NUMERICAL STUDY AND ANALYSIS OF FAILURE BETWEEN THE STRUCTURAL LAYERS OF FLEXIBLE PIPELINES

André Saikai Gomes, andre.saikai@gmail.com
Larissa Driemeier, driemeie@usp.br
Dias, Carlos Alberto Nunes, candias@usp.br
Group of Solid Mechanics and Structural Impact
Department of Mechatronics and Mechanical System Engineering
University of São Paulo
Av. Prof. Mello Morais 2231 – São Paulo – SP 05508-900 – Brazil

Abstract. *Risers are flexible pipelines used to transport fluids, mainly in the extraction of oil "Offshore". They are complex structures composed by several layers of different materials and geometries. Each layer has a well defined structural function and, together, they provide resistance and tightness, without compromising the flexibility, necessary for fluid conduction. There are many shortcomings when performing numerical analyses of riser: the complex geometry; the different materials and the difficulties of obtaining their properties; contact modeling between layers; applied load and boundary conditions. In the present work, a numerical model is proposed for the riser, embracing geometry, material and contact modeling. Moreover, a failure criterion is used in a drop-test simulation, considering different internal pressures.*

Keywords: *risers, contact, numerical analysis, failure.*

1. INTRODUCTION

Most of national oil reserves are localized in particularly deepwater, in offshore areas. One of the most important structural challenges in this field is the development of *risers* – flexible tubes that conduct the drilled oil to the platform or oil tanker ships. As risers go into deeper sea, their characteristics are those of a highly flexible slender body with higher loads and pressures, motivating many experimental and numerical studies. Thus, sophisticated knowledge of the mechanical behavior and properties of materials of the flexible line becomes critical (Ramos et al., 2008; Muñoz et al., 2009, Goto et. al., 1986).

Risers are complex structures with high strength, providing resistance to internal and external pressures, plus to loads due to the wave and marine current and the movement induced by the ship; without compromising the required flexibility. In this way, the riser is composed by several layers of different materials, as in Fig. 1, allowing the careful selection of materials in compliance with the specific requirements of that particular layer. The risers can be divided into two groups: unbounded and bounded lines. The difference is that in the bounded lines, layers are attached through the use of adhesives or applying heat or pressure (vulcanization), while in the unbounded lines, layers can move in relation to each other. The cross sections, material and applicability of each layer is detailed in Table 1.

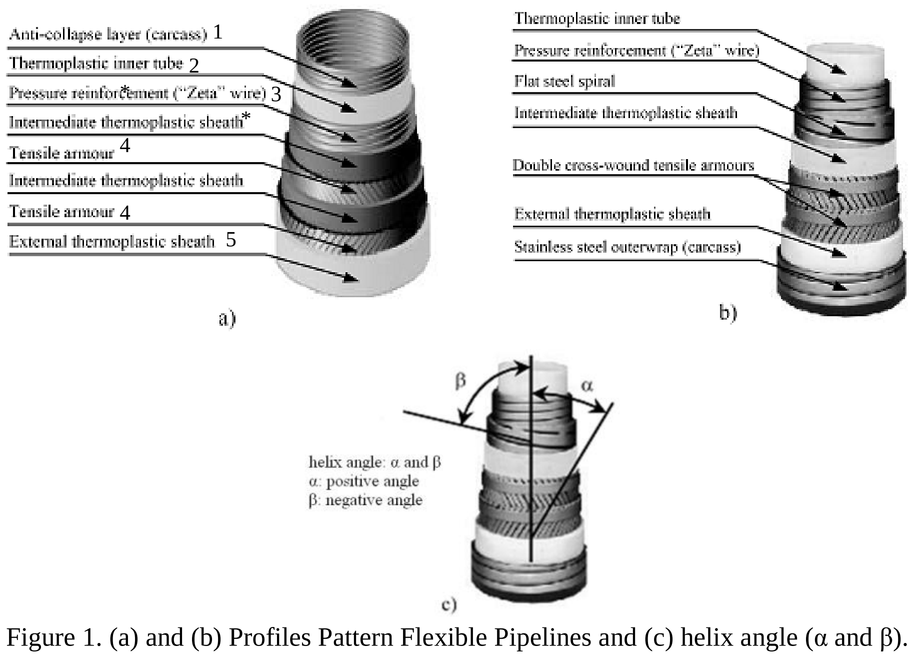
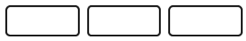


Figure 1. (a) and (b) Profiles Pattern Flexible Pipelines and (c) helix angle (α and β).
Extracted from Dias et al. (1995).

