Structural Analysis Of Dual Submarine Pipelines During Laying

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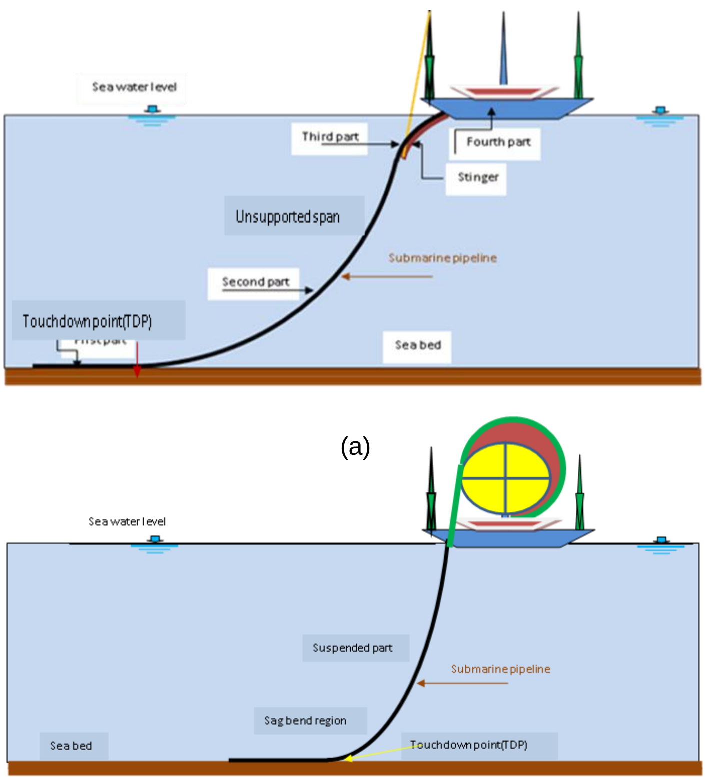
Abstract: Analysis of single pipeline project had been studied by many authors in last decades. In this study two(dual) pipelines are taken into consideration to transport oil separately. They are taken to be laid one beside the other or they may be one over the other. The other condition which studied was taking an equivalent pipe simulating the two pipes. An example was taken to study this analysis. A software called OFFPIPE was used to find out deflections, bending moments and bending stresses. The results show that the useful method in laying two pipelines is by installing them one beside the other (horizontal accumulation) because the obtained results of moments of this method for many values of tensions were one third of the results of other methods.

Index Terms: Bending moments, Dual, Equivalent ,Horizontal Accumulation, Stresses, Tension.

1 Introduction

Oil is still the easiest and cheapest source of energy all over the world. The major tools of transportation of this worth are pipelines especially when the oil is produced from sea beds. This pipeline exposed to so many familiar and unfamiliar forces related to static, dynamic and environmental forces. Due to the unknown shape of this pipeline and these huge forces besides the tremendous depths of water in the sea, the pipeline deflects in nonlinear geometrical shape. The deflected shape of the pipeline may take **S** or **J** shape depending on the depth of water and tension applied on the upper end of the pipeline as shown in Fig.(1).



(b)

Fig.(1): Methods of laying pipelines.(a) S-lay method.(b)J-lay method

The most appropriate technique for installations in deep waters is the so-called "J-lay method", where name comes after the shape of the pipeline during the laying and consists in lowering the pipe almost vertically into the water by an inclined ramp[1]. The stresses induced in this pipeline were studied by so many early authors[2,3,4,5,6,7]. High efforts were offered and spent in this media using many techniques in the solution of this problem depending on numerical solutions [8,9,10,11]. Whole of these efforts focus on the state of treating this pipeline as a single extended profile problem. No one, as in my opinion, study the state of installing more than one pipeline in the same time. This study took into consideration the simple condition which is laying two pipelines. The geometric shape of these two pipelines were taken to be in parallel or as it was used in the study horizontal accumulation and in vertical, as vertical accumulation. Another condition which was added is the transformed state or equivalent method.

