was noted that if material nonlinearity is taken into consideration the governed maximum bending moments were less by about two times compared to linear approach.

Index Terms: Material, Nonlinearity, Bending moments, Deflections, Stresses

1 Introduction

It is well-known that a submarine pipeline during laying presents a structural problem in which high bending stresses and large curvatures are created. Thus it is mathematically a nonlinear problem due to large curvatures because of the long route of pipes used. Structural nonlinearities can be classified as [1] geometric nonlinearity, material nonlinearities and boundary nonlinearities. Most of the authors were taking the effect of geometric nonlinearity and neglect the material nonlinearity which is very important factor . The main materials used for offshore pipeline are steel and concrete. The pipeline materials used under this guide are to be carbon steels , alloy steels or other special materials, such as titanium, manufactured according to a recognized standard. The materials are to be able to maintain the structural integrity of pipelines for hydrocarbon transportation under the effects of service temperature and anticipated loading conditions. Materials in near vicinity are to be qualified in accordance with applicable specifications for chemical compatibility [2]. Due to unfamiliar loads applied on pipes , it is very important to study any relative factors affecting on material properties especially nonlinearity. The American Petroleum Institute (API) took this matter into consideration as a code specifications. The material studied was classified according to its specified minimum tensile strength (SMTS) and specified minimum yield stress (SMYS). OFFPIPE program [4] was used in this study to determine the deflection and bending moment for pipeline during installation. Material nonlinearity arises when the material exhibits nonlinear stress- strain relationship. For linear elastic finite element analysis the only stress-strain relationship was defined via modulus of elasticity(E).

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In the case of non-linear material analysis, the modulus of elasticity is only the first definition point of or overall behavior. The typical definition and analysis in the non-linear material domain involves one of the post-yield(plastic) behavior. Typical elasto-plastic material characteristic under tension is shown in Fig.(1). When submarine pipelines are exposed to unloading the unloading line determines the residual (plastic) strain remaining in the system [3].

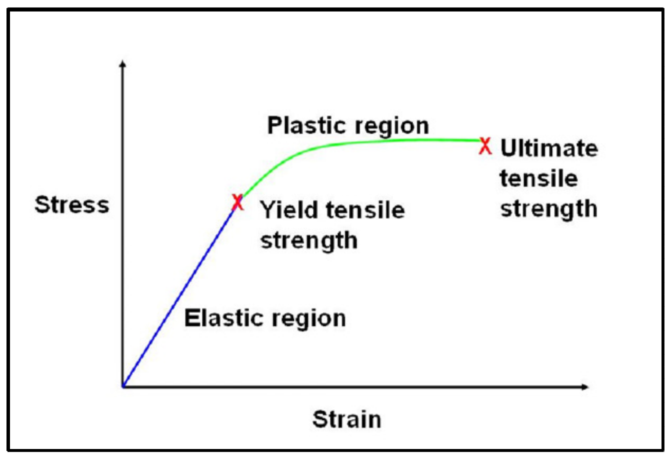

Fig.1 Typical elasto-plastic behavior

Fig. (1) also represents a structure which exhibits a softening behavior after yielding. The numerical solution of this type of non-linear problem involves approximating the non-linear segment of stress-strain curve with a series of piece-wise linear segments. Each linear segment is approximated by a tangent modulus (ET) which is computed as the ratio of stress over strain for that particular line segment.

2 Aim of the Study

The goal of this study is to determine the effect of taking material nonlinearity into consideration on pipeline deflection and induced stresses during the process of pipeline installation, as well as the bending moments obtained.

3 Material Nonlinearity

The nonlinear properties of the materials from which oil pipe are fabricated mean that all of the stages or history of loading are covered passing through elastic , plastic and failure stage. Due to unfamiliar loads applied on pipes , it is very important to study any relative factors affecting on material properties especially nonlinearity. The American Petroleum Institute (API) classified the material used according to its specified minimum tensile strength (SMTS) and specified minimum yield stress (SMYS) in an independent code specifications. The geometrical nonlinearity was studied clearly by a software used here called OFFPIPE. This program was including the material nonlinearity also in its execution. It permits the constant bending stiffness (EI) of pipe entries in the pipe property table to be replaced by a nonlinear moment curvature relationship [4]. This moment curvature relationship is assumed to be given by a Ramberg-Osgood equation of the form:

