COMPUTER GRAPHICS PROCEDURES FOR RISERS AND MOORING LINES VISUALIZATION

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Abstract. *This work shows the development of computer graphics procedures for the visualization of results from finite elements associated to the analysis of risers and mooring lines. Due to an increasing expansion of the activities done by the explored petroleum industry, the development of computational systems for the numerical analysis of offshore structures behavior has increased considerably. Thus, a better understanding of the physical phenomena related to these engineering problems requires the development of procedures that make the quantitative and qualitative visualization of the numerical analysis results obtained. The procedures proposed in this work are based on the integration of a flexible data structure, using object-oriented programming, with high computational graphic resources. The data structure allows a greater flexibility for an incorporation of new technologies. The graphical resources permit a bigger capacity of technical understanding of the physical phenomena associated with the problems studied. The procedures are incorporated in a computational environment that allows the visualization of risers and mooring lines analyzed by the Finite Element Method. Numerical examples are shown to validate the proposed procedures.*

Keywords*: Visualization of risers and mooring lines, Graphical computation, Data Structure*

1. INTRODUCTION

The computational modeling of risers and mooring lines have become even more used in many research centers in Brazil and also abroad. The usage of this research is increasing fast due to the high demand petroleum industry has provoked. They need computational systems capable of simulate all physical behavior of an offshore structure, including the visualization of the achieved results.

Nowadays, Petrobras frequently uses the mooring lines system to hold the platform to the bottom of the sea floor, like shown in Figure 1.This kind of clipping system is object of many researches (Silveira et al, 2000), (Ferreira et al, 2004), (Ferreira, 2005), (Silva, 2005). The system's final objective is to leash the platform on land found in the deepest parts of the sea.

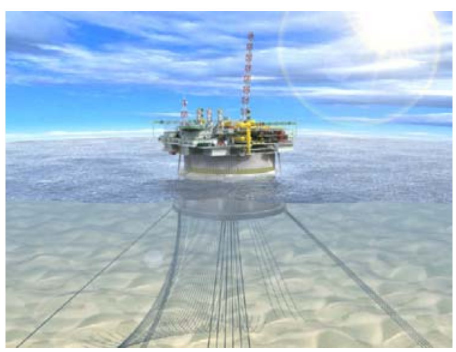


Figure 1: An offshore structure with risers and mooring lines. (Source: Ferreira, 2005).

Another element used on the composing of exploring petroleum systems is known as risers. This element is composed by ducts that stream the oil from the sea to the platform. Ferreira (2005) says the mechanical behavior of the risers and mooring lines are similar, once they are submitted to similar efforts.

Ferreira (2005) even says the risers and mooring line system is the most applied method by Petrobras of leashing platforms in deep water. In fact, Petrobras has the record of the deepest perforated soil.

With the great use of this system, appears the demand of studies on the dynamic behavior of this type of structure in the state of service, submitted to the many combined loads (tide stream, waves, clumps, buoy etc.). In the engineering point of view, this system is analyzed using the numerical methods, precisely the Finite Element Method (FEM), by which the structure is discrete in element and nodes. The reason why the FEM was chosen is because it has great versatility, quality and it is quite easy to program it.

On the other hand, the high technological development related to the exploration of petroleum has generated many numerical analyses of problems even more complex, creating a huge data volume and making the technical interpretation of the simulated problems really difficult. Examples of programs that calculate those analyses can be found at (Mourelle et al, 1995), (Coelho et al, 2001), (Fucatu e Nishimoto, 2003), (Silveira, 2001), and (Ferreira, 2005). The development of graphical tools for visualization of these mooring lines have become even more necessary, with the purpose of improving the capability of interpretation of phenomena associated to the mechanical behavior of the structure dynamics.

One of the most famous graphical programs with all the described features is Orcaflex (Orcina, 2005). Orcaflex is a computer system developed by Orcina, designated for dynamic analyses of flexible or rigid ducts. Therefore, beside this system being commercial, making difficult the use in researches, Orcaflex has problems associated to a better presentation (qualitative or quantitative) of the results, limiting the possibility of proper risers and mooring lines visualization.

Inside this context, this work shows the development of computer graphic procedures to the visualization of risers and mooring lines, results of FEM associated to the dynamical analysis of risers and mooring lines. The proposed procedures are based on the incorporation of a flexible data configuration, via Object Oriented Programming, with advanced resources of computer graphics. The data organization concedes great flexibility for the implementation of new technologies. The graphical resources permit a greater ability of technical understanding of the physical phenomena related to the studied problem. The procedures are incorporated into a computer environment which consents the visualization of risers and mooring lines analyzed by FEM.

Section 2 of this work shows a description of the flexible data structure used to support the development of the graphical procedures. Section 3 describes the graphical procedures based on the use of advanced methods of computer graphics. As a matter of illustration of the procedures, Section 4 offers graphical examples of the procedures in a developed computational environment. Section 5 has the final considerations of the work.

