**Proceedings of MSC - VPD 2004:**
**MSC Virtual Product Development Conference 2004**
**October 18-20, 2004, Huntington Beach, California, USA**

# VPD-2004-44

# MSC.PATRAN AS A MAIN TOOL TO INCREASE PRODUCTIVITY FOR MODEL GENERATION

Alejandro Andueza
SERCON Consulting Services
55 21 2240 7805
sercon@sercon-consultoria.com.br
Claudio dos Santos Amaral
R&D Center PETROBRAS
55 21 3865 6272
amaralcs@cenpes.petrobras.com.br

Alvaro Maia da Costa
R&D Center PETROBRAS
55 21 3865 6272
amaia@cenpes.petrobras.com.br

## ABSTRACT

PETROBRAS is the biggest Brazilian Company according to revenue and a worldwide leading company in the development of technology for deep-water petroleum production. The company has the challenging target to explore oil in Campos Basin – Brazil in water depths up to 3000 meters. Complementary to the production challenge the company has the complex task of transporting the produced oil through heated pipelines.

The design of anchoring systems for ultra deep waters required the design of piles with “fins” in order to increase the strength with reduced height. The finite element analysis of this problem required the generation of very complex 3D models that take into account the interaction between the soil and the pile. PETROBRAS/CENPES decided to use MSC.Patran to generate the models and AEEPEC3D as a solver for the problem. AEEPEC3D is a proprietary solver very powerful to deal with soil problems.

This paper presents the methodology used to integrate AEEPEC3D into MSC.Patran and the whole customization process used for the automatic model generation of 3D piles.

Heated pipelines buried in soft clay can develop a very challenging behavior. The pipeline thermal expansion normally causes buckling of the structure that will be supported by the passive reaction of the soil. The buckling of the pipeline in soft clay can evolve to a non-linear inelastic behavior that is an unstable condition named “snap through”. In such condition the pipeline can jump from a previous configuration with a maximum deflection of few centimeters to another configuration with deflections of the order of meters. During the “snap through” process there is the possibility of the development of local buckling in the pipeline wall. The local buckling, when it happens, will produce an accident (pipeline wall rupture) with the consequent leakage of oil.

In January 2000 an accident of a heated pipeline buried in soft clay happened in Guanabara Bay in Rio de Janeiro, Brazil. The accident produced the leakage of 1300000 liters of oil. The failure mode of the accident was the local buckling of the pipeline wall.

An ongoing large technical investigation has been carried out by PETROBRAS [6-8] in order to understand the soil-structure interaction phenomenon of heated pipelines buried in very soft clay. The fundamental question is “what are the physical and boundary conditions that will drive an inelastic global instability of a pipeline buried in or laying on very soft clay”. In this paper some of the results reached up to now, from this ongoing technical investigation, are presented.

This paper also presents the methodology for the model generation used by PETROBRAS/CENPES to analyze stability and safe-operating conditions of buried pipelines in soft clay. MS/Patran was used for the model generation and Abaqus from HKS for the analysis of the problem.

The basic idea behind the model generation process was the creation of a parametric model in order to decrease the required modeling time.

The pipe model generation is managed interactively through a proprietary MSC.Patran interface developed by PETROBRAS/ CENPES and SERCON Consulting.

## INTRODUCTION

The development of technology to explore oil at water depths up to 3000 meters is challenging and strategic to PETROBRAS. The company is currently using “Torpedo” piles to anchor rigs and FPSO (Floating Production and Offloading) units. The analysis of anchoring systems requires the development of 3D models in order to evaluate “torpedo” pile behavior. The model represents the pile and the surrounding soil including the interaction between soil and pile through contact elements. PETROBRAS/CENPES has a proprietary solver called AEEPEC3D specifically designed to deal with soil-structure interaction. PETROBRAS/CENPES and SERCON Consulting Company developed a proprietary preference to integrate AEEPEC3D solver into MSC.Patran environment. With this strategy PETROBRAS could generate very complex 3D models taking advantage of the full MSC.Patran modeling capabilities.

The development of a parametric model generator for the pile analysis was mandatory in order to increase the productivity for the analysis of several similar cases. The time for the generation of each model was reduced from several days to some minutes.

In January 2000 a leakage of 1.3 million liters of oil happened in Guanabara Bay, located between the cities of Rio de Janeiro and Niteroi in the state of Rio de Janeiro, Brazil. The leakage occurred through a failure mode of a local buckling caused by an excessive plastic strain produced by a thermal expansion of the whole line. The pipeline had the diameter of 16” fractured in half of its diameter, as can be seen in figure 1. The pipeline in question was responsible for the transportation of heavy heated oil from the refinery of Duque de Caxias to the ship terminal.

**Fig. 1 – Failure mode of the pipeline wall**

This paper also presents the methodology used by PETROBRAS/CENPES to generate automatically complex models of buried pipelines.

## AEEPEC3D PREFERENCE

The proprietary preference developed to integrate AEEPEC3D solver into MSC.Patran environment can be chosen through the window shown in Figure 5.

Figure 6 shows the window that activates the proprietary functions to create the new elements implemented in MSC.Patran.

## NEW ELEMENTS

The solver AEEPEC3D requires three elements not supported by MSC.Patran commercial version. The first one is a quadratic solid element with 20 nodes with a specific numbering sequence. Figure 2 shows this element graphically.

The second one is an infinite element with 12 nodes. Figure 3 shows this element graphically.

The third one is a contact quadratic solid element with 16 nodes and a special feature of zero volume. The opposite faces shown in blue in figure 4 are in the same spatial position.

The topology of the 3D solid element with 20 nodes defined in MSC.Patran commercial version was used to store the numbering information of these three elements. According to this technique, the infinite element with 12 nodes has 8 zeros when stored using the 20-node topology. In the same way, the contact element with 16 nodes has 4 zeros when using the same methodology.