2 Formulation of the Analysis of Single Pipeline

Most of earlier works depend on static analysis of the pipeline problem. The profile of the pipeline is unknown firstly and it is assumed to be a curve of **S** or **J** shape. To simplify the derivation of the governing differential equation, an element shown in Fig.(2) was taken from the suspended part of the pipeline in the sag bend of stiffness EI. The equilibrium equations for this element, which is subjected to horizontal and vertical forces H&V, bending moment M, and unit weight W can be derived through application of static equilibrium equations. When vertical summation is taken into account the following expression yields after some simple simplifications:

$dV=Wds$……………………………………………………………(1)

Summation of horizontal forces gives:

$dH=0$…………………………………………………………………..(2)

This means that H is constant and summation of moments yields:

$dM+Vdx-Hdy=$……………………………………………………….(3)

Dividing by dx:

$(dM/dx)+V-H\ (dy/dx)=0$………………………………………..(4)

From the free-body diagram ,$ds=(dx/\cos\theta)$

So if this is substituted in eq.(1) The following will be governed:

$dV=Wds=W\ (dx/\cos\theta)$ ……………………………………….(5)

Divide by dx :

$(dV/dx)=(W/\cos\theta)$ ……………………………………………(6)

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Taking the derivative of the moment expression (equation -4-) yields:

$$(d^2M)/(dx^2)+(W/\cos\theta)-H(d^2y)/(dx^2)=0 \quad\ldots\ldots(7)$$

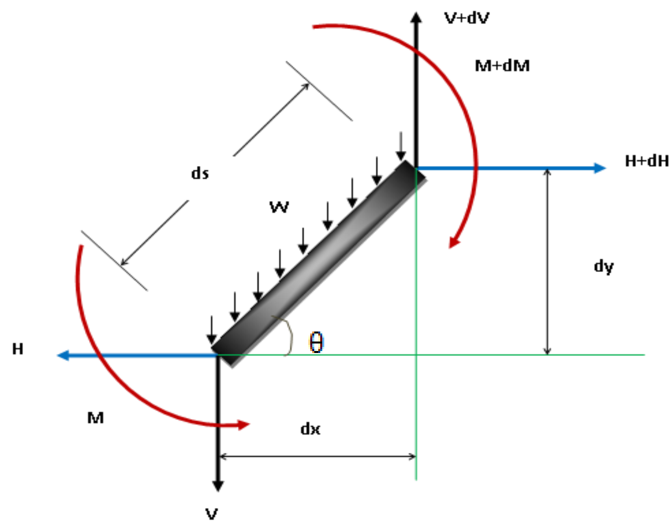

Fig.(2) : Free-body diagram of an element from the sag bend of the pipeline

Here, because the problem is a nonlinear geometric problem, therefore the exact basic beam theory equation must be used. This equation is as follows:

$$(M/EI)=(d^2y/dx^{(2)})/[1+(dy/dx)^2]^{1.5} \quad\ldots\ldots(8)$$

If eq.(8) is substituted in eq.(7),the governed equation will be a differential equation of fourth order from which all of the internal forces or translations can be calculated

3 Study of the Problem

The selection of the best method of connecting two submarine pipelines needs a study of the following research regions:

1. Methods of pipelines connections.
2. Study of the effect of depth variation on bending moments and deflections throughout the pipeline profile.
3. Study of the effect of varying tension applied on bending moment ,deflections .
4. Comparison of the obtained bending moments for all methods of accumulation. Also a comparison must be made for deflection in the three methods.

3.1 Pipeline layout

Sometimes and due to certain need in industry two pipelines need to be installed at the same time or one before the other. Examples of this need may be one of the following:

1. One pipe is used for transporting gas and the second for oil.
2. Two of them are used to transport oil.
3. One of them is in standby state.
4. One pipe is used for oil and other for backfilling with water the space left of the extracted oil.
5. 5.The capabilities of the available equipment (lay barges) are limited, so they install one pipeline and after finishing they achieve the installation of the other.

The layout may be by placing one pipe beside the other(in parallel) or as it was defined here by horizontal accumulation as shown in Fig.(3a). Analysis of this new geometrical shape was taken to treat each pipeline as an independent structural member. The second method of lay is to place the pipe over the other in vertical direction(vertical accumulation) as it is explained in Fig.(3b). Here the upper pipe was analyzed independently while the lower one was exposed to an additional force came from the weight of the upper pipeline. The two methods of laying were simulated by an equivalent method in which the gross area of the two pipes was equated to an equivalent area. The analysis was done to find out the best method of these three options.