2. DATA STRUCTURE

The graphics procedures developed in this work are based on a structured system created by the composition of elements of the group platform-lines-land, as shown in Figure 2.

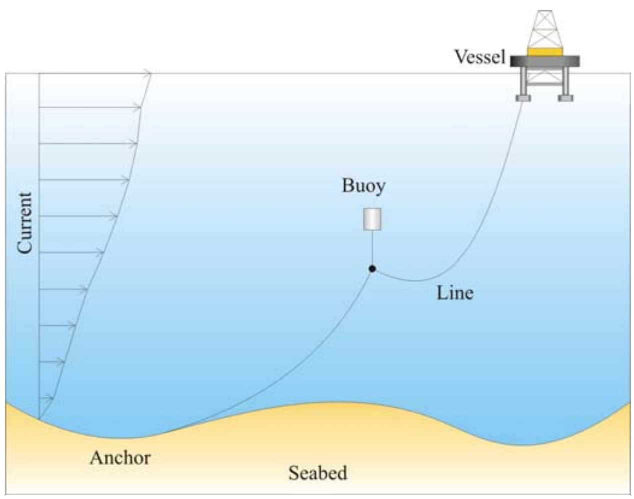


Figure 2: Studied physical problem. (Source: Silva et al, 2006).

To support dynamical visualization of data associated to the structural system, a topological data structure is produced to ease the use and manipulation of the associated information of each element of the system. This data structure is based on an organization of classes, agreeing to the paradigm of Object Oriented Programming (Ellis and Stroustrup, 1993) (Ricarte, 1995), which, among others advantages, allows an easier expansion of the algorithm: new functionalities are implemented without difficulties. Figure 3 illustrates the Class organization used to support the proposed procedures.

The system´s data structure is controlled by class Model. This class gets all info of the structure. The access of the information is conditioned to the manipulation of a Model-type element, disconnecting the whole data structure from the graphic interface. The other classes were conceived to convert the real problem into a computational arrangement, creating classes referred to real entities (Line, Segment, Node, Step etc.)

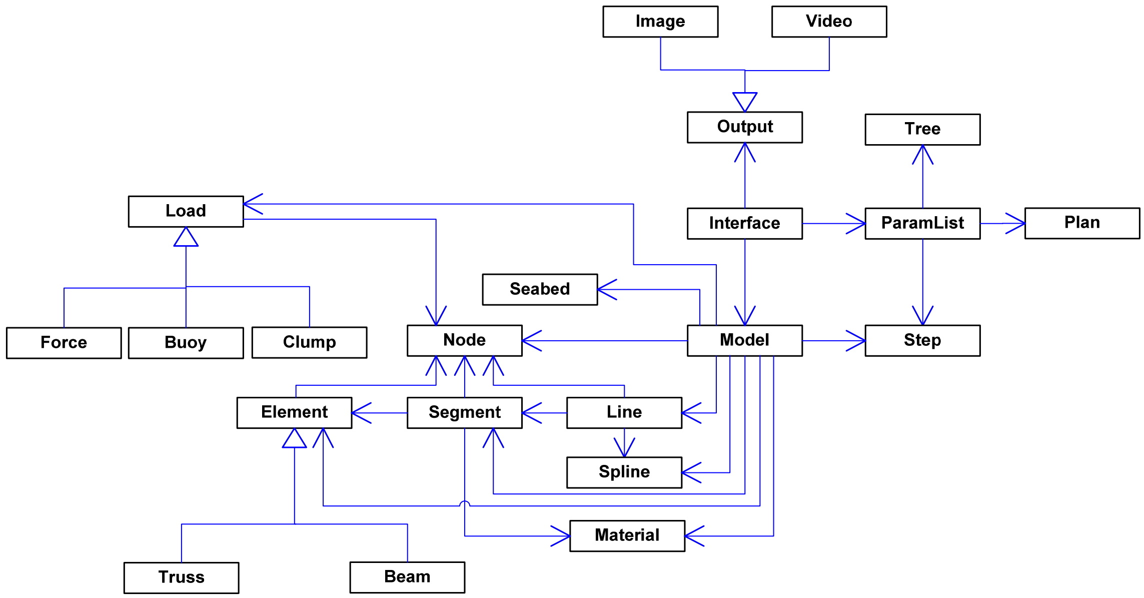


Figure 3: Class organization of the environment.

Figure 4 shows the model discrete procedure in Lines, Segments, Elements and Nodes. Each line inserted in the analysis is composed by two Nodes, each one on the extremity, called Anchor and Fairlead. These nodes represent the link soil-line (Anchor) and link Line-platform (Fairlead). Model´s Lines can be subdivided in Segments and every Segment keeps information of the different type of material incorporated in the analysis.