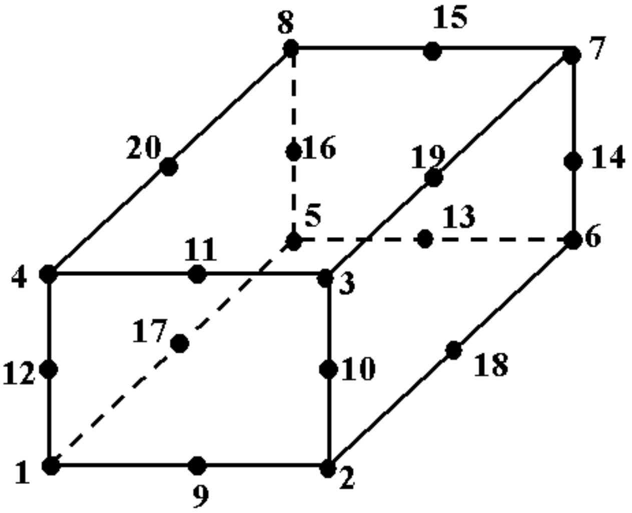


**Figure 2 - Solid element with 20 nodes**

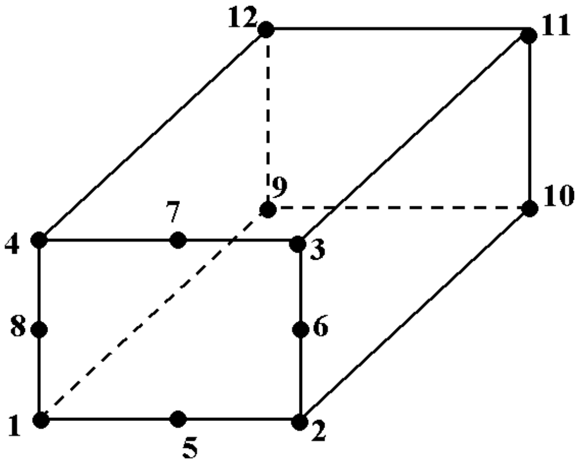


Figure 3 - Infinite element with 12 nodes

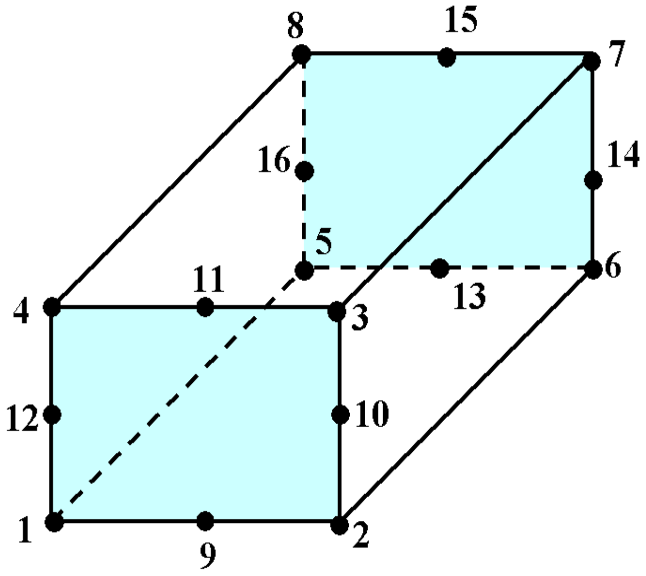
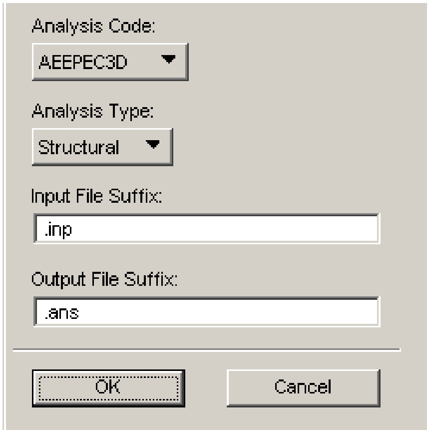


Figure 4 - Contact element with 16 nodes



Analysis Code: AEEPEC3D

Analysis Type: Structural

Input File Suffix: .inp

Output File Suffix: .ans

Figure 5 - Window for AEEPEC3D preference

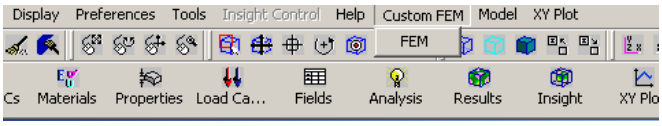
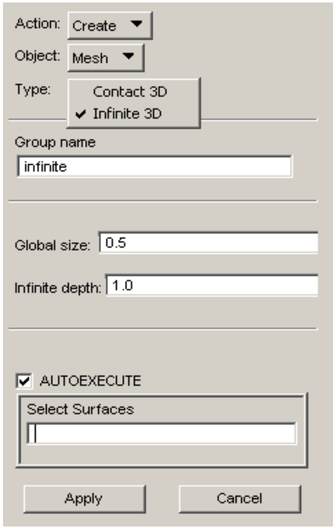


Figure 6 - Custom options to activate the proprietary functions

## MESH GENERATOR FOR INFINITE ELEMENTS

The infinite elements necessary to generate models for AEEPEC3D are created through a new mesh generator developed specifically to this purpose. Figure 7 shows the window that manages the new mesh generator. The methodology used to create this new mesh generator uses the standard isomesh generator for 2D surface as a basis to create HEX20 elements with 12 nodes. After the creation of the elements by the standard mesh generator the nodes not required by the element are removed from the database.



Action: Create

Object: Mesh

Type: Contact 3D / ✓ Infinite 3D

Group name: infinite

Global size: 0.5

Infinite depth: 1.0

☑ AUTOEXECUTE

Select Surfaces

Figure 7 - Mesh generator for infinite elements

## MESH GENERATOR FOR CONTACT ELEMENTS

The contact elements necessary to generate models for AEEPEC3D are created through a new mesh generator developed specifically to this purpose. Figure 8 shows the window that manages the new mesh generator. The methodology used to create this new mesh generator uses the standard isomesh generator for 2D surface as a basis to create HEX20 elements with 16 nodes.

## CUSTOM EQUIVALENCE FUNCTION

The specific contact element with 16 nodes and zero volume features requires special care. This element has 8 different positions for the nodes and two nodes for each of these positions. So, the solid element is degenerated for zero volume, with one face attached to one side of the model, and the opposite face to the other side. In order to deal with this problem, a custom function to proceed with the correct equivalence of the nodes was developed. Figure 9 shows the window where this function can be executed.

This function requires that each part of the model (pile, soil and contact elements) be stored in different MSC.Patran groups. These names must be informed for the correct execution of the equivalence procedure.


Action: Create
Object: Mesh
Type: Contact 3D
Group name: contact
Global size: 0.5
☑ AUTOEXECUTE

Figure 8 - Mesh generator for contact elements

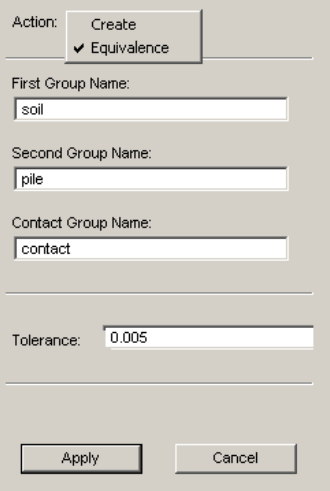
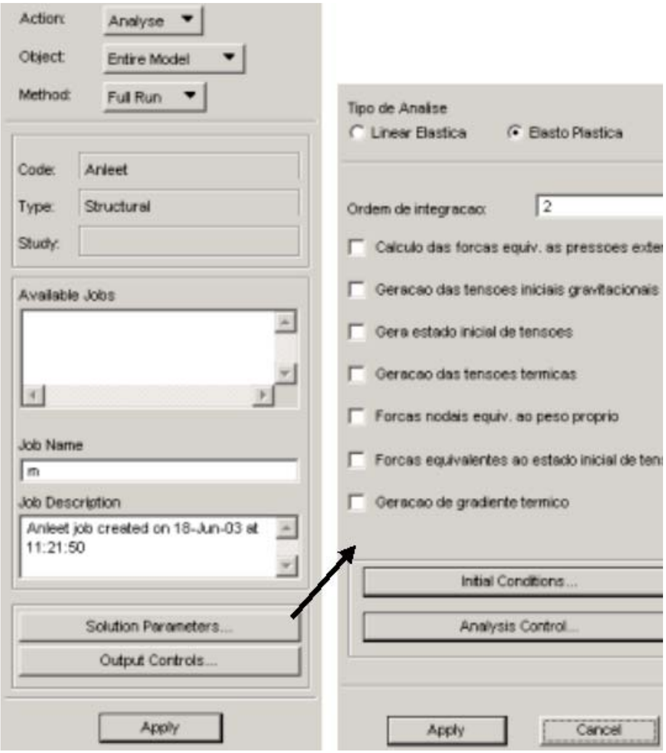