If disposed as shown in Fig.1, the layers of polymers provide internal fluid integrity, and also have they objective to avoid wear due to friction between adjacent layers of steel.

Table 1. Riser Layers Specification

Layer	***Name***	***Structural function***	***Cross Section***	***Material***
1	Carcass	Prevents collapse of the inner liner and provides mechanical protection against abrasive particles.		Metallic strip
2	Inner liner	Providing internal fluid integrity		Extruded polymer
3	Pressure reinforcement	Provide resistance to radial loads		Metallic wires and/or Metallic strips
4	Tensile armour	Provide resistance to axial tension loads		Thermoplastic
5	Outer sheath	Provide Torsional Stiffness		Extruded polymer

Risers are a challenge of structural engineering, since it evolves complex geometries, large deformations, plasticity, temperature variations, fluid-structure interaction, contact. Consequently, the use of numerical tools is essential. The study of the behavior of risers has been explored in the literature in many ways. For example, Gómez and Milioli (2005) simulated the fluid flow in the risers. In recent work, Ramos et al. (2008) conducted the analytical studies involving structural analysis of risers. They determined the equivalent stiffness coefficient for axial and torsional loads and compared the results with experimental tests performed at the Institute for Technological Research of São Paulo (IPT). Muñoz et al. (2008) presented a numerical simulation in tension and torsion of a simplified model.

Particularly due to the complex geometry of the riser, the use of numerical tools has a physical model limitation. However, following McNamara et al. (1989), traditional methods of analyzing the flexible tubes considering two-dimensional model with axissymmetric loads, cannot adequately account for the field of three-dimensional deformations.

Thus, the main objective of this work is the generation of a three-dimensional numerical model of a small portion of the riser, including all layers, with their own particular geometry – according to Dias and Cruz (1995). Moreover, the contact between consecutive layers and self contact are also considered. The material model for each layer was obtained from literature and a failure criteria was implemented. The model here proposed can be opened in some famous codes of finite elements analysis - such as ABAQUS ®, LS-DYNA ®, ANSYS® - and any sophisticated available material model and failure criteria can be used.

In order to validate the model, a drop-test with and without internal pressure was conducted. It is important to emphasize the qualitative sense of the validation, since material parameters for each layer cannot be easily found in the literature and is out of the scope of the present work.

2. NUMERICAL MODEL

2.1. Geometry

The generated numerical model is 190 mm length and it has 100 mm in diameter. The model is composed by 6 layers designed to detail each structural component of riser: 3 layers with hexagonal solid elements to characterize the polymer layers of the riser; 2 layers with beam elements to characterize the steel armour and 1 layer with plate elements to characterize the carcass layer.

According to Figure 2, the polymer layers from the first and third layers are composed by 7200 solid elements each, with a thickness of 6 mm and 8 mm respectively and the second layer consists of 3600 solid elements with a thickness of 2mm. The steel layers, Fig. 3(a), whose main function is to make the top of the riser resistant to axial and radial loads, were modeled with 3600 helical elements of beam type and they are arranged between the plastic layers. The carcass layer was modeled using 3600 shell elements with a thickness of 1.75mm. Located inside the riser, it is responsible for contributing to a resistance to prevent the collapse of the inner liner due to pressure, Fig. 3(b).

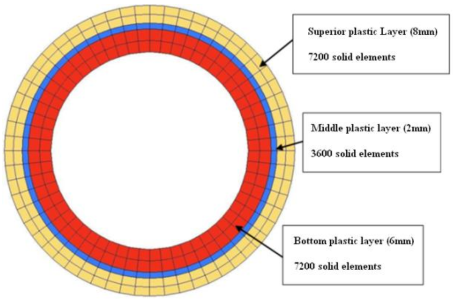


Figure 2. Details of the layers of Plastic Model Number.