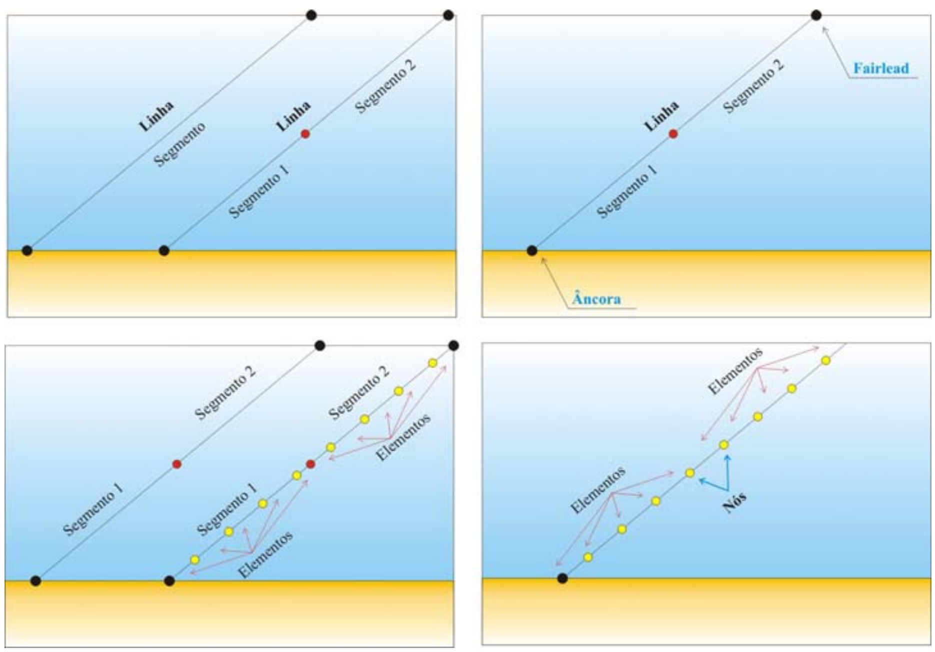


Figure 4: Model discrete.

A Segment can even be subdivided into elements that are composed by two adjacent Nodes, creating, thus, a mesh corresponding to the FEM mesh. It is important as well, to declare that the elements inserted in a segment will have the information of the material associated to the segment

3. PROPOSED GRAPHICS TECNOLOGY

This section shows the principal graphics technology proposed in this work to visualization of the dynamic behavior of risers and mooring lines (Fig. 5). Procedures here showed use advanced graphic resources, allowing facilities to represent the considered objects and improving its understanding. This section describes each one of these technologies.

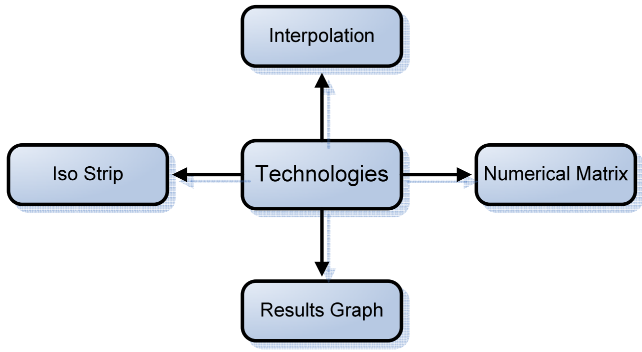
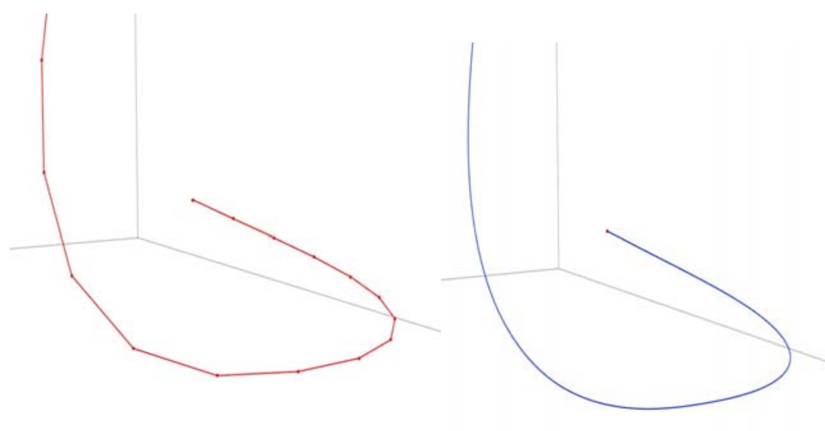


Figure 5: Graphics technology developed.

3.1. Interpolation of the nodal points, associated to the lines system

The interpolation of the nodal points consists on the implementation of a numerical strategy to interpolate the nodal points resulted by the FEM. The main subject of the development of this strategy is based on the need of a more detailed visualization. Applying smoothness to the lines brings more realistic lines which increases perception and technical interpretation. The proposed methodology consists of using B-Splines curves (Piegl e Tiller, 1997) to interpolate the mesh former's FEM nodes.