$$K/K_y = M/M_y + A(M/M_y)^B \quad (1)$$

A = Ramberg-Osgood equation coefficient
B = Ramberg-Osgood equation exponent.
K = Pipe curvature.
K_y = Pipe curvature at the nominal yield stress.
= $2\sigma_y/(ED_o)$
M = Pipe bending moment.
M_y = Pipe bending moment at the nominal yield stress.
= $(2\sigma_y I)/D_o$
E = Steel modulus of elasticity.
D_o = Steel pipe outside diameter .
I = Moment of the inertia of the steel pipe.
σ_y = Nominal yield stress of the steel pipe.

The above nonlinear moment-curvature relationship is primarily used to model the nonlinear behavior of the pipe when the yield strength of the pipe steel has been exceeded. Note that for A = 0, the above Ramberg-Osgood equation reduces to the usual linear relationship K = M/EI. There are three options for defining the coefficient A and exponent B moment used in equation (1). The coefficient and exponent in the Ramberg-Osgood equation may be given by:

1. Entering the values of the coefficient A and exponent B explicitly in the input data,
2. selecting OFFPIPE's built-in default moment curvature relationship and specifying the yield stress ratio R_y for the pipe steel,
3. specifying the values of the pipe curvature K and bending moment M at two points on the curve.

When the built-in, default moment curvature relationship is selected (option 2), OFFPIPE estimates the values of the coefficient A and exponent B based on the pipe properties and the yield stress ratio R_Y for the pipe steel. The yield stress ratio is used to specify the actual yield strength of the pipe steel. It is the ratio of the actual, measured yield strength of the pipe steel to its nominal or minimum specified value (SMYS). The yield strength ratio is usually in the range ($1 < R_Y < 1.3$). In OFFPIPE's default moment-curvature relationship, the coefficient and exponent for the Ramberg-Osgood equation have been chosen to approximate the nonlinear bending stiffness of a "typical" or "average" pipe steel. The default moment curvature relationship is a composite based on pipe bending stiffness data from several sources. It is provided for use in analyses in which the actual properties of the pipe steel are not known, or when only an approximation for the nonlinear behavior of the pipe materials is required. It should be noted that the properties of pipe steels can vary dramatically as a result of differences in the pipe grade, chemistry and manufacturing process. OFFPIPE's default moment-curvature relationship is not intended to be a substitute for curves based on the actual properties of the pipe materials being modeled, when this information is available. Accurate curves based on measured data should always be used when a precise model of the pipe's material properties is required. The default moment curvature relationship presently used by OFFPIPE is shown in Fig.(2).When an actual moment curvature relationship is available, the corresponding Ramberg-Osgood equation can be defined by entering the values of the pipe curvature and bending moment at two points on the curve (option 3). OFFPIPE will then calculate the values of the coefficient A and exponent B required to make the pass through the two points.

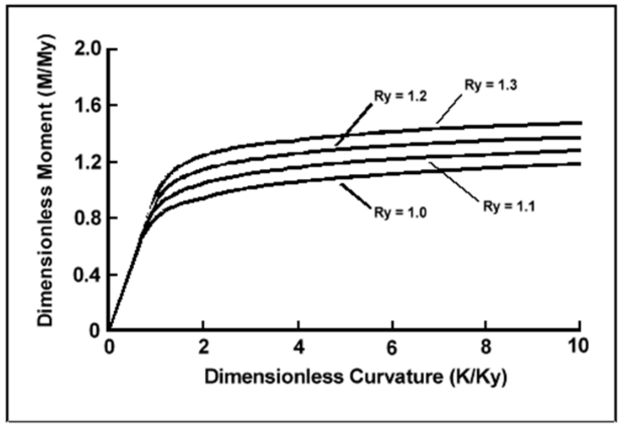

Fig.2 The default nonlinear moment-curvature relationship for the pipe depends on the yield strength ratio R_y [4].

In the present work option(1) was used to represent the Ramberg-Osgood equation, Where the value of coefficient A and exponent B are given in the input data explicitly. The type of steel used was (X52) where the specified minimum yield stress is 52 Ksi (358MPa) and allowable strain is (0.205%) as mentioned in Table (1).