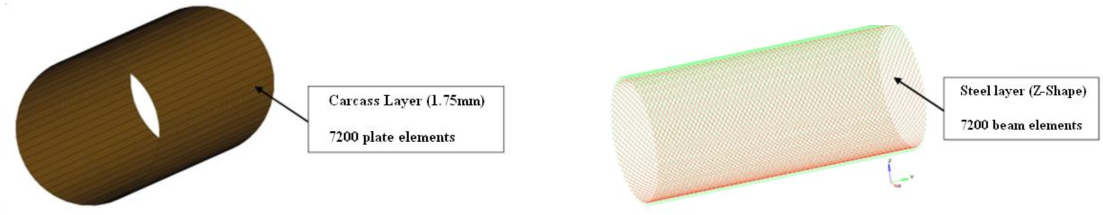


Figure 3. Details of layers (a) of the carcass layer and (b) of the steel layers.

2.2. Material

Traditional materials such as plastic kinematic and piecewese linear plasticity were used. Due to great difficulties to obtaining more detailed experimental results of the materials that compound the risers, all values were obtained from the literature.

In the polymer layers, linear plasticity model was used and the properties are from a standard thermoplastic material. Failure occurred when the plastic strain reaches 30%. For the interior and external polymer layers, the linear plasticity model was used, with the parameters presented by Ramos et al. (2008). For the rupture, the values of equivalent plastic strain were defined in Dias and Cruz (1995). A summary of the obtained values is presented in Tables 2 - 4.

Table 2. Material specifications data from steel layers.

Steel Layer Material Properties	
Density	7850 Kg/m³
Poisson's Ratio	0.3
Modulus of Elasticity	210 GPa
Elongation at Failure	15.0 %
Ultimate Tensile Strength	540 MPa

Table 3. Material specification data from interior layer.

Interior Pressure Layer (*)	
Density	1750 Kg/m³
Poisson's Ratio	0.45
Elasticity Modulus	13.2 GPa
Elongation at Failure	200%
Ultimate Tensile Strength	20,4 MPa

(*): Average values calculated from Ramos et al. (2008).

Table 4. Material specification data from external layer.

External Pressure Layer (*)	
Density	1750 Kg/m³
Poisson's Ratio	0.45
Elasticity Modulus	13.2 GPa
Elongation at Failure	260%
Ultimate Tensile Strength	39,3 MPa

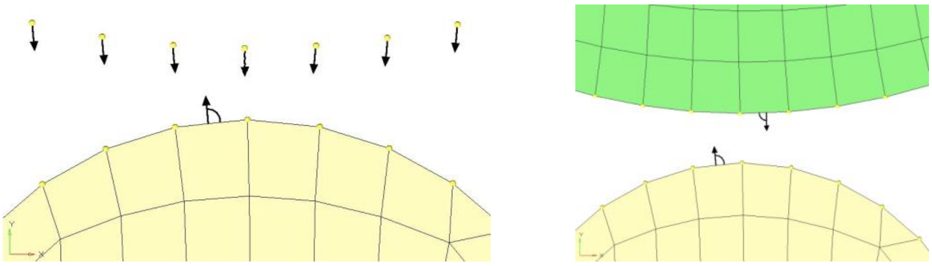
(*): Average values calculated from Ramos et al. (2008).

2.3. Contact

Generic codes of contact, as the contact automatically provided by the manufacturers of commercial softwares, are not suitable for the simulation of risers, due to the presence of large pressures and the existence of several layers made of different materials.

For the simulation, three of contact algorithms were used, each with their specific function. To represent the contact between the internal layers, the contact "*nodes to surface*", Fig. 4(a), presented the best results. This option includes the possibility to attribute value for the static friction, leading one layer slide over the other, when this friction value is overcome. Assuming that self-contact can occur in the layers, "*single surface*" contact is properly assigned to each layer, although it was not activated in the following examples.