Using conventional methods of drawing lines, composed of element and nodes only, can be clearly seen straight parts due to a weak discretization of the FEM model. Using nodal points´ interpolation with B-Splines curves, a smooth curve is achieved, with realistic approximation of the real one and its behavior. Figure 6a-b illustrates the difference using both methods.



(a) (b)

Figure 6: Nodal points´ interpolation: a) FEM line; b) B-Splines interpolation line.

The numerical strategy is to run over the lines of the model stored in the data structure, its segments and elements, with the purpose of capture all nodal points that order a line, as shown in Figure 4. The taking of the nodal points follows this strategy: in a line, occurs an identification of the segments that compose the line and, consequently, the element that are part of the line. With this information, the adjacent nodes are stored, exercising care to not get the same node repeatedly. Then, it is used an algorithm to organize the nodes belonged to every line of the model. Only now the B-Splines interpolation method can be applied.

A B-Spline is represented by a p-degree curve, defined by the following form (Eq. 1):

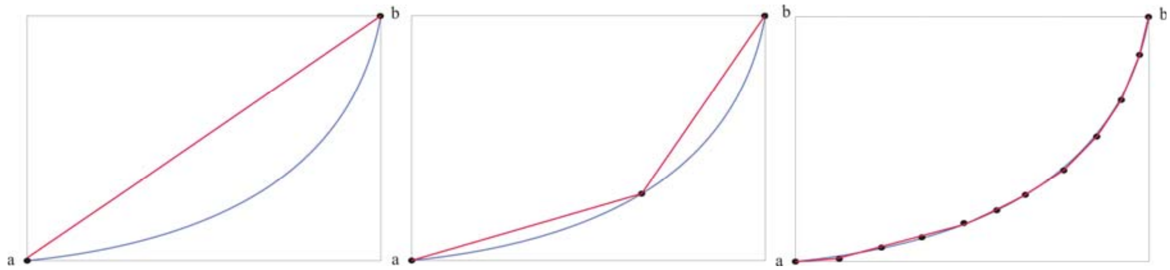
$$\{C(u)\} = \sum_{i=0}^{n} N_{i,p}(u)\{P_i\}, \quad a \le u \le b, \tag{1}$$

where $\{ P_i \}$ are the control points, $\boldsymbol{N_{i,p}(u)}$ are the base-function with degree $\boldsymbol{p}$, $\boldsymbol{u}$ is a parametric value, located between the parametrical limits $\boldsymbol{a}$ e $\boldsymbol{b}$.

More information about the B-Splines interpolation method can be found in (Piegl e Tiller, 1997).

As a refinement criterion for interpolation of the curve's points, the most used technique to plot B-Splines curves is based on its approximation by an equivalent polygonal. Normally this refinement is uniform, meaning the polygon's representative points are equally spaced. However, it is desirable that, in regions with more accentuated curves, the quantity of points is increased. Because of it, a practice proposed by (Figueiredo, 1995), which calculates the equivalent polygonal with an adaptive way, is applied. In regions with accentuated curves, the number of points is amplified. This scheme is based on the following steps:

1 Determination of a tolerance for the construction of the polygonal;
2 The curve is examinated, starting from its extremity, like shown in Figure 7 (a);
3 Part of the line is measured, verifying if the part is as straight as the tolerance allows;
4 If yes, a segment, connecting the extremities of the part, is drew;
5 If not, the segment is divided in two parts and the whole process is remade (Fig. 7(b)(c), until all curve is inspected and tolerance is followed in every part.
6



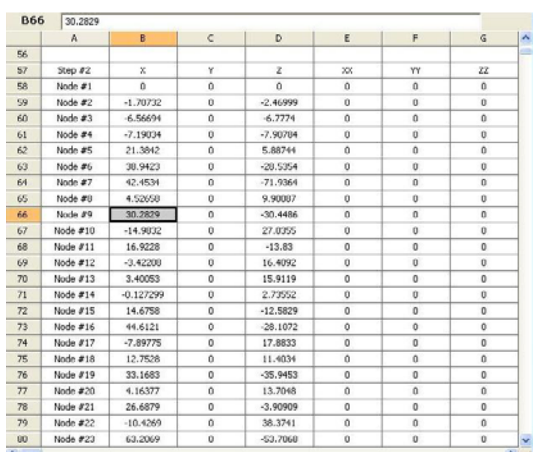
(a) (b) (c)

Figure 7: Presentation of the method to calculate the adaptive polygonal:
a) part examination, from an extremity; b) drawing of the segments on the extremities of the examinated part;
c) final drawing of the adaptive polygonal, compared with the curve.

3.2. Numerical Matrix

This section shows technology used in the numerical visualization of the information related to the results of the analysis. This procedure permits the study of the results, such as displacement and velocities at each step of the simulation. The results are organized in numerical matrices, giving a higher sensibility to the understanding of the problem. This matrix is shown in Figure 8.