Action: ✔ Equivalence
First Group Name: soil
Second Group Name: pile
Contact Group Name: contact
Tolerance: 0.005

Figure 9 - Custom equivalence window

## ANALYSIS WINDOWS

The development of the preference for AEEPEC3D solver also required the creation of specific windows to enter the solution parameters, analysis control, initial conditions and output controls. Figure 10 shows two of these specific windows.


Action: Analyse
Object: Entire Model
Method: Full Run
Code: Anleet
Type: Structural
Study:
Job Name: m
Job Description: Anleet job created on 18-Jun-03 at 11:21:50

Tipo de Analise
○ Linear Elastica ● Elasto Plastica
Ordem de integracao: 2
☐ Calculo das forcas equiv. as pressoes exte
☐ Geracao das tensoes iniciais gravitacionais
☐ Gera estado inicial de tensoes
☐ Geracao das tensoes termicas
☐ Forcas nodais equiv. ao peso proprio
☐ Forcas equivalentes ao estado inicial de ten
☐ Geracao de gradiente termico

Figure 10 - Analysis windows

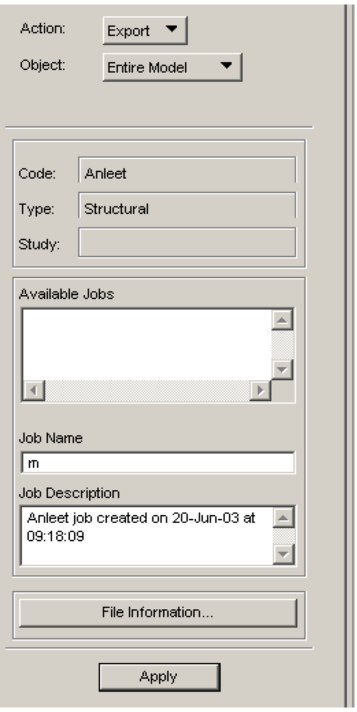
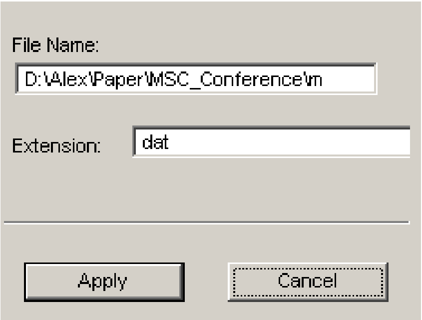

Action: Export
Object: Entire Model
Code: Anleet
Type: Structural
Study:
Job Name: m
Job Description: Anleet job created on 20-Jun-03 at 09:18:09

Figure 11 - Text file creation execution procedure

The interface between MSC.Patran and AEEPEC3D solver is done through a text file in ASCII format. The creation of this text file is started with the window shown in figure 11. The file name is supplied through the window shown in figure 12 that is activated by the button “File Information”.


File Name: D:\Alex\Paper\MSC_Conference\m

Extension: dat

**Figure 12 - Text file creation execution procedure**

## PARAMETRIC MODEL GENERATOR

Besides the interactive usage of the functions developed to integrate AEEPEC3D solver, PETROBRAS/CENPES decided to create parametric models generators in order to shorten the required time required for analysis.

The great number of models necessary to perform the analysis of the behavior of “Torpedo” piles encouraged PETROBRAS/CENPES to develop a parametric model generator. Figure 13 shows the start up window for the parametric model generator functions.

**Figure 13 - Parametric model generator start up window**

Two kinds of models were created for the analysis of “torpedo” piles. The first one is a simple cylindrical pile surrounded by soil elements. The second model considers a pile with “fins”, as shown in figure 14. The purpose of the fins in the second model is to increase the bearing capacity of the pile for similar dimensions. It is also allowed the creation of symmetric and non-symmetric models by the choice of a switch option. The non-symmetric models are full 3D models. Another important parameter that was considered in the model generation was the inclination angle of the pile with the vertical direction.

According to this methodology, four different functions were developed for the generation of “torpedo” piles models.

Figure 15 shows the input data window for pile models with fins. It was also created sub-windows for the definition of the mesh seeds and the ratio of the mesh seeds. Figures 16 and 16 show these sub-windows.

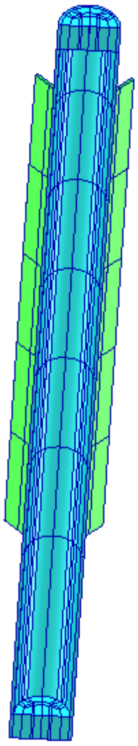


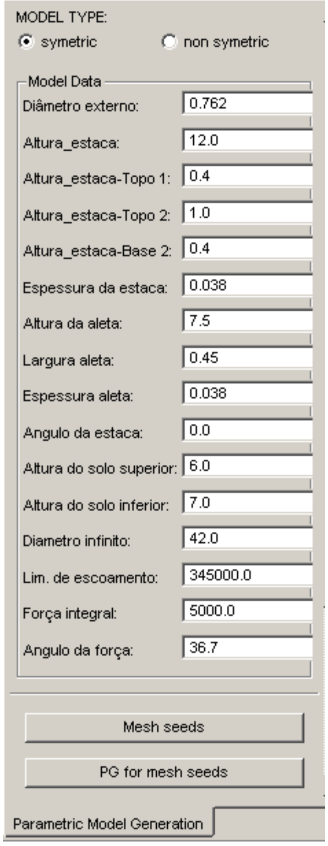
**Figure 14 - Pile model with "fins"**

In order to make easier the input data procedure for the parametric model generation, it was created the text file shown in figure 18. The values in this file are default and will feed the windows shown in figures 15-17 during MSC.Patran start-up. Any default value can be changed interactively.

The complete symmetric model of a straight pile with “fins” embedded in soil is presented in figure 19. Figure 20 shows a detail of the model in the region of the pile. The elements presented in magenta represent the soil in the neighborhood of the pile.

