# ANALYTICAL STUDY IN AN END FITTING ASSEMBLY OF FLEXIBLE RISERS

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***Abstract.*** *This work presents an analytical investigation about a problem occurred while an end fitting for unbonded flexible pipe was being assembled. An inside component, known as Inner Seal Ring (ISEA), used for sealing the internal flow was assembled showing a restriction in the internal layers (Carcass and Barrier). The project of the components was made supposing non-deformation of internal layers in the assembly, ensuring a predicted stress in the interface metal-metal, between ISEA and Body (other internal component from end fitting). The objective of this work is to analyze the mechanical behavior and stress distribution in the end fitting components.*

***Keywords:*** *Flexible pipe, end fitting and Inner Seal Ring*

## 1. INTRODUCTION

Since the world depends a lot on the petroleum, so many new technologies and high amount of money are spent in the business of petroleum exploration. One of these new technologies is the Flexible Pipe Line, which many analytical approach have been developed to analyze the mechanical local behavior of this type of pipes (MacNamara, 1989 and Witz, 1992).

The structure of the flexible tube was initially proposed by the French Oil Institute (IFP) in 1960 and the first introduced in the market in 1972. In 1991, it was installed about 2,300 kilometers of pipes lines around the world (Porciúncula *et al.* 1999).

Being Petrobras the greatest costumer of this flexible pipes lines, some of these companies established their facilities here in Brazil as Wellstream International Ltd, which is one of the biggest companies that manufacture flexible pipes and it is where our analysis takes place.

A flexible pipe is made up of several different layers. The main components are leakproof thermoplastic barriers and corrosion-resistant steel wires. The helically wound steel wires give the structure high-pressure resistance and excellent bending characteristics, providing flexibility and superior dynamic behavior. This modular construction, which is composed of independent layers, is designed to actuate at different form where the layers are independent, but designed to interact with one another, means that each layer can be made fit-for-purpose and independently adjusted to suitable meet a specific field development requirement (*Typical structure of a non-adhesive flexible pipe, Chen et al. and API 17B*).

To connect these pipes with each other or with sub-sea equipments or rigid pipes is necessary a specific end fittings with specific internal parts to provide the structural resistant and isolation in order to extract petroleum from deep sea. Because of these internal parts each company have ours methodology to assembly the end fitting. In this specific case, it was observed that after an end fitting assembled a deformation of internal layers is generate. This effect is due to inner seal ring (ISEA) energizing.

The present paper shows an analytical investigation of mechanical behavior of one particular inner layer of the flexible pipe, known as the carcass, when the end fittings was being assembled for an unbonded flexible pipe.

## 2. PROBLEM PRESENTATION

The analyzed problem was observed when an end fitting was assembled in a 4" inner diameter flexible pipe. In the assembly of end fitting the inner seal ring is press against flexbarrier (Pressure Sheath – another inner layer of the flexible pipe) to make an internal isolation. However, the transferred load for the layer above generated an unexpected deformation for carcass. This layer is generally either in the form of a carcass made of interlocked strip, profiled strip in an almost circumferential lay or armour wires or strips in a longitudinally orientated lay. These helical layers are designed to provide the main contributions to the collapse, hoop and longitudinal resistance of a flexible pipe subject to pressure and axisymmetric loads. The "S" form of carcass generate a discontinuity (gap) in the layer and when submitted to external contact pressure of inner seal ring is detected a local deformation. This study aims analyzed a behavior of carcass for bend moment and tensions for future studies to compare an ovality allowed with this pre-deformation.

To illustrate the present problem let us take the Fig. (1), (2) and (3) as bellow. In Fig. (1) is shown an end fitting partially assembled, where can be seen the body with the flange API and the outer collar. Moreover, it is illustrated a schema, showing the internal parts of end fitting after the assembly. Finally, in Fig. (3) is presented the carcass profile and the reinforced area and the Gap.

Figure 1. Assembled end fitting cut out from the pipe to analysis.