In the presented results matrix, some functionalities were incorporated, such as statistical functions, whose permit better manipulation of the model´s data in a more convenient way. This way, the other cells of the matrix can be used to solve calculus about the values of the simulation or about any interesting information.



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	A	B	C	D	E	F	G
56							
57	Step #2	X	Y	Z	XX	YY	ZZ
58	Node #1	0	0	0	0	0	0
59	Node #2	-1.70732	0	-2.46999	0	0	0
60	Node #3	-6.56694	0	-6.7774	0	0	0
61	Node #4	-7.19034	0	-7.90704	0	0	0
62	Node #5	21.3842	0	5.88744	0	0	0
63	Node #6	38.9423	0	-20.5354	0	0	0
64	Node #7	42.4534	0	-71.9364	0	0	0
65	Node #8	4.52658	0	9.90087	0	0	0
66	Node #9	30.2829	0	-30.4486	0	0	0
67	Node #10	-14.9832	0	27.0355	0	0	0
68	Node #11	16.9228	0	-13.83	0	0	0
69	Node #12	-3.42208	0	16.4092	0	0	0
70	Node #13	3.40053	0	15.9119	0	0	0
71	Node #14	-0.127299	0	2.73552	0	0	0
72	Node #15	14.6758	0	-12.5829	0	0	0
73	Node #16	44.6121	0	-28.1072	0	0	0
74	Node #17	-7.89775	0	17.8833	0	0	0
75	Node #18	12.7528	0	11.4034	0	0	0
76	Node #19	33.1683	0	-35.9453	0	0	0
77	Node #20	4.16377	0	13.7048	0	0	0
78	Node #21	26.6879	0	-3.90909	0	0	0
79	Node #22	-10.4269	0	38.3741	0	0	0
80	Node #23	63.2069	0	-53.7068	0	0	0

Figure 8: Matrix with numerical results.

The alteration of information in the matrix modifies automatically the data stored in the data structure used. This allows flexibility for information adjustments amongst other graphical procedures shown and the numerical matrix. For example, the modification of the velocity data of a node on the matrix alters as well as the speed of that node in the data structure.

3.3. Results graphics

Most of the time, the technical quantitative interpretation of physical information associated to the dynamical behavior of risers and mooring lines demands visualization in a graph. In fact, classical interactive computational procedures must be used with the intention of ease the interpretation.

Basically, in this work, the techniques developed in the elaboration of graphs are crucial in the characterization of the dynamical study of physical info, such as velocity or acceleration fields *versus* time. The results are visualized in a specific node of the FEM mesh, permitting the comprehension of the behavior as the analyzed time passes. Figure 9 demonstrates an example of a graph with results associated to the physical quantities.

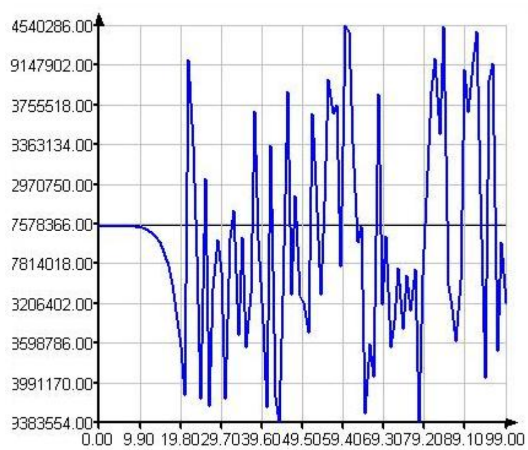


Figure 9: Graphical interface.

Inside this context, is also described a mechanism that allows the graph animation of results associated to a specific node at time’s length, as shown in Figure 10. It’s possible to accompany all the behavior of specific

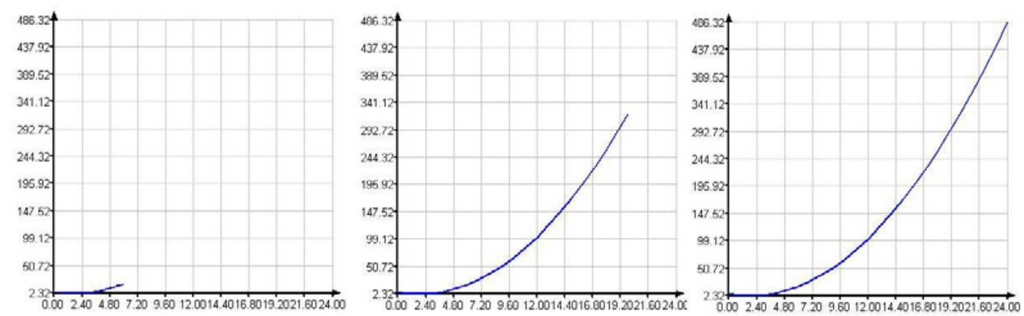


Figure 10: Graph´s animation.