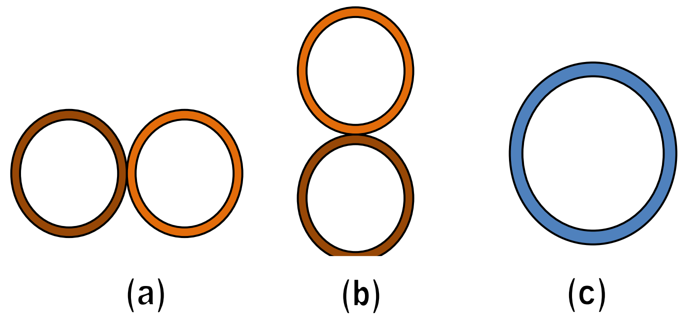

Fig.(3): Arrangement of pipes,(a)Horizontal accumulation,(b)Vertical accumulation,(c) Equivalent

3.2 Effect of depth variation on bending moment and deflection

To study the effect of so many parameters on the obtained bending moments and deflections, an example was taken which was studied by Malahy[12] for single pipeline. The software used was OFFPIPE [12]which was investigated by Malahy through his thesis work to solve the problem. 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.

Two values of the applied tensions were tested to see the effect of variation of depth values on the governed shape (deflected shape) and the induced bending moment. The first tension value was taken to be 200 KN and it was kept constant while the depth was varied from 80 m till buckling occurred by an increment of 10 m. Fig.(4) shows the deflected shapes of the pipeline. As the depth increases, the shape of the pipeline will be more steep taking a shape of **J**. The bending moments obtained for the four values of depths are shown in Fig. (5). The four curves show that as depth increases, maximum positive and negative moments increase.

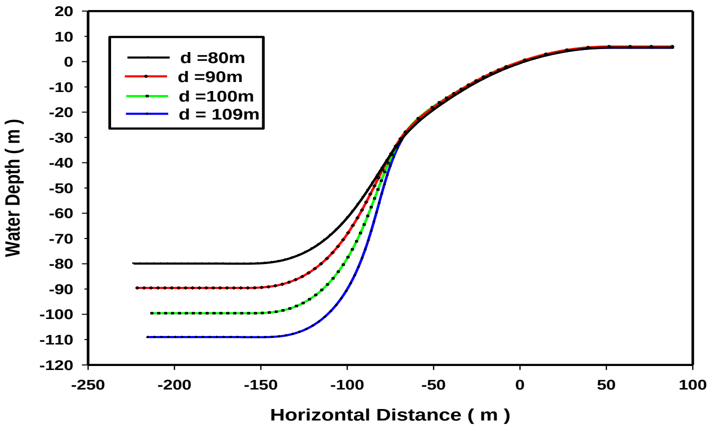

Fig.(4) : shape of the deflected pipeline when it is exposed to constant tension (200KN) and laid in different water depths

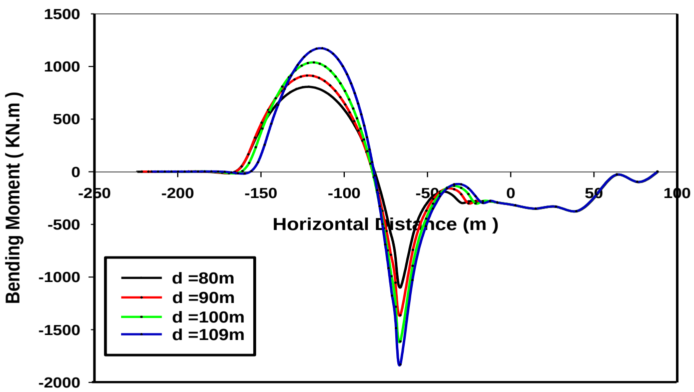

Fig.(5) : Bending moment diagrams of the deflected pipeline when it is exposed to constant tension (200KN) and laid in different water depths

To overcome new deep regions of sea depths, the tension applied must be increased. The tension value taken was 400 KN. The depth was increased by an increment of 40m starting with a first depth value of 140m. The increments were continued until buckling occurred at a value exceeds 238m. Fig.(6)shows the deflected shape of these four depths. Same truth was registered here that as depth increased, shape of deflection will be J-shape. High values of bending moments were recorded especially negative moments for these new values of water depths for this pipeline exposed to 400 KN tension especially for the depth value of 238m. These can be shown in Fig.(7).