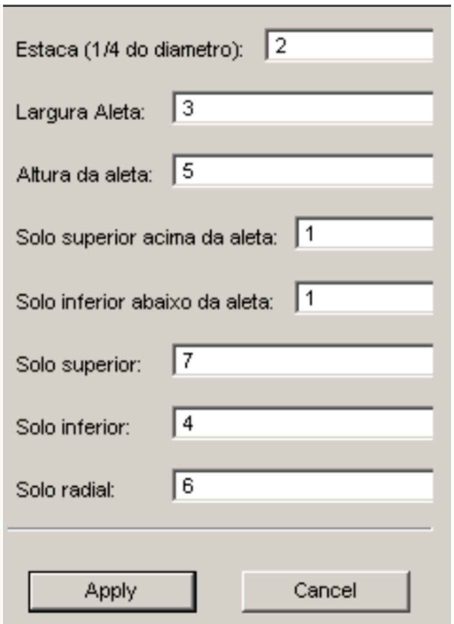
The non-symmetric model of an inclined pile with “fins” embedded in soil is presented in figures 21 and 22. The inclination angle of the pile is 30°.

The soil data can vary significantly according to the depth of the model. The soil data can be defined up to a maximum of 4 different layers. The soil properties for each layer can be defined by a linear equation. Figures 23 and 24 show the windows for the soil data input. The model generator program calculates the depth of each element (center of gravity of the element) and creates the corresponding material property according to this value using the supplied equations for the corresponding layer.



Diâmetro externo: 0.762
Altura_estaca: 12.0
Altura_estaca-Topo 1: 0.4
Altura_estaca-Topo 2: 1.0
Altura_estaca-Base 2: 0.4
Espessura da estaca: 0.038
Altura da aleta: 7.5
Largura aleta: 0.45
Espessura aleta: 0.038
Angulo da estaca: 0.0
Altura do solo superior: 6.0
Altura do solo inferior: 7.0
Diametro infinito: 42.0
Lim. de escoamento: 345000.0
Força integral: 5000.0
Angulo da força: 36.7

**Figure 15 - Parametric model generation window**

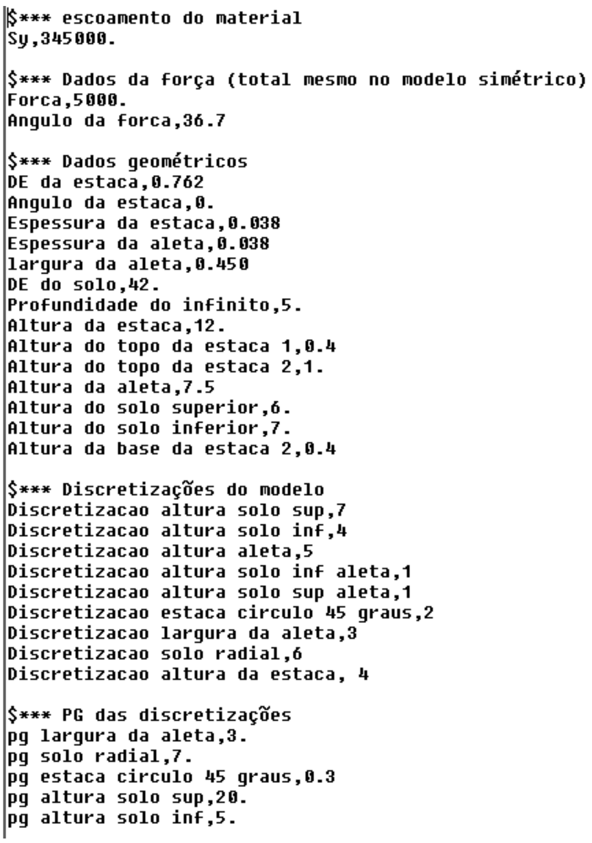


Estaca (1/4 do diametro): 2
Largura Aleta: 3
Altura da aleta: 5
Solo superior acima da aleta: 1
Solo inferior abaixo da aleta: 1
Solo superior: 7
Solo inferior: 4
Solo radial: 6

**Figure 16 – Mesh seeds definition window**

Estaca (1/4 do diametro): 0.3
Largura Aleta: 3.0
Solo superior: 20.0
Solo inferior: 5.0
Solo radial: 7.0

**Figure 17 – Mesh seeds ratio definition window**



```
$*** escoamento do material
Sy,345000.

$*** Dados da força (total mesmo no modelo simétrico)
Forca,5000.
Angulo da forca,36.7

$*** Dados geométricos
DE da estaca,0.762
Angulo da estaca,0.
Espessura da estaca,0.038
Espessura da aleta,0.038
largura da aleta,0.450
DE do solo,42.
Profundidade do infinito,5.
Altura da estaca,12.
Altura do topo da estaca 1,0.4
Altura do topo da estaca 2,1.
Altura da aleta,7.5
Altura do solo superior,6.
Altura do solo inferior,7.
Altura da base da estaca 2,0.4

$*** Discretizações do modelo
Discretizacao altura solo sup,7
Discretizacao altura solo inf,4
Discretizacao altura aleta,5
Discretizacao altura solo inf aleta,1
Discretizacao altura solo sup aleta,1
Discretizacao estaca circulo 45 graus,2
Discretizacao largura da aleta,3
Discretizacao solo radial,6
Discretizacao altura da estaca, 4

$*** PG das discretizações
pg largura da aleta,3.
pg solo radial,7.
pg estaca circulo 45 graus,0.3
pg altura solo sup,20.
pg altura solo inf,5.
```