The contact between the external layer and rigid body used in the drop test was simulated by the "*surface to surface"* algorithm, where the surface of the rigid body is configured as "*master*" and the polymer layer is configured as the "*slave*" of the contact, see Fig 4(b).



(a) (b)

Figure 4. (a) Contact Nodes to Surface and (b) Contact Surface to Surface.

3. RESULTS

As a validation of the proposed model, drop-tests, with and without internal pressure, were simulated in the commercial software LS-Dyna®.

3.1 Drop Test withouth any internal pressure

Fig. 5 shows the geometry, boundary conditions applied to the unbounded riser and applied initial velocity in the dropper.

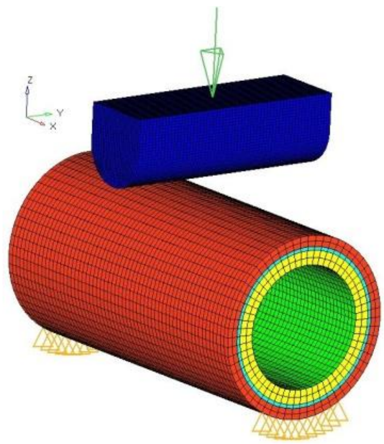


Figure 5. Model of the riser without internal pressure.

According to Fig. 6, the solid dropper is modeled as a rigid with 125mm long, 40mm wide, 40mm height and with 185 kg of mass. This solid body reaches the riser at a speed of 100 m/s.

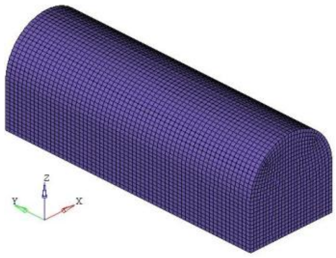


Figure 6. Dropper.

Fig. 7 shows the high tension in the inner section of contact between the riser and the solid body, leading to failure of the material in this region. As can be seen in Fig. 8, where different instants of the test are captured, the layers are unbounded and, as the dropper perforates the layers, the elements are eroded from the original mesh, simulating the failure.

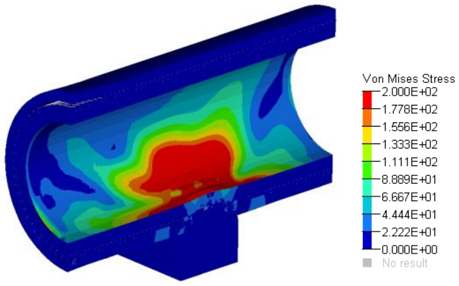


Figure 7. Stress in the riser during simulation of drop test.

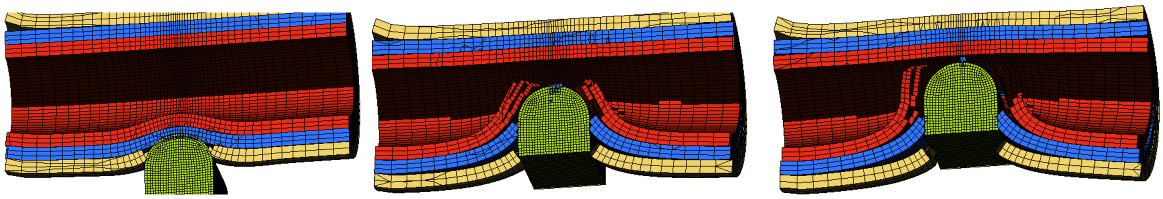


Figure 8. Failure of the riser during a drop test.

3.2 Internal Pressure

3.2.1 Internal Pressure of 60 MPa

The new drop test includes an initial internal pressure in the riser. In the first case was chosen 60MPa. The internal pressure value applied in the simulation has a qualitative character since its real value is unknown. In this new configuration of the test, the riser is launched on the fixed solid body, as illustrated in Fig. 9, with initial velocity of 100m/s.