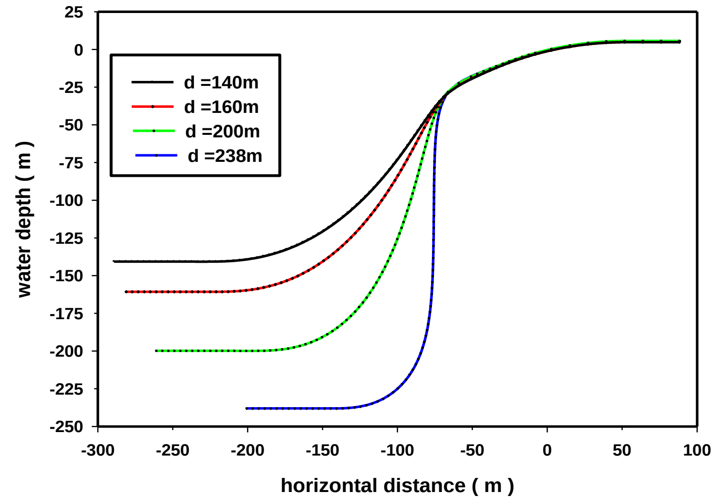

Fig.(6) : shape of the deflected pipeline when it is exposed to constant tension (400KN) and laid in different water depths

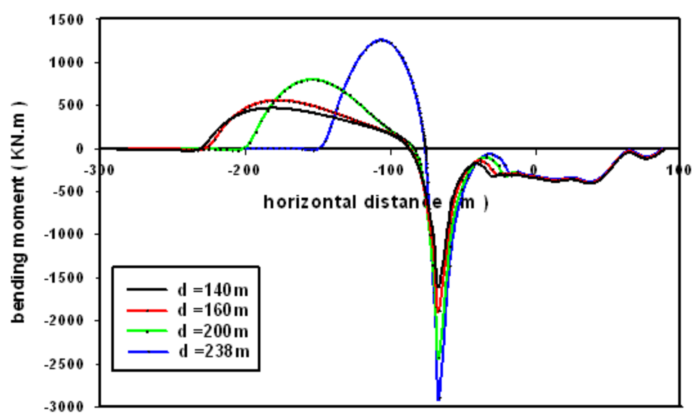

Fig.(7) : Bending moment diagrams of the deflected pipeline when it is exposed to constant tension (400KN) and laid in different water depths

The tension applied on a pipeline is a pull force minimizing the length of the pipeline and reducing deflection. This can be shown in Fig.(8) where the horizontal distance was kept constant of value 500 m for all curves. If these curves are checked to find out their total length, then the curve of maximum total length and maximum points of deflections is that corresponding to minimum tension applied. This phenomenon can be seen for all curves of tensions 400KN,600KN,800KN and 1000KN respectively. So tension applied at the end of the pipeline plays as an effective role in decreasing total length of pipeline and minimize deflection. Other important effect of increasing tension is that the maximum positive bending moment is reduced as it is clearly pointed out in curves of Fig.(9). The maximum negative bending moments seem to be approximately at a same region of values. The variation of bending moment in positive horizontal distances really represents the pipe on the lay barge whereas negative bending moments are for over bend region. The bending moments induced in sag bend region is positive in its effect. The stresses induced in the pipeline were calculated and drawn in Fig.(10). Maximum bending positive and negative stresses are when the value of tension applied was 200KN which is the lowest value. As tension increased these stresses are reduced as shown for all tension values more than 200KN. The stresses are an image for the bending moments induced throughout pipeline length.

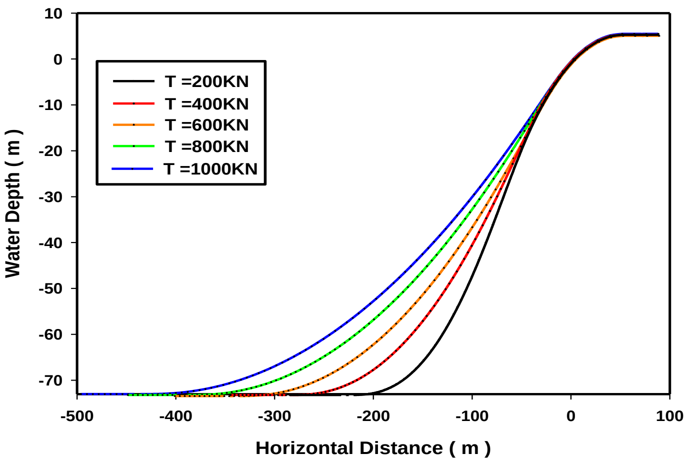

Fig.(8) : shape of the deflected pipeline when it is exposed to different values of tension