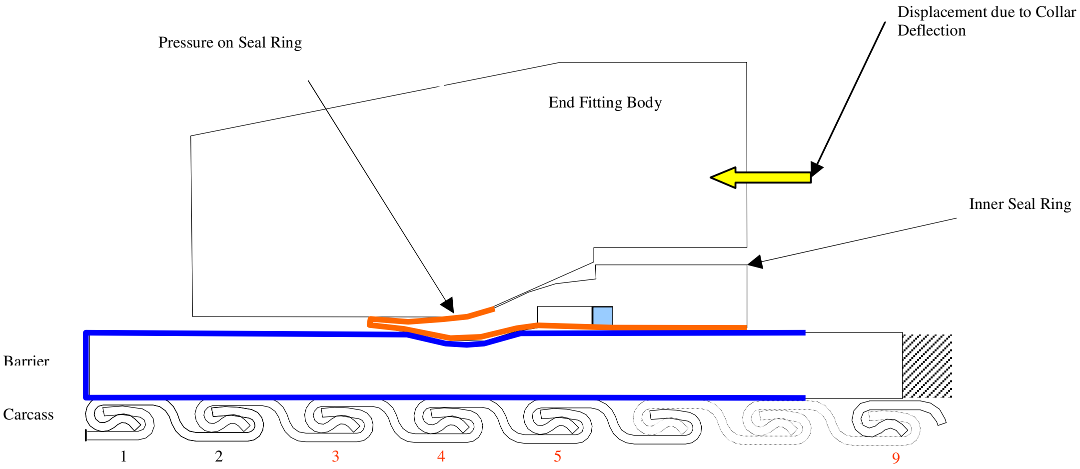


Figure 2 . Carcass/Barrier/ISEA after energized

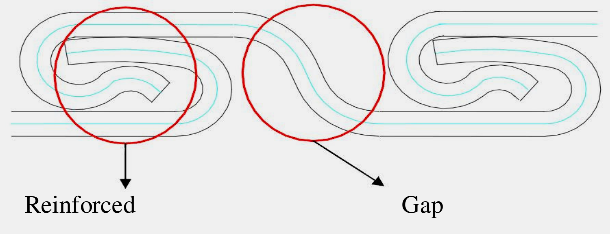


Figure 3. Carcass Profile showing the Gap where the deformation happen.

## 3. METODOLOGIA

In this study, for simplicity, let´s suppose that the thickness of carcass is small in comparison with the radii and it will be considered only the region that is in contact with inner seal ring, neglecting the longitudinal effects. Let us assume that a local deformation $\mathbf{w_0}$ is generate in the inner seal ring (ISEA), due to one gap in layer ring.

In order to determinate the magnitude of the bending moment **N** and reaction forces, **F** and **B**, it will be used the Castigliano theorem. Let us consider the bending moment of curved bar (ring) at any cross section, as illustrated in Fig (4) it can be given by:

$$M(\xi,\theta)\equiv\begin{cases} M_r = M(\rho,\theta), & 0\le\theta<\pi/2 \\ M_L = M(r,\theta), & \pi/2\le\theta\le\pi \end{cases} \tag{1}$$

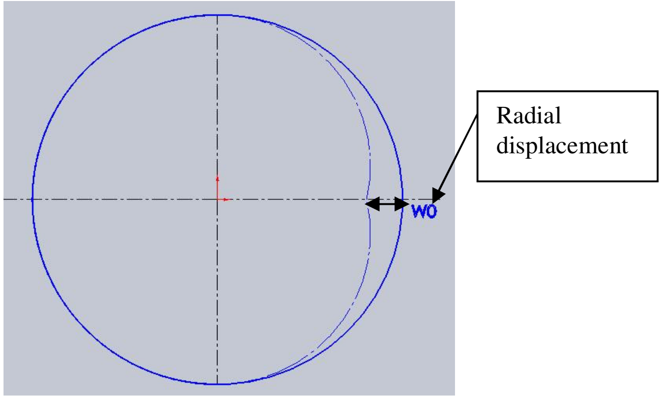


Figure 4. Displacement Ring after applied a uniform external pressure with a radial displacement ($W_0$).