Table (1) Simplified criteria, overbend [5]

Criterion	*X70*	*X65*	*X60*	*X52*
Static	0.270 %	0.250 %	0.230 %	0.205 %
Dynamic	0.325 %	0.305 %	0.290 %	0.260 %

4 Results and Discussion

To make sure that the aim of this work was fulfilled an example used by Malahy [6] 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 , steel*

density is 76970 N/m^3 and maximum allowable strain =0.205%
The material linearity and nonlinearity effect was studied through their influence on deflection and bending moments. To achieve this task the following cases were taken into consideration

- Case one (Depth variation)
- Case two (Diameter variation)
- Case three (Tension variation)
- Case four (Thickness variation)

4.1 Case one (Depth variation)

In this case the tension applied was kept constant and equal to 200KN where the depth was taken to be 73m and 238m. the graphs corresponding to these depth values were divided into two groups to show the effect of linearity and nonlinearity of pipe steel material. The first group represents pipe deflection whereas second group are for induced bending moments. The first group of curves are shown in Figs.(3, 5). From these two curves it was seen that for a constant tension and lower values of depths the curves of deflection are lying one over the other as shown in Fig.(3). As the depth increases the effect of material nonlinearity is tendency of pulling the pipe and converts its shape to S-shape while it is takes J-shape when linearity is considered as seen in Fig.(5).The second group of curves are representing the governed bending moments. The same rate recorded later on for deflection was seen here for bending moments. The results of bending moments for small depths are same if linear or nonlinear material is used as explained and shown in Fig.(6) for depth 73m. when the depth was increased to 238m the shape and values of bending moments differ mainly when taking linear or nonlinear material property as seen in Fig.(6). It was noted that using material nonlinearity means economy in design because maximum positive or negative registered values of bending moments were less than that for linear mechanism.

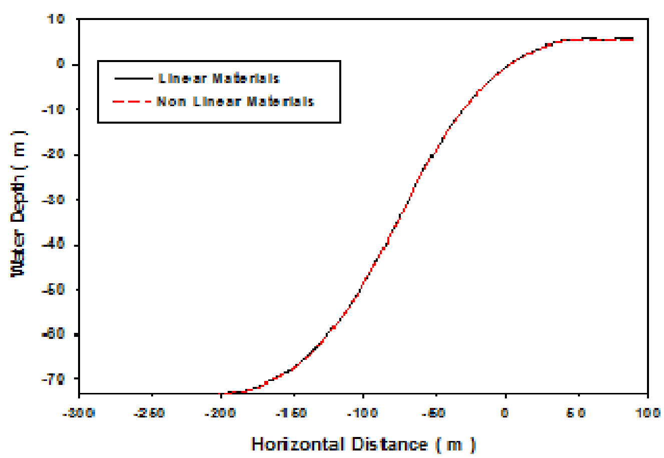

Fig.3 Pipe Deflection comparing between linear and nonlinear material with (d=73m, T=200KN)

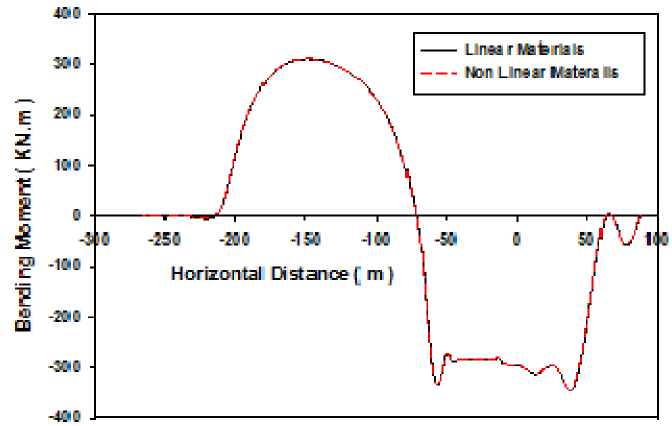

Fig.4 Bending Moment for pipeline comparing between linear and nonlinear material with (d=73m, T=200KN)