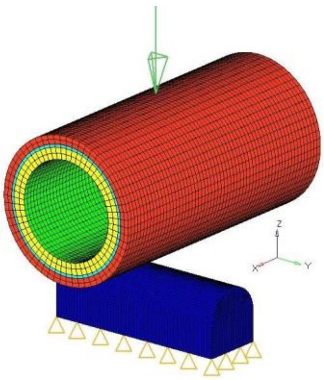
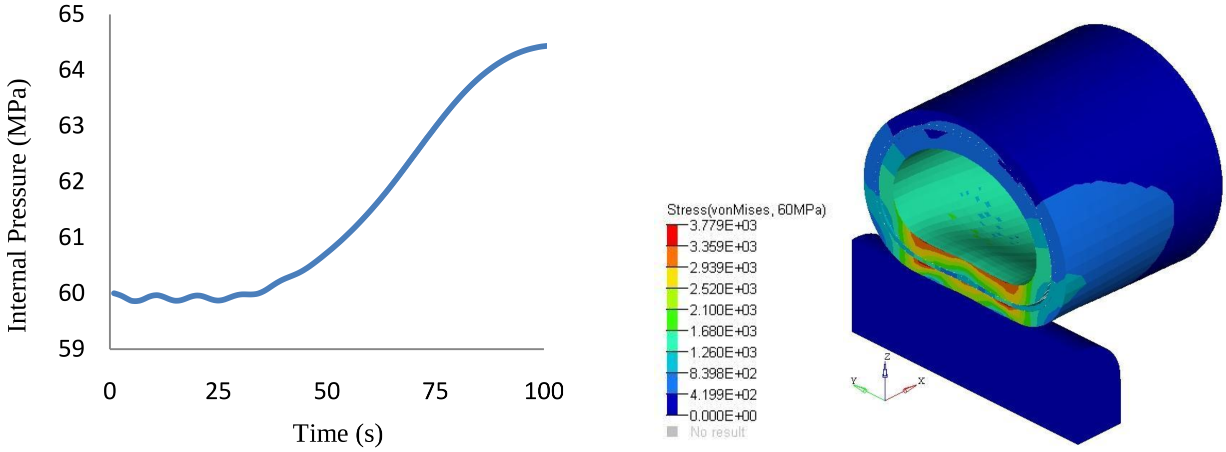


Figure 9. Model of the riser with internal pressure.

The initial pressure is simulated with *airbag model* in LS-Dyna®, since the option for internal pressure is available only for axissymmetric models. The software Abaqus® has an easier option for pressure applied in a closed surface. As shown in Fig. 10(a), when the riser impacts the target the internal volume is reduced and, therefore, the pressure increases.

Since only a small portion of the riser is modeled, a control condition was implemented in the extremities of the opened riser, avoiding the occurrence of loss of pressure. It is important to point out that the change in the pressure is significantly dependent on the considered length of the riser. Fig. 10(b) shows the higher von Mises stresses during the impact.

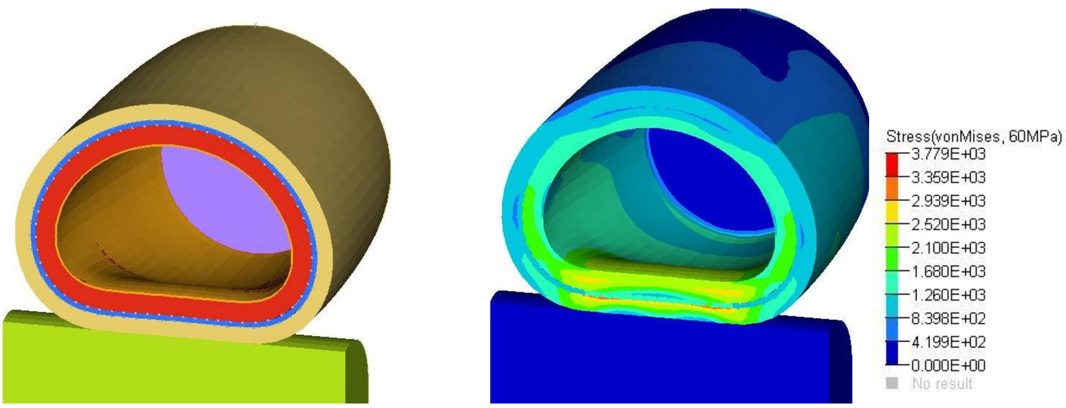


(a) (b)

Figure 10. (a) Internal pressure and (b) von Mises stress at critical instant of the drop test.