**Figure 18 - Text data file for the parametric model**

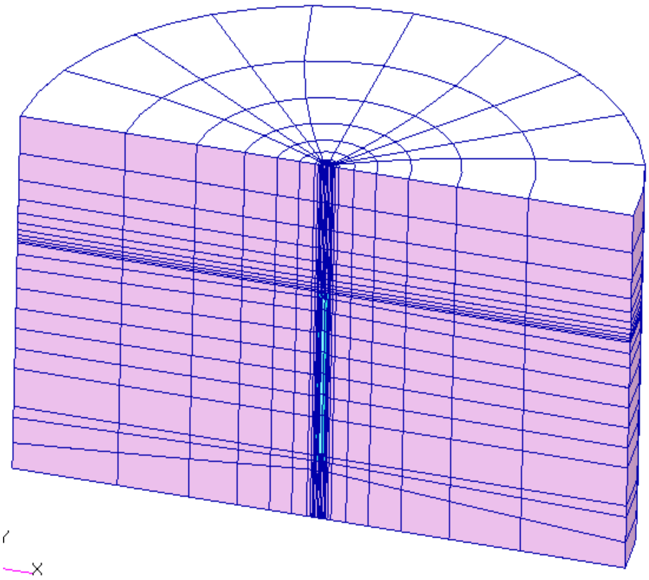


Figure 19 – Mesh seeds ratio definition window

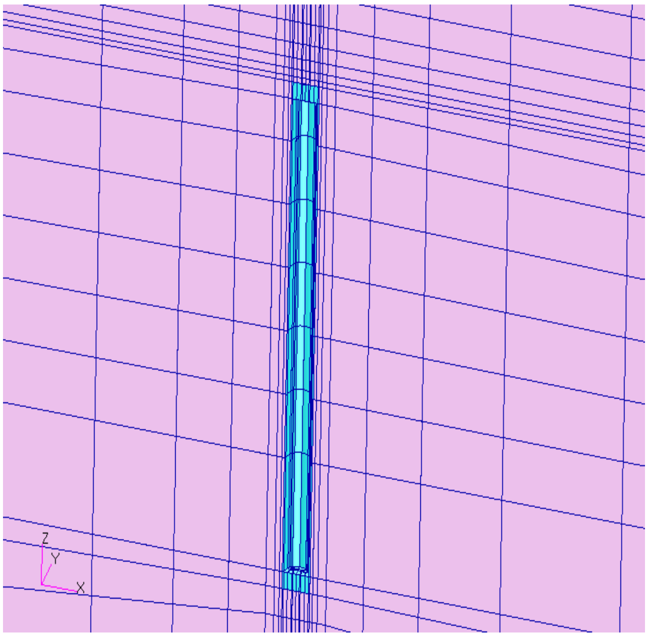


Figure 20 – Mesh seeds ratio definition window

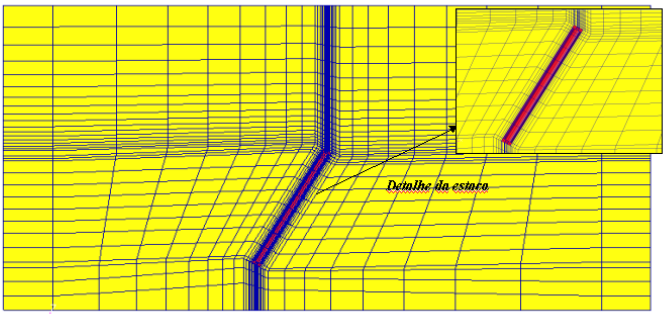


Figure 21 – Model of inclined pile inside soil

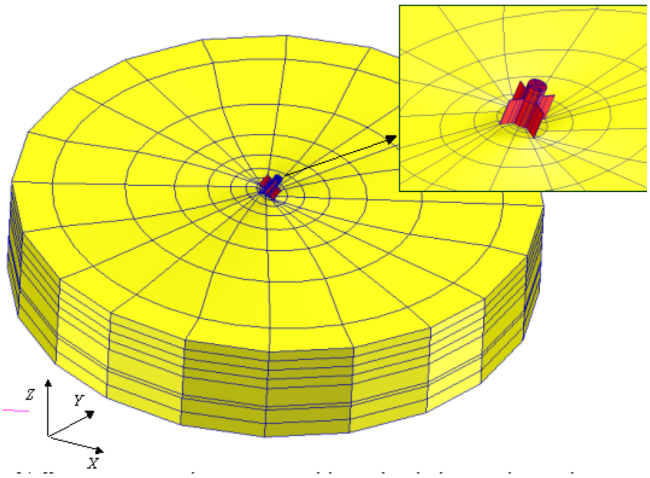
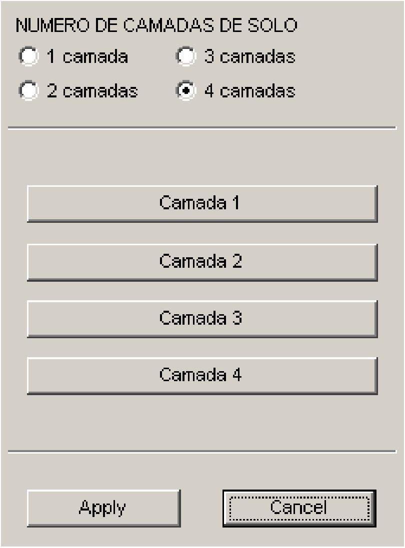


Figure 22 – Non-symmetric model of inclined pile inside soil

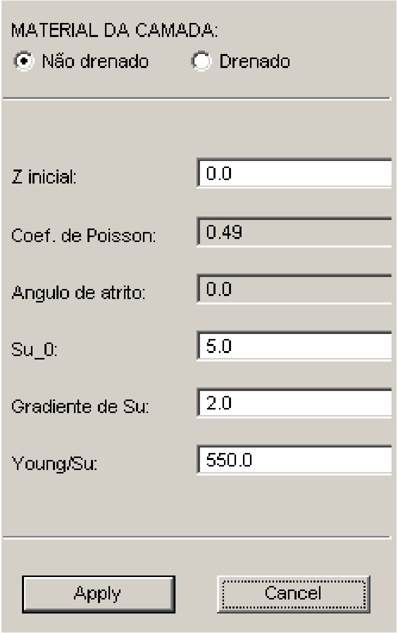


NUMERO DE CAMADAS DE SOLO

○ 1 camada ○ 3 camadas

○ 2 camadas ● 4 camadas

Figure 23 – Soil data definition window



MATERIAL DA CAMADA:
● Não drenado ○ Drenado

Z inicial: 0.0

Coef. de Poisson: 0.49

Angulo de atrito: 0.0

Su_0: 5.0

Gradiente de Su: 2.0

Young/Su: 550.0

**Figure 24 – Soil data definition for undrained material**

## RESULTS POST PROCESSING FOR PILE MODELS

The results post-processing for the models were performed with a proprietary program called POS-3D developed by Catholic University of Rio de Janeiro. The development of this program was sponsored by PETROBRAS/CENPES. Figures 25 and 25 show the plasticity ratio for the soil of an inclined pile model of 30° for two different viewpoints.