## 3.1. MATHEMATICAL FORMULATION AND SIMPLIFICATION

In figure (5) we have a simplicity demonstration about semi-ring, illustrated in fig. (4), in our case is one wire of carcass in one section, supposing radial displacement ($W_0$) because a external pressure applied by ISEA energizing .

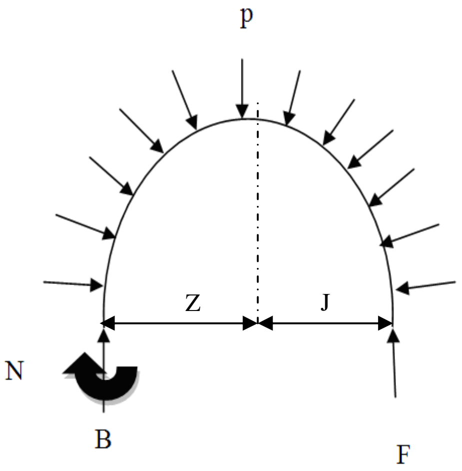


Figure 5. A ring supporting an external uniform pressure and a radial displacement on point where force **F** is applied.

In which **p** is the external uniform pressure, **F** and **B** are symmetry force, **N** is the bending moment of point showed in the picture and Z and J are the radius, they are different because of displacement happen only in one point.

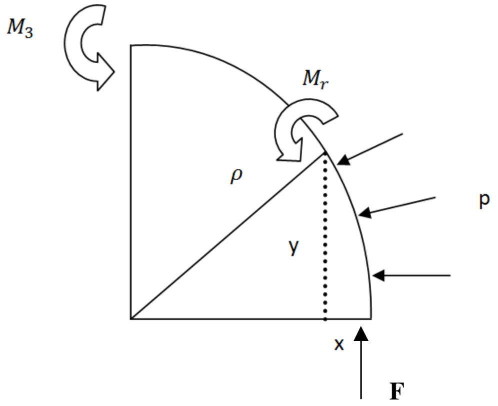


Figure 6. Right side of ring subjected to uniform pressure.

Less us considering only the right side of the ring which $M_r$ is a bending moment in any position in the ring edge, $M_3$ is a moment only when $\theta = \pi/2$, $\rho$ is the radii, **y** is a distance between a point of $\rho$ in the ring edge to horizontal coordination and **x** is difference between $\rho$ less the distance of a point in line **y** in the horizontal coordinate to center of the ring.

Therefore, can be obtained the moment $M_r$, given by

$$M_r = p/2(x^2 + y^2) - Fx \tag{2}$$

where

$$x = r - w_0 - \rho \cos\theta$$

$$y = \rho \; sen\theta$$

$$\rho = r - w_0 + w_0 sen\theta$$

and the bending moment when $\theta = \pi/2$ is:

$$M_3 = M^R_{\theta=\pi/2} = p/2[(r - w_0)^2 + r^2] - F(r - w_0) \tag{3}$$

Here will be used the equation (1) again considering the left side of the ring to determinate the moment $M_{L.}$ as illustrated fig. (7).

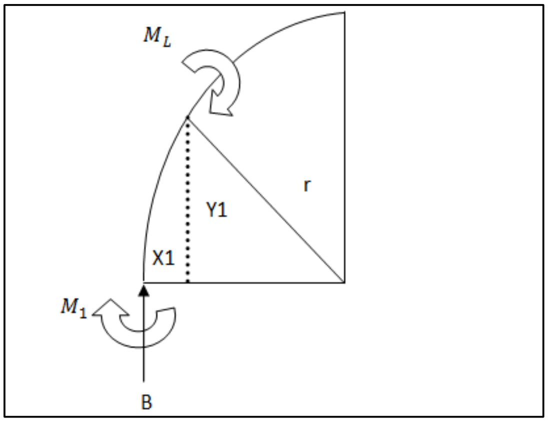


Figure 7. Left side of ring subjected to uniform pressure.