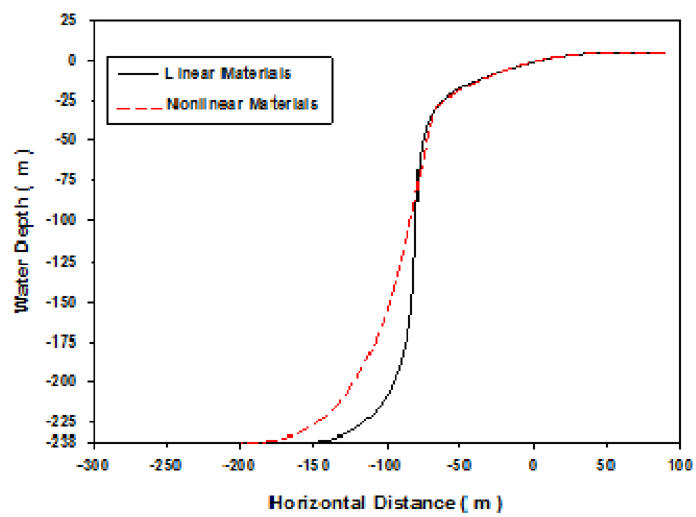

Fig.5 Pipe Deflection comparing between linear and nonlinear material with (d=238m, T=200KN

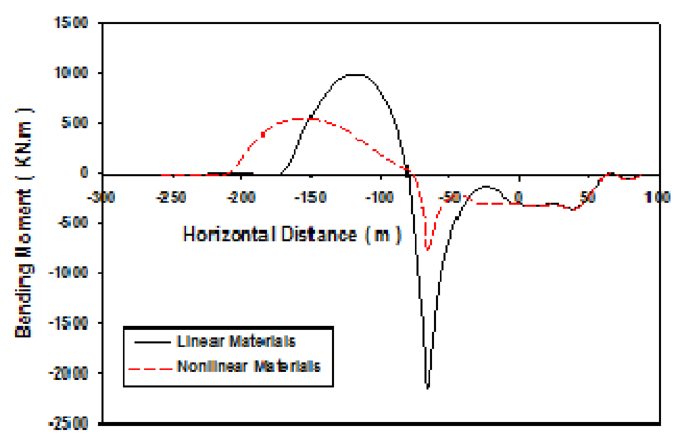

Fig.6 Bending Moment for pipeline comparing between linear and nonlinear material with (d=238m, T=200KN)

4.2 Case two (Diameter variation)

Two values of pipe outer steel diameter were takes to be studied to see the effect of material linearity and nonlinearity under constant applied tension. These values are (711.2mm) and (1625.6mm) under tensile force of 200KN. First group of curves are corresponding to deflection and second group were for bending moments. Fig.(9) shows that there is no effect of how to represent material (linearity or nonlinearity) on deflection. When a maximum value of the available pipe outer steel diameter (1625.6mm) is used the effect is very small in deflection and can be considered as negligible as shown in Fig.(9). Bending moment curves are shown in Fig.(8) and (10). It is seen from these two curves that for pipes of small diameters , the bending moments for the two conditions of materials property (linearity or nonlinearity) are the same except small difference in negative moment as it is clear from Fig.(8). In Fig.(10) when the pipe outer steel diameter was increased to (1625.6mm) the difference between the two conditions in negative moments was approximately twice than that for nonlinearity condition.

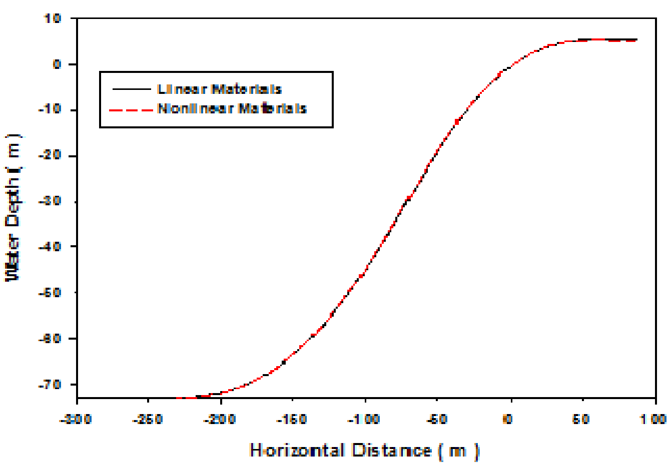

Fig.7 Pipe Deflection comparing between linear and nonlinear material with (D_o=711.2mm, T=200KN)