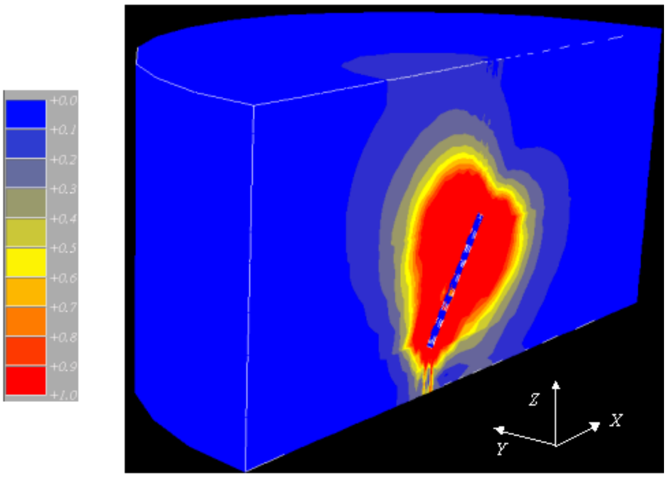


**Figure 25 – Plasticity ratio of a 30° inclined model – view 1**

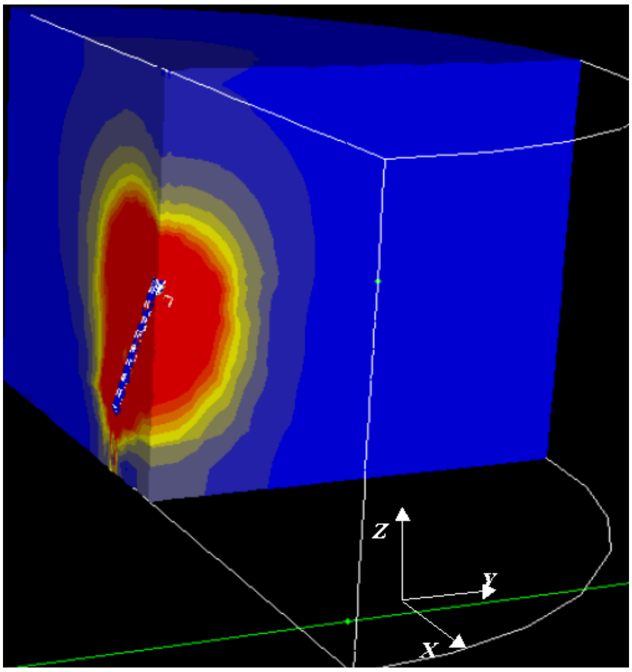


**Figure 26 – Plasticity ratio of a 30° inclined model – view 2**

## PIPELINE 3D MODEL

The pipeline is analyzed through a global model of beam elements subjected to thermal loads and internal pressure. The element type PIPE31 from Abaqus was used to model the pipe. The soil behavior is highly non-linear and is represented through either non-linear springs with fixed direction feature (element type Abaqus SPRING 2) or elastic-plastic bar elements. Figure 27 shows the 3D model of the problem with 3 spring elements per node representing the passive reaction of soil for each principal direction.

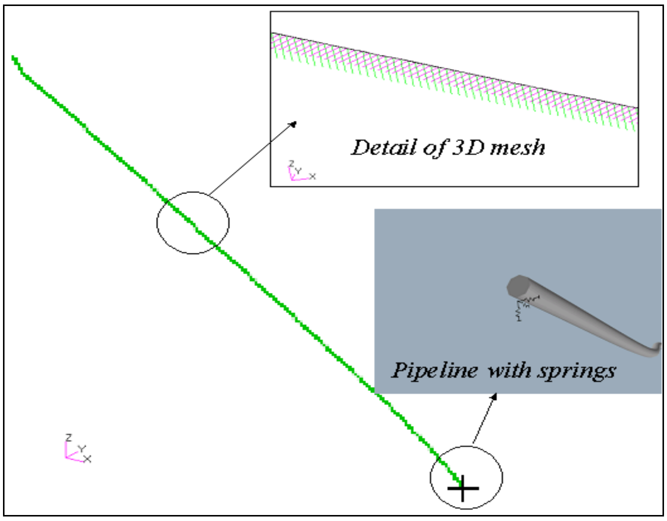


**Figure 27 - 3D global model of the pipeline**

The non-linear spring constants necessary to define the soil resistance are defined using the curves presented in figures 28 and 29. These curves were obtained through the analysis of 2D models that represented the pipe and soil interaction using AEEPECD proprietary solver developed by PETROBRAS/ CENPES[2].

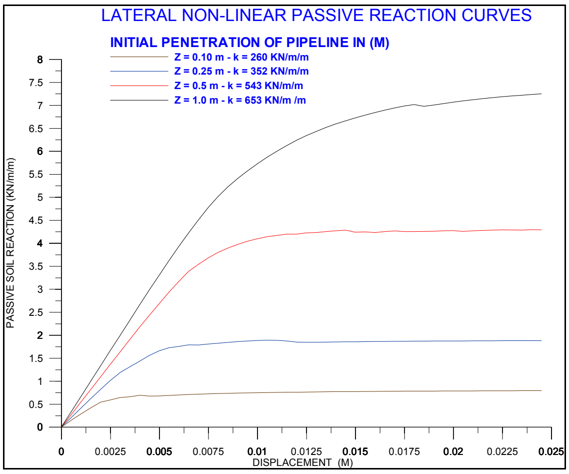


**Figure 28 - Lateral non-linear passive reaction curves**

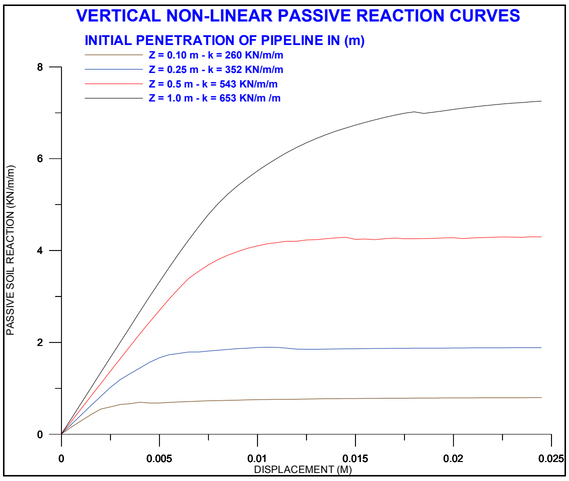


**Figure 29 - Vertical non-linear passive reaction curve**

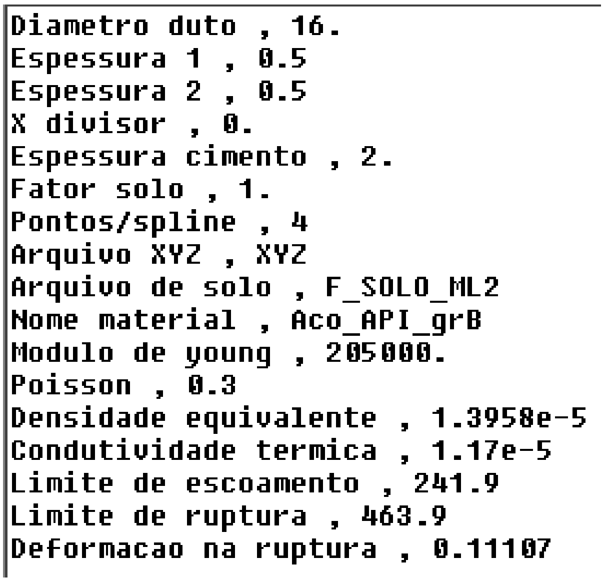
## PARAMETRIC PIPE MODEL GENERATOR

The geometry information of the pipeline is obtained through a measuring procedure using inertial pig (Geopig). The data comes for analysis in a text file format.

A model generation procedure using Parametric Command Language (PCL) was used to create a complete pipeline model reading automatically all the geometry and material information.

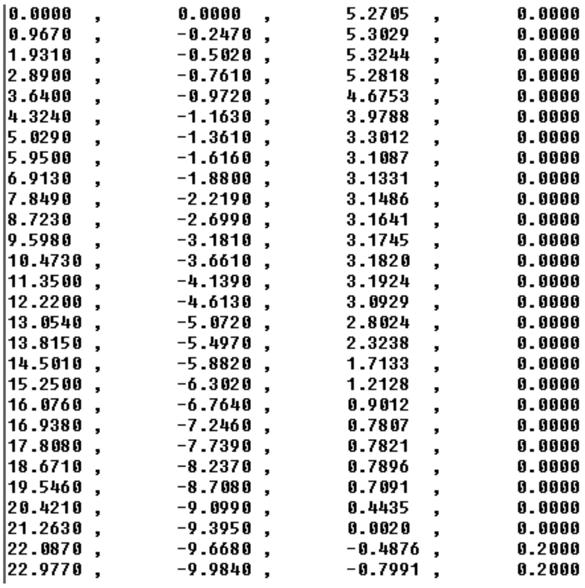
The input data for the model generation can be supplied in an easy way through the text file shown in figure 30. Figure 31 shows the file with the geometry and level of embedment information of the pipeline and figure 32 shows the text file with the material information for the soil springs.