Which $M_L$ is a bending moment in any position in the ring boarded, $M_1$ is a moment only when $\theta = \pi$ , $r$ is radii, $y_1$ is distance between point of $r$ in the ring to horizontal coordination and $x_1$ is difference between $r$ less the distance of point in line $y_1$ in the horizontal coordinate to center of the ring.

So the bending moment is,

$$M_L = -M_1 - Bx_1 + p/2(x_1^2 + y_1^2) \tag{4}$$

$$x_1 = r(1-\cos\alpha), \quad \alpha = \pi - \theta$$

$$y_1 = rsen\alpha$$

therefore,

$$M_L = -M_1 + (pr^2 - Br)(1-\cos\alpha) \tag{5}$$

Due to the symmetry and assuming that it doesn't have rotation movement and the Castigliano theorem,

$$\frac{d\upsilon}{dM_1} = 0 = \int_0^{\pi/2} \frac{d}{dM_1}\left(\frac{M^2}{2EI}\right) rd\alpha = \int_0^{\pi/2} \frac{M_r}{2EI}\frac{dM}{dM_1} d\alpha$$

and knowing that,

$$\frac{dM}{dM_1} = -1$$

then,

$$\int_0^{\pi/2} M d\alpha = 0 \tag{6}$$

and,

$$M_1 = (pr^2 - Br)(1 - 2/\pi) \tag{7}$$

$$M_L = (pr^2 - Br)(2/\pi - \cos\alpha) \tag{8}$$

we still don't know what are the symmetry force **B** and **F**, but when $\alpha$ is equal to $\pi/2$ the bending moment will be know,

$$\alpha = \pi/2 \text{ so } M_L = M_3$$

using the equilibrium equation,

$$(pr^2 - Br)2/\pi = p/2[(r-w_0)^2 + r^2] - F(r - w_0)$$

$$B = 2pr - pw_0 - F \tag{9}$$

finally we have:

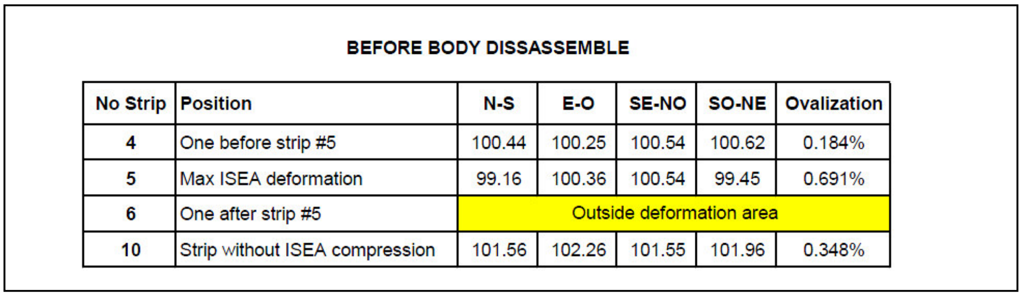
$$B = \frac{pr^2(2/\pi) - (p/2)[(r-w_0)^2 + r^2] + p(2r-w_0)(r-w_0)}{(2/\pi)r + r - w_0} \tag{10}$$

Now we can determine all elements of fig. (6) and (7). To determine the bend moment using the equations (3) and (7), was measured the displacement of the carcass before disassembled the end fitting and the information of the pipe layers as shown in table (1) and (2).

Table 1. Information of the layers from the Pipe

| | ID (mm) | Thin (mm) | OD (mm) | Material |
|---|---|---|---|---|
| Carcass (Flexbody) | 101.60 | 5 | 111.60 | Stainless Steel |
| FlexBarrier | 111.60 | 5 | 121.60 | Polyamide |
| ISEA | 122.60 | - | - | Stainless Steel |

Table 2. Information measured before end fitting disassemble



**BEFORE BODY DISSASSEMBLE**

| No Strip | Position | N-S | E-O | SE-NO | SO-NE | Ovalization |
|---|---|---|---|---|---|---|
| 4 | One before strip #5 | 100.44 | 100.25 | 100.54 | 100.62 | 0.184% |
| 5 | Max ISEA deformation | 99.16 | 100.36 | 100.54 | 99.45 | 0.691% |
| 6 | One after strip #5 | Outside deformation area | | | | |
| 10 | Strip without ISEA compression | 101.56 | 102.26 | 101.55 | 101.96 | 0.348% |

The information in the table (2) about ovalizations were calculated using equation (11) from *Souza et al* (3).

$$Ovality\ \% = \frac{OD\max - OD\min}{OD\max + OD\min} \tag{11}$$

Now to know the pressure applied in the carcass to energize the ISEA and assemble the end fitting we have to calculate the force **B**.