3.2.2 Internal Pressure of 600 MPa

In order to obtain the different behavior of riser at different pressures, the same test was conducted with an internal pressure of 600MPa. Fig. 11 shows in the stress at critical instant of the test.



(a) (b)

Figure 11. (a) Deformed profile of the riser and (b)Von Mises stress, for the drop test with internal pressure of 600MPa.

In the internal pressure monitoring, Fig. 12(a), an initial change in value of the internal pressure is detected. The internal pressure is instantaneously generated by the activation of the *airbag*, leading to an increase in the internal volume, decreasing the pressure.

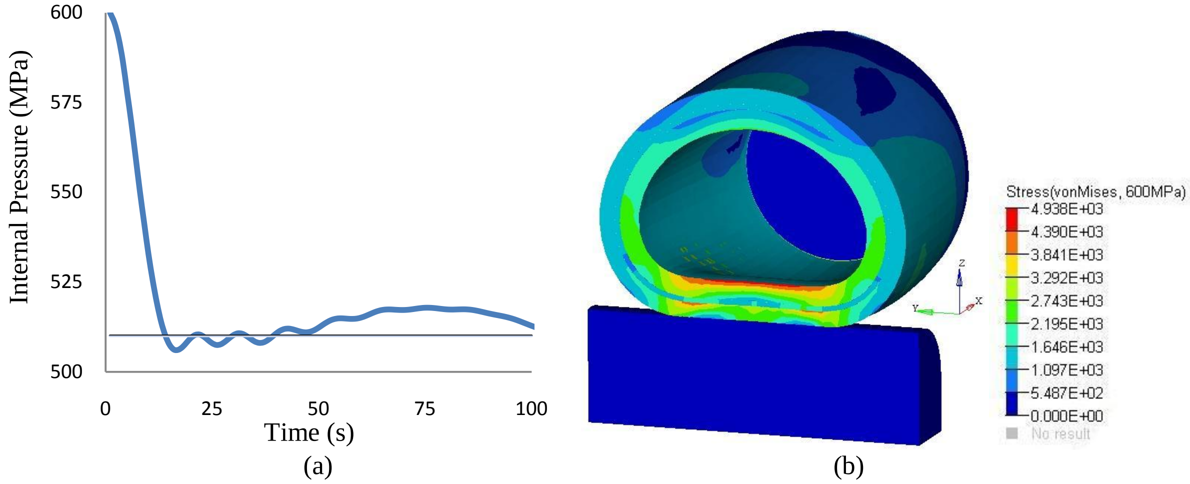


Figure 12. (a) Internal pressure and (b) von Mises stress at critical instant of the drop test.

Fig. 13 compares both results, 60MPa and 600MPa of internal pressure. As expected, a harder model is obtained with higher internal pressures.

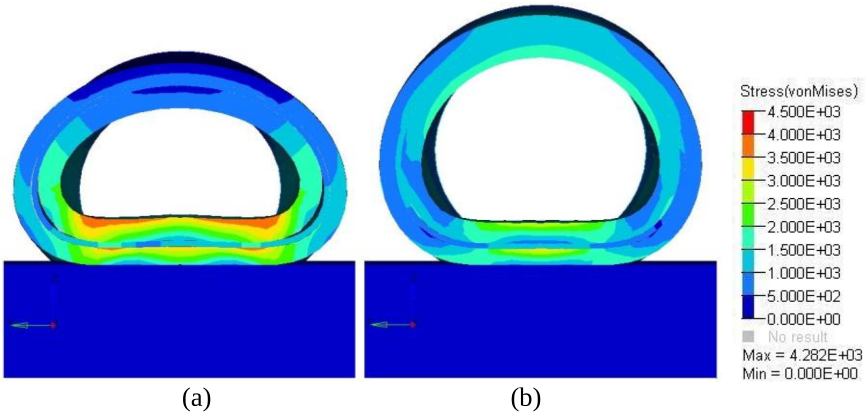


Figure 13. Comparison between tests at (a) 60MPa and (b) 600MPa of internal pressures.