3.4. Iso-stripes

The visualization of iso-stripes (Fig. 11) is a procedure that allows a graphical interpretation, in a fast and easy way, of the results of the analysis, achieving an enhanced capability of evaluate the real problem. These iso-stripes correspond to regions that have the same field value, such as velocity and acceleration.

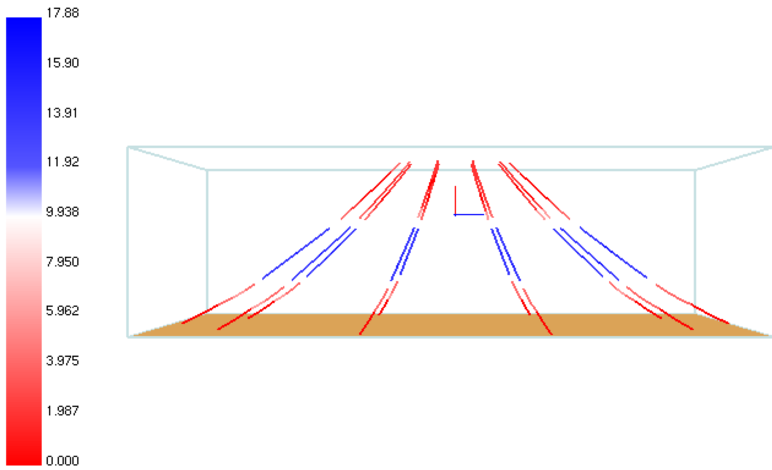


Figure 11: Iso-stripes example.

The iso-stripes are obtained from a description of a standard color scale, like illustrated in Figure 12.The values represented by the colors are globally actualized for each model studied. If the model has more than one step of analysis, all steps are evaluated and the highest and lowest values are kept (Fig. 12a).

This scale is divided in intervals, creating intermediate values associated to it (Fig. 12b). To minimal and maximal values found are assigned colors and an interpolation method is applied to find the intermediate colors (Fig. 12c). To find a color corresponding to a specific value, the following rule is used (Fig. 12d):

a) The interval containing the desired value is found;

b) The colors for the limits of the interval are established;

c) Using linear interpolation (Eq. (2)), the desired color is acquired. Figure 10 shows the final scale of colors,

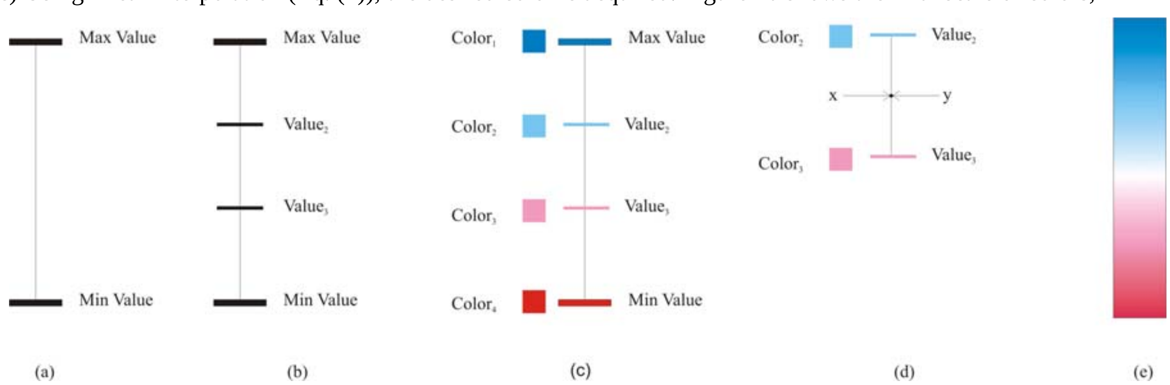


Figure 12: a) lowest and highest values of the scale; b) intermediate values of the scale; c) link between the values and the color; d) scheme for association between color and value; e) complete scale.

$$x = color_3 + \frac{(y - value_3)\cdot(color_2 - color_3)}{(value_2 - value_3)} \qquad (2)$$

With this tool, it is possible to generate iso-stripes and map all fields of velocity, acceleration of the risers and mooring lines involved in the analysis. With this method, analyze the behavior of all physical information becomes really easy.

4. APPLICATIONS

The graphical procedures and the data structure previously described were integrated and incorporated to a computational environment for the visualization of risers and mooring lines. The graphic interface of the system is supported by the IUP library (Scuri et al, 2003) which offers, among other advantages, portability for the use of the program in many operational systems, besides, it allows the development of the interface in an easy and intuitive way. Graphical system OpenGL (Open graphics Library) (Woo et al, 1997) is used in the visualization of 3D objects, permitting the user a better capability of technical interpretation of the physical phenomena involved, making available the drawings of the entities with an adequate standard of development. VGL library (Abraham et al, 2006) is used as a support tool to apply 3D visualization based on OpenGL. This library contains advanced resources of computer graphics, including facilities to interactive manipulation of the objects and stereoscopy. It is function in this work allows a simple application of geometric transformations on the objects inserted in the scene.