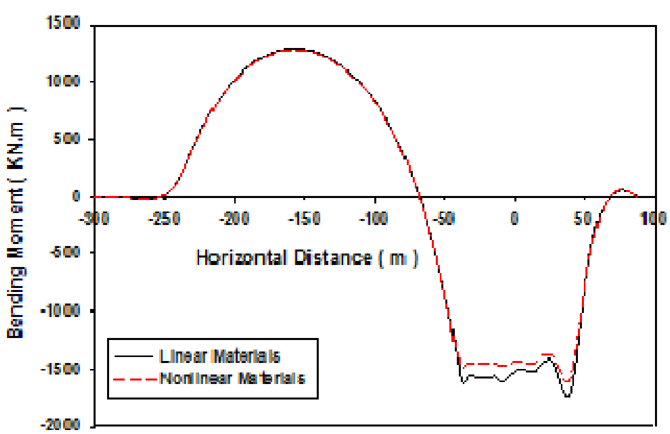

Fig.8 Bending Moment for pipeline comparing between linear and nonlinear material with (D_o=711.2mm, T=200KN)

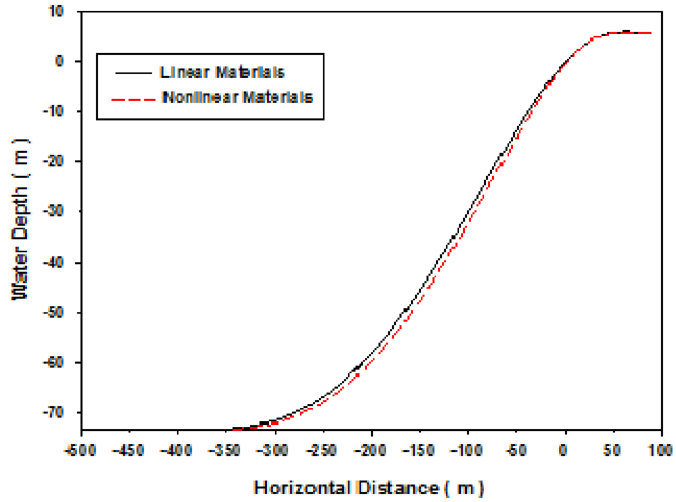

Fig.9 Pipe Deflection comparing between linear and nonlinear material with (D_o=1625.6mm, T=200KN)

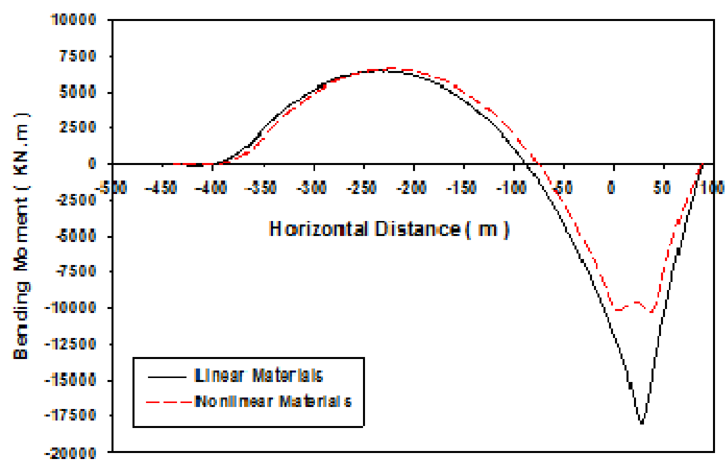

Fig. 10 Bending Moment for pipeline comparing between linear and nonlinear material with (D_o=1625.6mm, T=200KN)

4.3 Case three (Tension variation)

The values of tension which were tested including 200KN as minimum value under constant depth equal to 73m. curves (3) and (11) shows a truth that there is no any effect of how to take material linear or nonlinear on deflection curves as shown from these two figures of bending moments where relatives of linearity or nonlinearity are coincided as it was seen in Fig.(4) and (12).