The pipeline is modeled using MSC.Patran spline native geometry entity. The user must define the number of points used for the generation of each spline. A minimum of 4 points is required to start the process. The developed algorithm guarantees a perfect tangency between the several splines of the model.



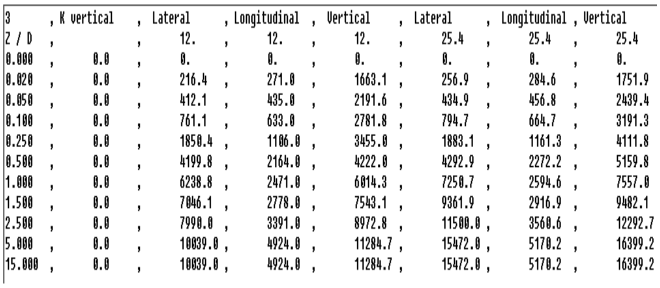
```
Diametro duto , 16.
Espessura 1 , 0.5
Espessura 2 , 0.5
X divisor , 0.
Espessura cimento , 2.
Fator solo , 1.
Pontos/spline , 4
Arquivo XYZ , XYZ
Arquivo de solo , F_SOLO_ML2
Nome material , Aco_API_grB
Modulo de young , 205000.
Poisson , 0.3
Densidade equivalente , 1.3958e-5
Condutividade termica , 1.17e-5
Limite de escoamento , 241.9
Limite de ruptura , 463.9
Deformacao na ruptura , 0.11107
```

**Figure 30 - Text file data for the parametric model**



```
0.0000  ,     0.0000  ,    5.2705  ,     0.0000
0.9670  ,    -0.2470  ,    5.3029  ,     0.0000
1.9310  ,    -0.5020  ,    5.3244  ,     0.0000
2.8900  ,    -0.7610  ,    5.2818  ,     0.0000
3.6400  ,    -0.9720  ,    4.6753  ,     0.0000
4.3240  ,    -1.1630  ,    3.9788  ,     0.0000
5.0290  ,    -1.3610  ,    3.3012  ,     0.0000
5.9500  ,    -1.6160  ,    3.1087  ,     0.0000
6.9130  ,    -1.8800  ,    3.1331  ,     0.0000
7.8490  ,    -2.2190  ,    3.1486  ,     0.0000
8.7230  ,    -2.6990  ,    3.1641  ,     0.0000
9.5980  ,    -3.1810  ,    3.1745  ,     0.0000
10.4730 ,    -3.6610  ,    3.1820  ,     0.0000
11.3500 ,    -4.1390  ,    3.1924  ,     0.0000
12.2200 ,    -4.6130  ,    3.0929  ,     0.0000
13.0540 ,    -5.0720  ,    2.8024  ,     0.0000
13.8150 ,    -5.4970  ,    2.3238  ,     0.0000
14.5010 ,    -5.8820  ,    1.7133  ,     0.0000
15.2500 ,    -6.3020  ,    1.2128  ,     0.0000
16.0760 ,    -6.7640  ,    0.9012  ,     0.0000
16.9380 ,    -7.2460  ,    0.7807  ,     0.0000
17.8080 ,    -7.7390  ,    0.7821  ,     0.0000
18.6710 ,    -8.2370  ,    0.7896  ,     0.0000
19.5460 ,    -8.7080  ,    0.7091  ,     0.0000
20.4210 ,    -9.0990  ,    0.4435  ,     0.0000
21.2630 ,    -9.3950  ,    0.0020  ,     0.0000
22.0870 ,    -9.6680  ,   -0.4876  ,     0.2000
22.9770 ,    -9.9840  ,   -0.7991  ,     0.2000
```

**Figure 31 – Text file with geometry and level of embedment information**



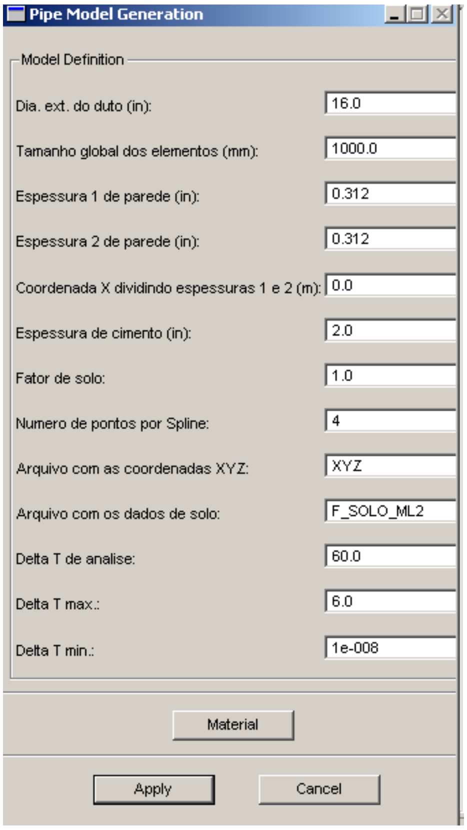
```
3       , K vertical    , Lateral     , Longitudinal , Vertical     , Lateral     , Longitudinal , Vertical
Z / D   ,               ,     12.     ,     12.      ,     12.      ,     25.4    ,     25.4     ,     25.4
0.000   ,      0.0      ,     0.      ,     0.       ,     0.       ,     0.      ,     0.       ,     0.
0.020   ,      0.0      ,     216.4   ,     271.0    ,     1663.1   ,     256.9   ,     284.6    ,     1751.9
0.050   ,      0.0      ,     412.1   ,     435.0    ,     2191.6   ,     434.9   ,     456.8    ,     2439.4
0.100   ,      0.0      ,     761.1   ,     633.0    ,     2781.8   ,     794.7   ,     664.7    ,     3191.3
0.250   ,      0.0      ,     1850.4  ,     1106.0   ,     3455.0   ,     1883.1  ,     1161.3   ,     4111.8
0.500   ,      0.0      ,     4199.8  ,     2164.0   ,     4222.0   ,     4292.9  ,     2272.2   ,     5159.8
1.000   ,      0.0      ,     6238.8  ,     2471.0   ,     6014.3   ,     7250.7  ,     2594.6   ,     7557.0
1.500   ,      0.0      ,     7046.1  ,     2778.0   ,     7543.1   ,     9361.9  ,     2916.9   ,     9482.1
2.500   ,      0.0      ,     7990.0  ,     3391.0   ,     8972.8   ,     11500.0 ,     3560.6   ,     12292.7
5.000   ,      0.0      ,     10039.0 ,     4924.0   ,     11284.7  ,     15472.0 ,     5170.2   ,     16399.2
15.000  ,      0.0      ,     10039.0 ,     4924.0   ,     11284.7  ,     15472.0 ,     5170.2   ,     16399.2
```

Figure 32 – Material information for soil springs

The parametric model generation start-up window is made through the MSC.Patran interface shown in figure 33. SERCON Consulting Services developed this proprietary interface to PETROBRAS/CENPES. This procedure opens the window shown in figure 34 that controls the input data for the parametric model generator. It was also created a sub-window for the definition of the material properties of the pipeline, shown in figure 35.