4. CONCLUSIONS

The main objective of this paper is to generate a reliable numerical model of the riser, based on its real complex geometry, with the interaction between layers acting with consistent performance. The generated model was checked for drop test and showed good performance.

Among the difficulties, the implementation of contact in the model is pointed out. After several simulations, the results showed that only one type of contact is not sufficient to represent the real movement of the layers when the riser is subjected to impact. The best solution was the use of individual contacts for each layer together with the general contact, embracing all layers. In the generated model, the parameters considered were the standards of the program, and the values of static and dynamic friction were determined after calibration of the coefficient by numerical test.

The most important characteristic of the proposed input file is the facility of change of any input data, such as the parameters of the material and the control variables for the contact and the failure. It demonstrates, in the author's point of view, a great potential for future work.

Currently, plastic linear model is used to represent the various material layer. As discussed in the text, the material model and failure criterion for each layer were obtained from literature. Many material models and failure criteria are available in the commercial software and they can easily be used in the proposed input file. However, all models need a complete parameterization, which is possible only with experimental tensile, shear and compression tests of each material that compound the riser. In this way, the work aimed the qualitative modeling of the problem, since not sufficient information about the material is available to introduce parameters based on experimental simulation.

5. ACKNOWLEDGEMENTS

The ANP and the financial support PRH19 by the first author. The financial support of FAPESP, a funding agency for research and development of São Paulo / Brazil, is recognized by all authors.

6. REFERENCES

Muñoz, H.E.M., Souza, J.R.M., Roitman, N., Magluta, C., Mata, D., 2008, "Correlação numérica-experimental de risers flexíveis submetidos a cargas de tração e torção", CILAMCE , Alagoas, Maceió.

Gómez, L. C., Milioli, F. E., 2005, "Numerical simulation of fluid flow in CFB risers – A turbulence analysis approach"; J. Braz. Soc. Mech. Sci. & Eng., Vol.27, No. 2, Rio de Janeiro, Apr./June

Ramos, R.Jr., Martins, C.A., Pesce, C.P, 2008, "A case study on the axial-torsional behavior of flexible risers", Proceedings of the ASME 27th International Conference on Offshore Mechanics and Arctic Engineering (in press), OMAE2008-57514, June 15-20, , Estoril, Portugal.

Dias, C.A.N., Cruz, F.T.L., 1995, "Programa GERFLEX Programa para geração automática de modelo tridimensional de tubas flexíveis para análise estrutural pelo Método dos Elementos Finitos Ref.: Modelo Tridimensional para Analise de "Risers" Flexíveis Por Elementos Finitos", Projeto 253 do Centro de Estruturas Navais e Oceanográficas da Escola Politécnica da Universidade de São Paulo.

Dias, C.A.N., Cruz, F.T.L., 1995, "Modelo Tridimensional para Análise Estrutural de "Risers" Flexíveis por Elementos Finitos.", Relatórios Técnicos nos. 001/253 e 002/2523, Centro de Estruturas Navais e Oceânicas da Universidade de São Paulo.

Goto, Y., Okamoto, T., Araki, M., Fuku T., 1986, "Analytical Study on Mechanical Strength of Flexible Pipes", 9th Annual ASME Energy Sources Technology Conference &1st OMAE Offshore & Artie Frontier Specialist Symposium, pp. 337-341.

McNamara, J. F., Harte, A. M., 1989, "Three Dimensional Analytical Simulation of Flexible Pipe Wall", 8th International Conference on Offshore Mechanics and Artie Engineering, Vol. 5, pp. 477-482.

Ramos, R.Jr., Pesce, C.P., 2002, "A Review on the Flexural Structural Behaviour of Flexible Risers", 3rd Workshop on Subsea Pipelines.

Silva, A.P., 2006, "Análise da influencia da temperatura na rigidez à flexão de linhas flexíveis", Tese de Mestrado, Engenharia Oceânica, dezembro, COPPE/UFRJ.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.