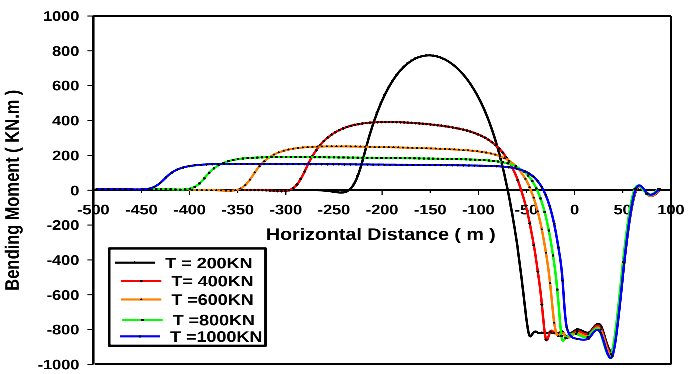

Fig.(9) : Bending moment diagrams of the deflected pipeline when it is exposed to different values of tension

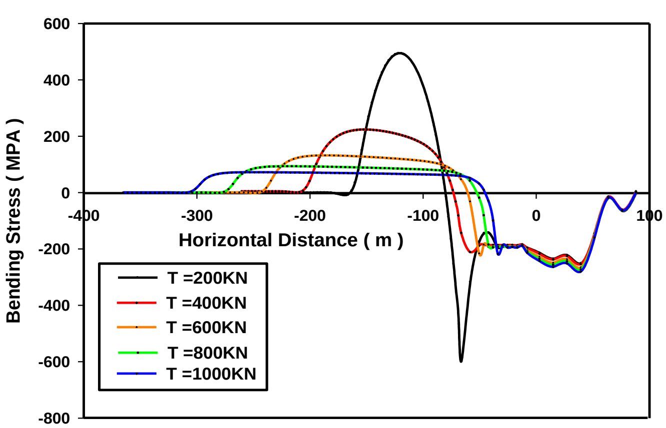

Fig.(10) : Bending stress diagrams of the deflected pipeline when it is exposed to different values of tension

3.3 Moments and deflections obtained

To know which method is suitable and beneficial a diagram is shown in Fig.(11) between bending moments and horizontal distances. From this figure it is clear that maximum positive and negative moments are obtained by the equivalent method and the accumulation technique when the pipes are placed vertically. The corresponding values for horizontal accumulation seem to be one third of that in others. High values of bending moment means maximization in cost therefore it is recommended to use the horizontal accumulation which gives low cost in design. This can be taken as a correct conclusion when same material(oil or gas) need to be transported through these pipes. Another point can be noted in Fig.(12) in which the presented curves are deflection curves related to the governed shape of the pipeline. Deflection shapes of pipelines during installation are the most important order to lead designers and construction consultants to select the appropriate method of installation. From these curves the steepest deflected curve is that for vertical accumulation where the shape is near J-shape nor S-shape. In equivalent method the shape of the deflected curve is approximately sigmoid, therefore it is recommended here to use S-lay method for such technique. In between these two deflected curves the horizontal accumulation curve is presented. So when the results of figures (11) and (12) are taken together to know the most suitable decision in selecting the favorable method, the selection will be horizontal accumulation technique which means low cost and simple installation method.

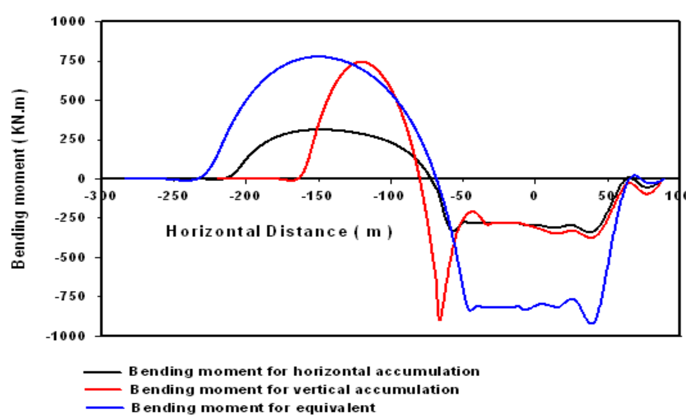

Fig.(11) : Bending moment diagrams of the deflected pipeline when the three techniques of accumulation are used