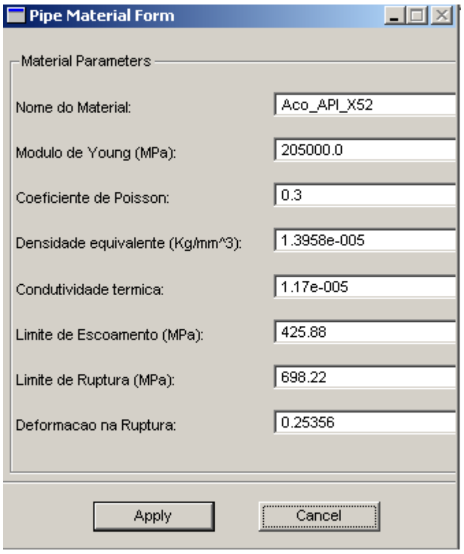
In order to make easier the input data procedure for the parametric model generation, it was created the text file shown in figure 36. The values in this file are default and will feed the windows shown in figures 34-35 during MSC.Patran start-up. Any default value can be changed interactively.

Figure 33 - Parametric model generator start up window



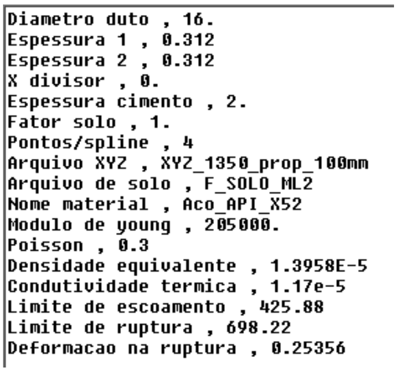
Dia. ext. do duto (in): 16.0
Tamanho global dos elementos (mm): 1000.0
Espessura 1 de parede (in): 0.312
Espessura 2 de parede (in): 0.312
Coordenada X dividindo espessuras 1 e 2 (m): 0.0
Espessura de cimento (in): 2.0
Fator de solo: 1.0
Numero de pontos por Spline: 4
Arquivo com as coordenadas XYZ: XYZ
Arquivo com os dados de solo: F_SOLO_ML2
Delta T de analise: 60.0
Delta T max.: 6.0
Delta T min.: 1e-008

Figure 34 - Parametric model generator window



Nome do Material: Aco_API_X52
Modulo de Young (MPa): 205000.0
Coeficiente de Poisson: 0.3
Densidade equivalente (Kg/mm^3): 1.3958e-005
Condutividade termica: 1.17e-005
Limite de Escoamento (MPa): 425.88
Limite de Ruptura (MPa): 698.22
Deformacao na Ruptura: 0.25356

Figure 35 – Material property data window



```
Diametro duto , 16.
Espessura 1 , 0.312
Espessura 2 , 0.312
X divisor , 0.
Espessura cimento , 2.
Fator solo , 1.
Pontos/spline , 4
Arquivo XYZ , XYZ_1350_prop_100mm
Arquivo de solo , F_SOLO_ML2
Nome material , Aco_API_X52
Modulo de young , 205000.
Poisson , 0.3
Densidade equivalente , 1.3958E-5
Condutividade termica , 1.17e-5
Limite de escoamento , 425.88
Limite de ruptura , 698.22
Deformacao na ruptura , 0.25356
```

**Figure 36 - Text data file for the parametric model**

## CONCLUSIONS

The creation of parametric models integrated into MSC.Patran environment allowed PETROBRAS/CENPES to shorten dramatically the required time necessary for the generation of very complex 3D models. The time required to create each model was reduced from several days to some minutes, allowing the analysis of the problem with more accurate models. Another great advantage of this procedure is the great confidence we got in the model generation process, reducing the chance of errors occurrence.

The development of a preference for AEEPEC3D solver allowed PETROBRAS/CENPES to perform very complex and accurate 3D analysis of “torpedo” piles with its proprietary solver specifically designed for that purpose. This integration gave the possibility to take advantage of full MSC.Patran capabilities for the model generation process.

Another great advantage of the customization process is that it allows the generation of very complex models by non-experts in MSC.Patran.

## REFERENCES

[1] MSC.Patran Reference Manual.

[2] Andueza, A., Amaral, C. S. e Costa, A. M. Integration of ANLEET and ANVECT Programs in MSC.PATRAN Environment, MSC Users Conference, MSC Solution Opening New Frontiers, Universal City October 1998.

[3] Costa, A. M. e Amaral. C. S. Two and Three-Dimensional Modeling of Bucket Foundations for Application in Deep Water Anchoring, X International Symposium on Offshore Engineering, Brazil Offshore 97, Setembro de 1997.

[4] Amaral C. S., Costa, A. M., outubro 2000: "Comportamento Longitudinal da Interface Solo Duto“, Relatório Parcial de Projeto – Projeto 600378.

[5] Costa, A. M. e Amaral. C. S. Application of Suction Piles as Anchors for Floating Production Platforms in Deep Water at the Campos Basin, Symposium on Recent Developments on Soil and Pavement Mechanics, COPPE/UFRJ, Rio de Janeiro, Junho de 1997.

[6] Pope M. A., Pimenta, G. S. et al, 1997: "Análise de falha do vazamento do oleoduto Reduc-Ilha dágua “, Comunicação Técnica, 079/97.

[7] Amaral C. S., Costa, A. M., 2000: "Avaliação da Interação Solo Duto no Problema Ocorrido do Duto da REDUC de 16” “, Comunicação Técnica DIPREX/SEDEM, 016/2000.

[8] Amaral C. S., Costa, A. M., outubro 2000: "Comportamento Longitudinal da Interface Solo Duto“, Relatório Parcial de Projeto – Projeto 600378.

[9]Costa, A. M., 1984 : "Uma Aplicação de Métodos Computacionais e Princípios de Mecânica das Rochas no Projeto e Análise de Escavações Subterrâneas Destinadas à Mineração Subterrânea", Tese de Doutorado, COPPE/UFRJ.

[10] Kerr, A. D., 1978, “Analysis of Thermal Track Buckling in Lateral Plane “, Acta Mecanica, Vol. 30, p.p 17-50

[11] Hobbs, R. E., 1984, “In Service Buckling of Heated Pipelines “, Journal of transportation Engineering, ASCE, Vol. 110, No 2, p.p 175-189