Figure 13 corresponds to the visualization of the dynamical behavior of 10 mooring lines clipped to the ground. This example was numerically simulated in (Ferreira, 2005). Figs. 14a-e shows a sequence of images, representing an animation of the lines system. Figures 15 e 16 illustrates some graphical procedures used. In Figure 15 colored scales and iso-stripes can be seen and on Fig. 16, it is shown a refinement on the interpolation of the nodal point of a line.

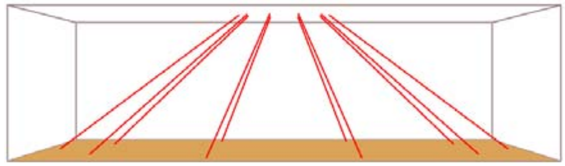
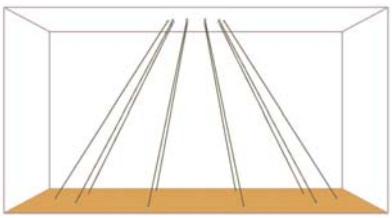
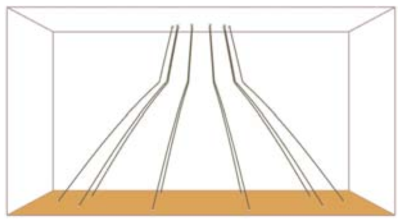


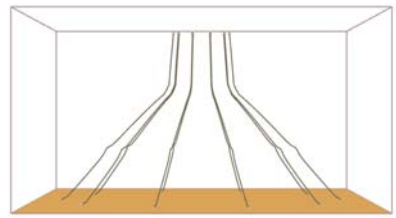
Figure 13: Visualization of 10 mooring lines clipped to the ground.



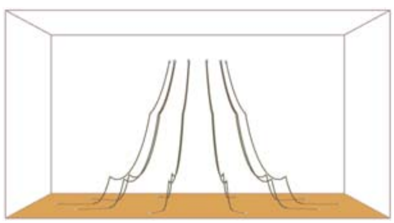
(a)



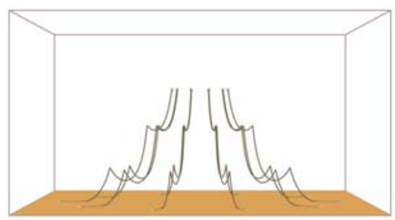
(b)



(c)



(d)



(e)

Figure 14: Lines animation.

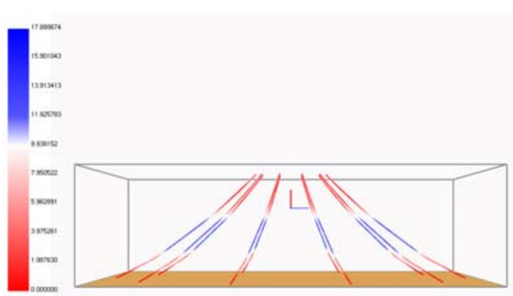


Figure 15: Iso-stripes and color scale.

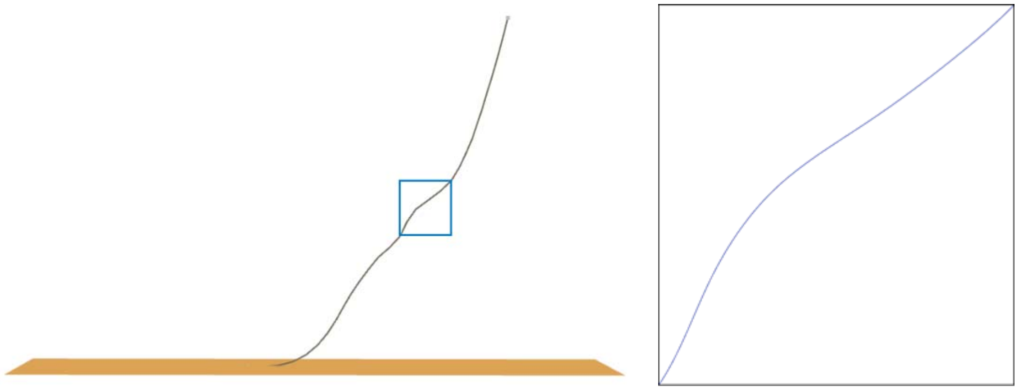


Figure 16: Detail of the line, showing nodal interpolation.

5. FINAL CONSIDERATIONS

This work demonstrates the development of many graphical technologies used in the visualization of FEM results associated no mooring lines and riser analysis, making the understanding of the physical problems associated to studies of this nature easier. These technologies are conceived using advanced resources of graphic computer, allowing greater ability of technical reading of the phenomena associated to the risers and mooring lines. A flexible data structure is used, inside the perspective of the Object Oriented Programming, to give support do developments achieved. This structure makes possible, among other things, the adequate representation of the structural elements involved in researches of this nature, as well as representation of the numerical model (FEM mesh and simulation attributes) used in analysis.