The torque (**T**) applied in the capscrew was 59N.m, using the equation (11) to find the resultant force (*fi*) in the equipment as shown in fig. (8),

$$T = C * D * f_i \tag{12}$$

where,

*C – friction coefficient for capscrew ;*

*D – diameter of capscrew;*

*T – torque applied;*

*fi – resultant force in the equipment.*

$$f_i = 25.81\,kN$$

*fi* is the force that one capscrew applies in the ISEA, and the $F_i$ is the force for all twelve capscrew which are used to energisis the ISEA completely.

$$F_i = 309.72\,kN$$

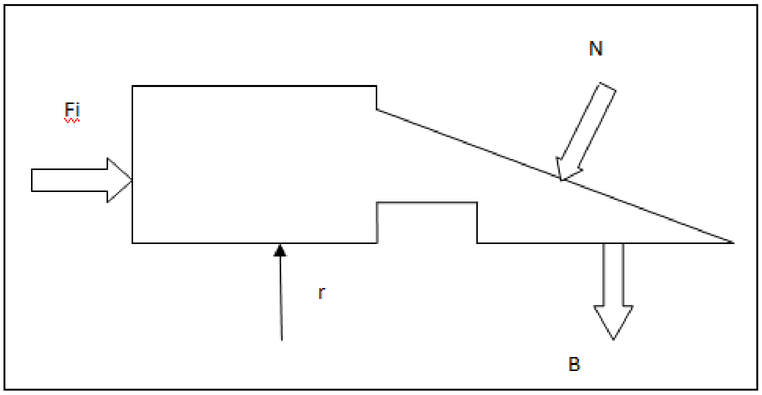


Figure 8 – Scheme of ISEA in an energizing moment.

In the fig. (8) are shown the forces resultants, N (reacting force by Body), *Fi* (force applied for ISEA energizing), B (force component applied in Barrier/Carcass), disregarding any displacement from the other equipments used in the assembly, and r (radii – distance from pipe center).

Using the equilibrium equation:

$$F_i = N sen\alpha + \mu N \cos\alpha \tag{13}$$

$$B = N \cos\alpha - \mu N sen\alpha \tag{14}$$

Now isolating the N in these two equations and using $\alpha =$ 12º.20, this is obtained when the component was manufactured.

$$B = F_i [\frac{\cos\alpha - \mu sen\alpha}{sen\alpha + \mu\cos\alpha}] \tag{15}$$

$$B = 958{,}31kN$$

when B is substituted in the equation (10) is obtain the bend moment.

But only the bending moment is not enough to know the behavior of the carcass wire, because the stress at the wire is important too, so using the equation (16) to calculate the pressure applied, can be determinate the pressure and with the equation (17) can be calculated the stress.

$$p = \frac{B}{2 * \pi * D} \tag{16}$$

$$p = 2.733MPa$$

and ,

$$\sigma =^{+}_{-} \frac{M}{I}\frac{t}{2} + \frac{pr}{t}, \tag{17}$$

$$I = \frac{t^3}{12}, \text{ inertial moment;} \tag{18}$$

when:

$$0 < \theta < \pi/2, \quad M = M_r \quad and \quad \pi/2 < \theta < \pi, \quad M = M_L$$

The distribution of the stress and the bend moment at the carcass wire can be illustrated in the figures 9, 10 and 12.