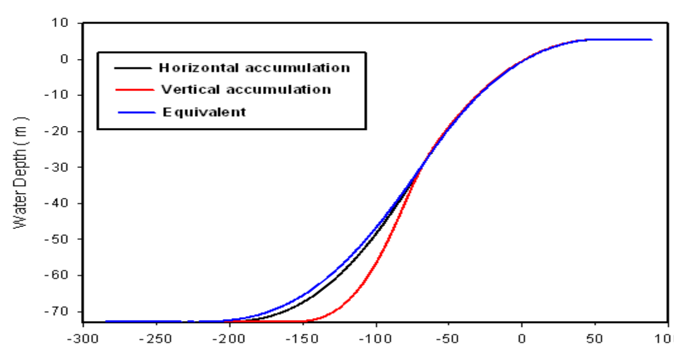

Fig.(12) : Deflection curves of the pipeline when the three techniques of accumulation are used

As tension applied increases, positive bending moment decreases while the negative moment is kept at approximately constant value. This can be shown in figures (13 ,14 ,15,16) respectively. The truth explained earlier that the lowest positive and negative obtained bending moments were due to the use of horizontal accumulation. This truth is mentioned here to check if it is still working when the tension increased. This can be shown in the five figures of bending moment where the first tension applied was 200KN and increased by an increment of 200KN till 1000KN maximum tension. A huge values were recorded ,if the equivalent method was used, in positive and negative bending moments. This is due to the excessive load added to the pipe where it was modeled to represent two pipes. The bending moments which were obtained by vertical accumulation were taking an average path between equivalent and horizontal accumulation methods. The cost of construction pipelines depend mainly on two aspects, pipeline material and labor cost of construction. Pipeline material cost depends on the design considerations and basis requirements especially induced stresses due to bending moments. As bending moments decreased or reduced a minimization in cost is gained. So the best method in laying two pipelines is the horizontal accumulation. The labor cost depends mainly on the method of pipeline installation. The major two methods in pipe laying are S-lay and J-lay method. The J-lay method is costly method compared to S-lay because it is originally specified for deep water seas. The control of selecting the suitable method is the deflected shape of the pipeline. As the tension applied decreased the profile of the suspended part of the pipe will be more steep. This means the shape will be like a **J** letter, so J –lay is the most appropriate method for laying. This can be shown in figures (17,18,19,20). In these four figures the deflection curves of equivalent method and horizontal accumulation method are coinciding. Increasing tension will not affect on this truth but the clear effect of tension was on the profile of these curves to be taking the shape of sigmoid function.

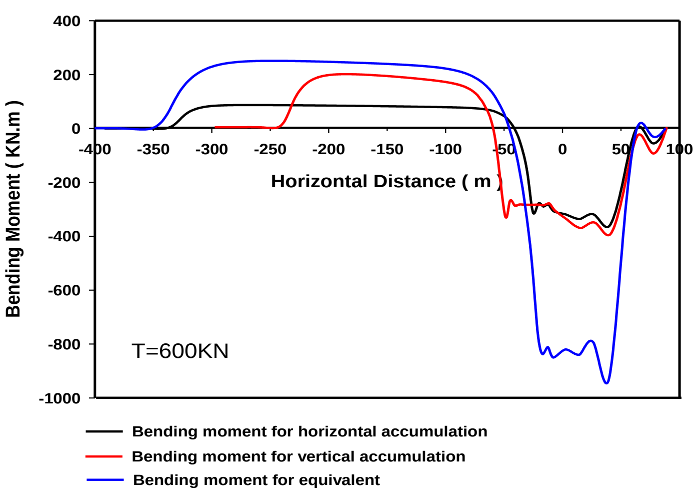

Fig.(13) : Bending moment diagrams of the deflected pipeline when the three techniques of accumulation are used and applied tension is 400KN

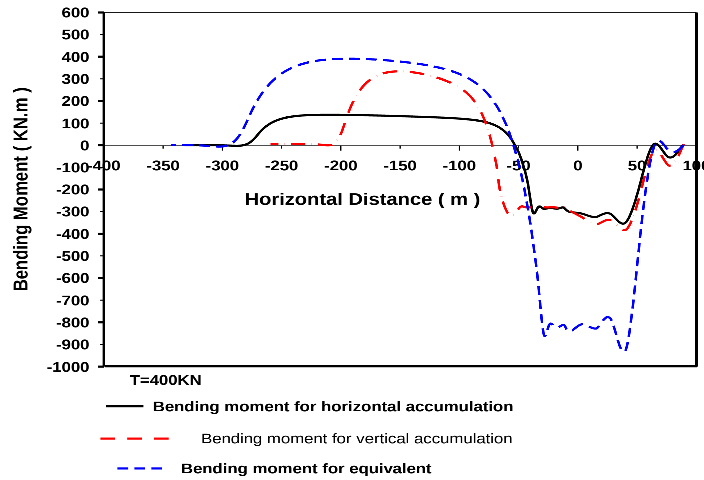

Fig.(14) : Bending moment diagrams of the deflected pipeline when the three techniques of accumulation are used and applied tension is 600KN