Mixing all those computational aspects, a post-processor capable of creating an efficient graphical environment and with the necessary tools for a better interpretation and technical comprehension of the results is achieved. The system is satisfactory for the study and visualization of FEM results related to risers and mooring lines.

Graphical examples are shown with the objective of illustrating the abilities of visualization of the proposed procedures, whereas the results obtained are reasonable.

Inside the line of action of this work, it is wanted, in future researches, to improve the presented technologies, also develop new tools to make even easier the process of interpretation of the problems related to the dynamical behavior of risers and mooring lines. More specifically, develop and incorporate procedures that bring even more realistic visualization of the problem using virtual reality caves.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Abraham, F.R., Celes Filho, W., 2006. VGL Documentation – Version 2.0a, http://www.tecgraf.puc-rio.br/~fabraham/vgl/, Tecgraf/PUC-Rio.Coelho, L.C.G., Nishimoto, K., Masetti, I.Q., 2001, “Dynamic Simulation of Anchoring System Using Computer

Graphics”. In Omae Conference. Rio de Janeiro. Ellis, M. A., Stroustrup, B., 1993, C++ Manual de Referência Comentado. Editora Campus. Fucatu, C.H., Nishimoto, K., 2003, “Implementação de Modelos Hidrodinâmicos de Navios no Sistema Prosim”,

Departamento de Engenharia Naval e Oceânica, USP. São Paulo.

Ferreira, F.M.G., 2005, “Desenvolvimento de um Framework Orientado a Objetos para Análise Dinâmica de Linhas de Ancoragem e de Risers”, Dissertação (Mestrado em Engenharia Civil, ênfase: Estruturas) – Universidade Federal de Alagoas, UFAL, Alagoas.

Ferreira, F.M.G., Silveira, E.S.S., Masetti, I. Q., Menezes, I.F.M., 2004, “Uma Estratégia para a Geração de Configurações Iniciais 3D para Análise Dinâmica de Linhas de Ancoragem”, Anais do XXV CILAMCE – Congresso Ibero-Latino Americano sobre Métodos Computacionais em Engenharia, Recife.

Figueiredo, L. H., Adaptive sampling of parametric curves, in A. Paeth (ed.), *Graphics Gems V*, Academic Press, 1995, 173-178.

Mourelle, M.M., Gonzalez, E.C., Jacob, B.T., 1995, “Anflex: Computacional System for Flexible and Rigid Risers Analysis”, In: Proceedings of the 9th International Symposium on Offshore Engineering. Rio de Janeiro.

ORCINA, 2005, Disponível em: <http://www.orcina.com>.

Piegl, L., Tiller, W. 1997, “The NURBS Book”, 2nd Ed. Springer-Verlag Berlin Heidelberg, Germany.

Scuri, A. S., Pinheiro, H. D. M., Glasberg, M. S., 2006. IUP – Portable User Interface
Version 2.5”, http://www.tecgraf.puc-rio.br/iup , Tecgraf/PUC-Rio.

Silva, D.M.L., 2005, “Geração de Configurações Equilibradas de Sistemas de Linhas Flexíveis Através do Método de Relaxação Dinâmica”, Dissertação (Mestrado em Ciências de Engenharia Civil, ênfase: Estruturas) – Universidade Federal do Rio de Janeiro, COPPE-UFRJ, Rio de Janeiro.

Silva, R.M.S., Filho, R.S.E., Silveira, E.S.S., Ferreira, F.M.G., 2006, “Um Módulo Orientado a Objetos para Análise Estática de Estruturas” Anais do XXVII CILAMCE – Congresso Ibero-Latino Americano sobre Métodos Computacionais em Engenharia, Belém, Pará.

Silveira, E.S.S., Martha, L.F., Menezes, I.F.M, Masetti, I.Q., 2000, “Um Sistema Computacional Integrado para Análise Dinâmica Não-Linear Geométrica de Linhas de Ancoragem”, Anais do XXI CILAMCE – Congresso Ibero-Latino Americano sobre Métodos Computacionais em Engenharia, Rio de Janeiro.

Silveira, E.S.S., 2001, “Análise Dinâmica de Linhas de Ancoragem com Adaptação no Tempo e Subciclagem”, Tese (Doutorado em Engenharia Civil, ênfase: Estruturas) – Pontifícia Universidade Católica do Rio de Janeiro. Rio de Janeiro.

Ricarte, I. L. M., 1995, “Programação orientada a objetos com C++” Notas de apoio a cursos, FEEC/UNICAMP. Disponível em: <http://www.dca.fee.unicamp.br/˜ricarte>.

Woo, M., Neider, J., Davis, T., Shreiner, D., 1997. The OpenGL Programming Guide 3rd Edition The Official Guide to Learning OpenGL Version 1.2, OpenGL Architecture.

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