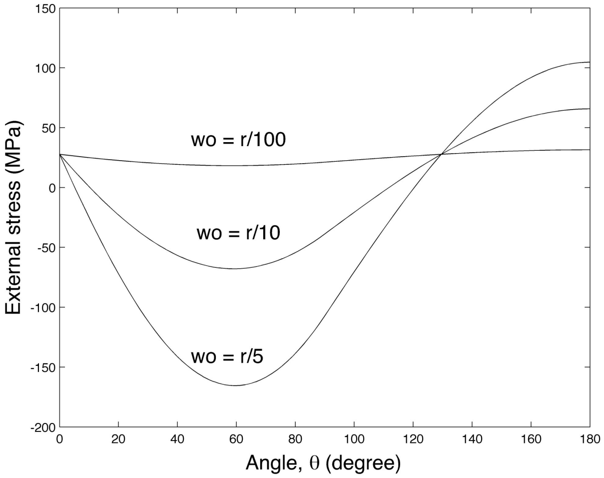


Figure 9. External Stress x Angle $\theta$ and carcass radii displacement ($w_0$) as a function of radii.

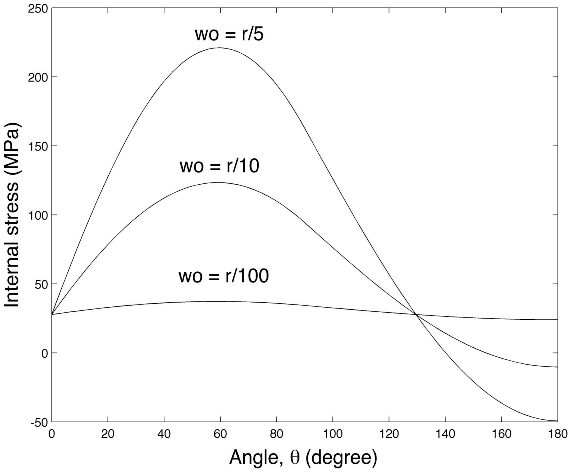


Figure 10. Internal Stress x Angle $\theta$ and carcass radii displacement ($w_0$) as a function of radii.

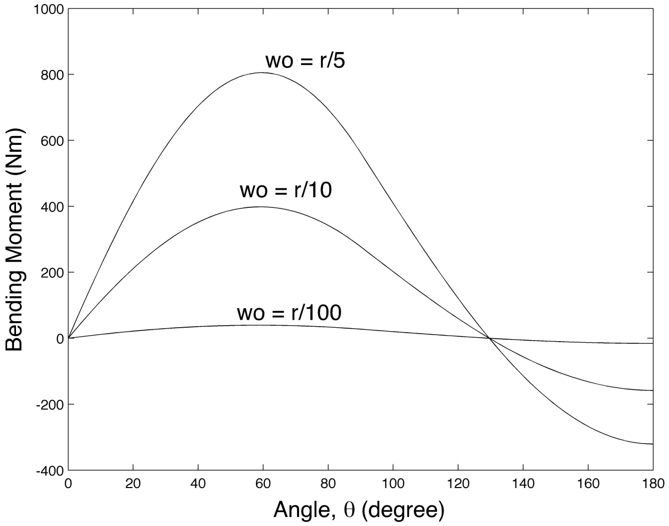


Figure 11. Bending Moment x Angle $\theta$ and carcass radii displacement ($w_0$) as a function of radii.

## 4. CONCLUSION AND DISCUSSION

Taking into account the results in figure 10, which present the external, internal stress and bending moment, can be seen that the maximum stress and moment occur when the $\theta$=60°.

In this analysis the barrier layer was not included in the study. In case when the barrier layer is considered the results of deformation of carcass are less than the results presented in Fig. 10 due to polymer properties.

The deflection of other equipments were not included in this study because is supposed that after a ISEA energization all equipments were ready assembled and the measurement made after disassembled inform the exactly deformation that happened and was know the force applied to energized the ISEA .

This is a preliminary work aims to adding knowledge to future study on the influences of displacement observed in the carcass of flexible pipe to calculate the allowed ovality.

## 5. ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the Wellstream International Ltd. The present paper received all support, information and help from your Brazilian office and manufacture.

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