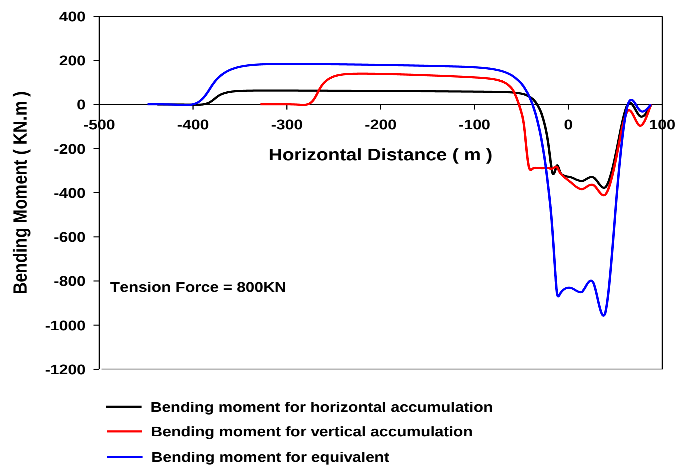

Fig.(15) : Bending moment diagrams of the deflected pipeline when the three techniques of accumulation are used and applied tension is 800KN

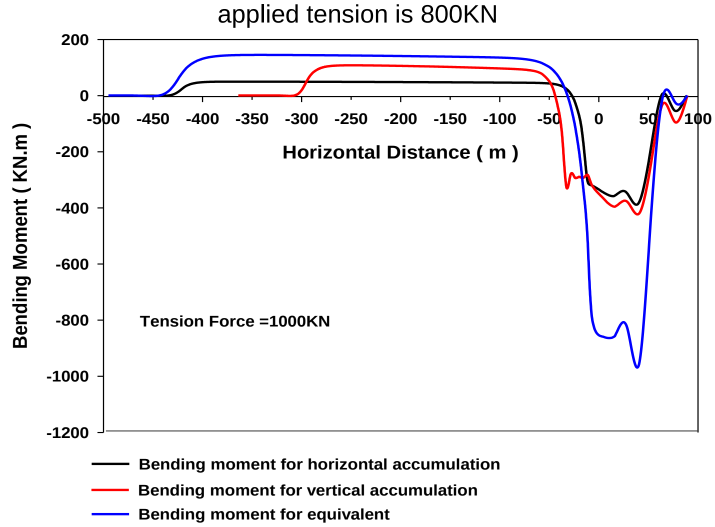

Fig.(16) : Bending moment diagrams of the deflected pipeline when the three techniques of accumulation are used and applied tension is 1000KN .

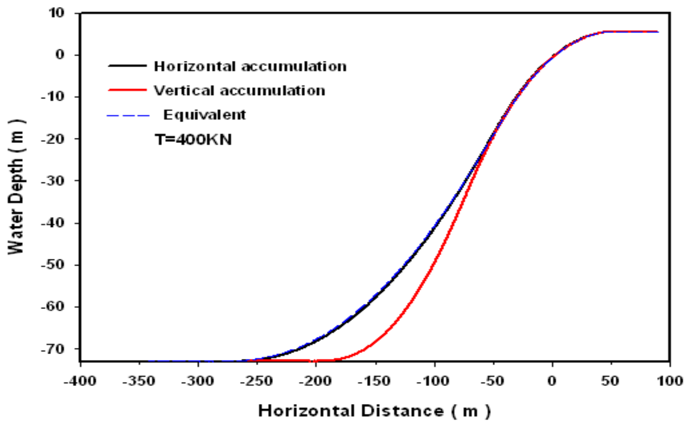

Fig.(17) : Deflection curves of the pipeline when the three techniques of accumulation are used under applied tension of 400KN