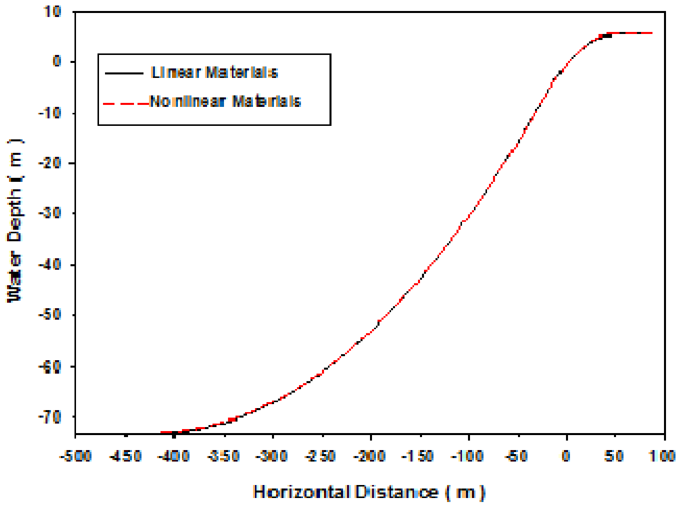

Fig.11 Pipe Deflection comparing between linear and nonlinear material with (d=73m, T=1000KN)

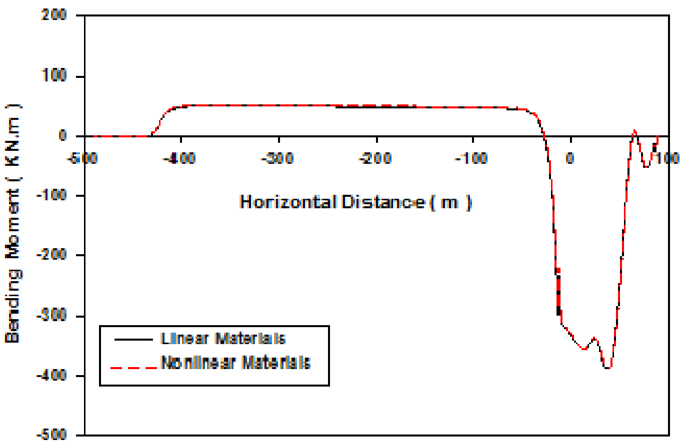

Fig.12 Bending Moment for pipeline comparing between linear and nonlinear material with (d=73m, T=1000KN)

4.4 Case four (Thickness variation)

The effect of taking material linear or nonlinear under the variation of pipe wall thickness was studied also. Two values of pipe wall thickness were taken as (21.44mm) and (28.58mm) under constant depth and tension. Depth was taken 73m and tension equals to 200KN. As a final summary it was noted that there is no any effect of material property on deflections curves or bending moments and all of the values are coincided and one over the other as it is clearly shown in Figs.(13), (15),(14) and (16) respectively.

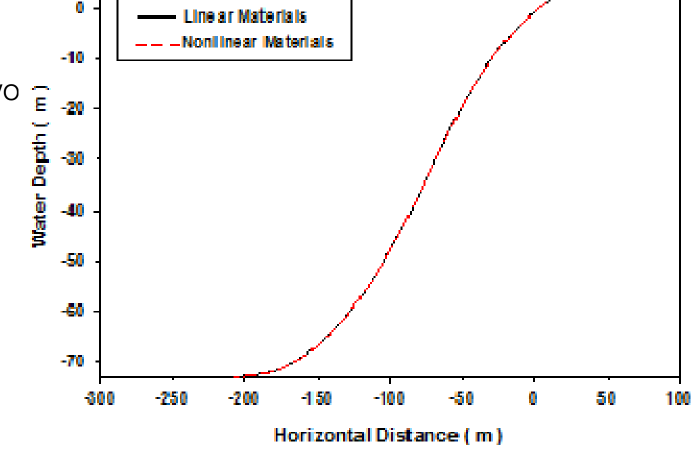

Fig.13 Pipe Deflection comparing between linear and nonlinear material with (t = 21.44mm, T=200KN)