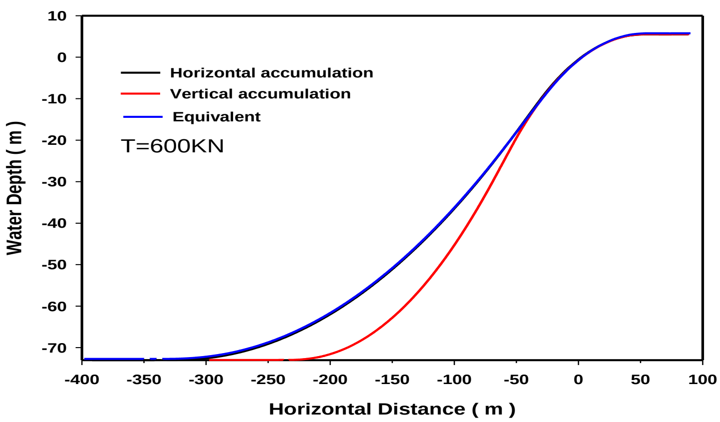

Fig.(18) : Deflection curves of the pipeline when the three techniques of accumulation are used under applied tension of 600KN

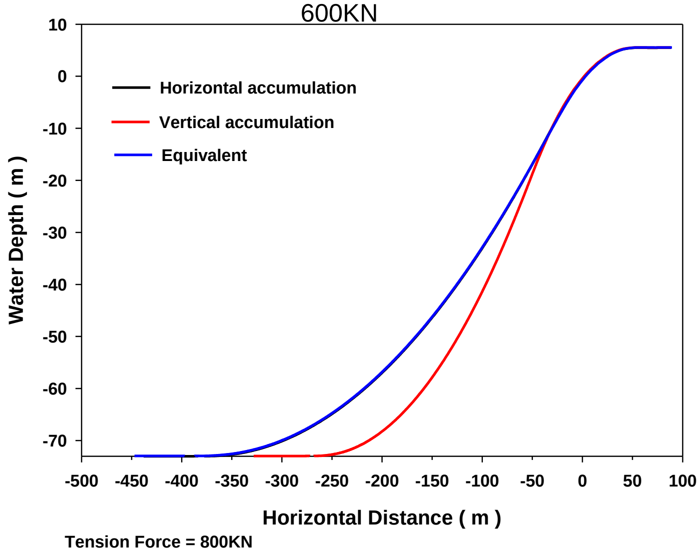

Fig.(19) : Deflection curves of the pipeline when the three techniques of accumulation are used under applied tension of 800KN

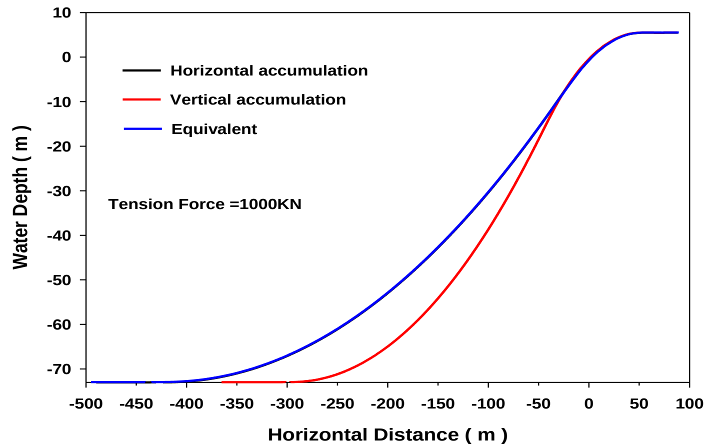

Fig.(20) : Deflection curves of the pipeline when the three techniques of accumulation are used under applied tension of 1000KN

4 Conclusions and Recommendations

The analysis of dual submarine pipelines lead to the following points:

- **a)** Such analysis is needed when there are two liquids to be transported or the capacity of lay barge is not sufficient to lay one pipe easily.
- **b)** The analysis took three mechanisms in laying two pipes namely horizontal accumulation, vertical accumulation and equivalent mechanism.
- **c)** The results of analysis of bending moments and deflections show that the most reasonable method for laying two pipes is the horizontal accumulation method. This is because the induced bending moment is around one third compared to other methods, besides that the values of the recorded deflections are in between the results of the other two methods.
- **d)** Lower obtained bending moments or bending stresses mean lower cost in design and labor requirements.
- **e)** The results of bending moments obtained either in varying tension or water depth lead to a laminated truth that horizontal accumulation is the preferable method.

The following regions of research can be studied as a future work:

- **a.** Analysis must be done for more than two pipes.
- **b.** Dynamic analysis can be done and check if the above recommendations still valid.
- **c.** Study of the effect of transporting two different liquids.
- **d.** Study of the effect of varying pipe diameter and thickness.

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