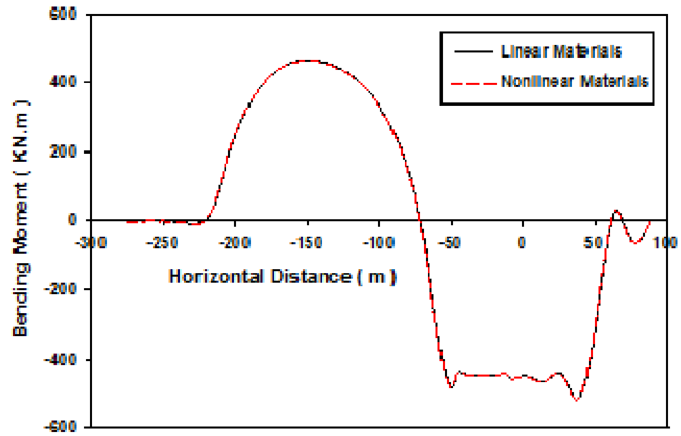

Fig.14 Bending Moment for pipeline comparing between linear and nonlinear material with (t = 21.44mm, T=200KN)

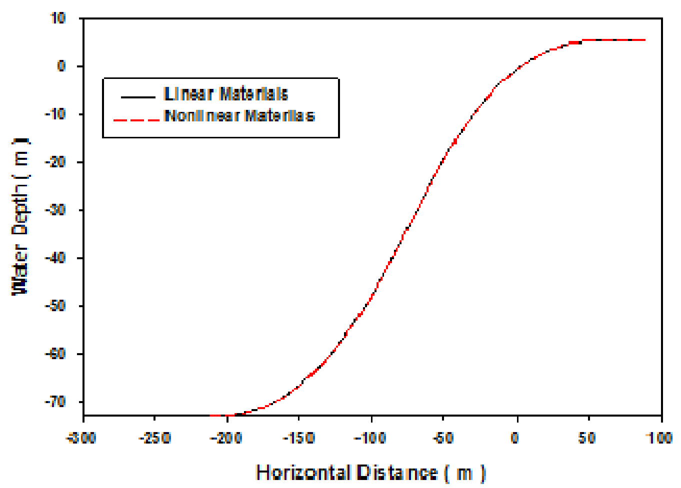

Fig.15 Pipe Deflection comparing between linear and nonlinear material with (t = 28.58mm, T=200KN)

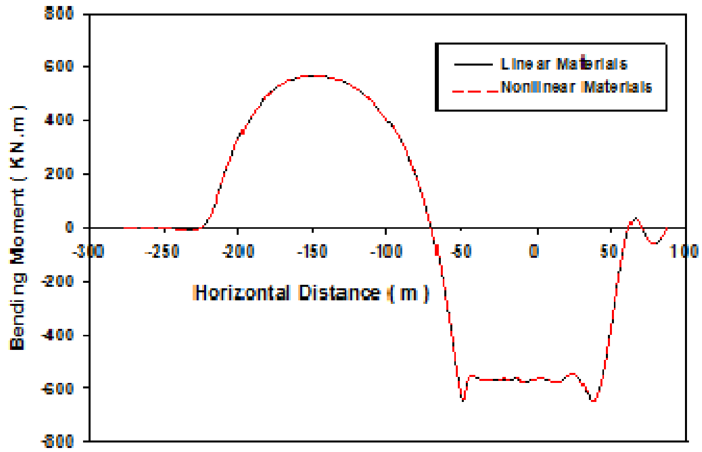

Fig.16 Bending Moment for pipeline comparing between linear and nonlinear material with (t = 28.58mm, T=200KN)

5 Conclusions And Recommendations

The following points were recorded and concluded during this study:

1. 1.During the study of taking material nonlinearity, the effect of nonlinearity on deflection curves and bending moments were studied through variation of depth, pipe diameter, tension and thickness variations. Maximum positive and negative registered values of bending moments were less by approximately two times than that for linearity approach during depth variety at stinger tip.
2. As material nonlinearity is taken into consideration its effect when taking maximum pipe diameter is noticed to be in reducing the maximum bending moments by about 1.75 of the same condition when taking material as linearity approach.
3. It is advised to use linear approach because it is more safe and such projects are costly and risk is not allowed here.

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