



**Phillip Afonso de Melo Grainger**

**Numerical Analysis Of The  
Mechanical Behavior Of Cement  
Sheaths In Wells Through Salt Formations**

**DISSERTAÇÃO DE MESTRADO**

**DEPARTAMENTO DE ENGENHARIA CIVIL**

Programa de Pós-Graduação em  
Engenharia Civil

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May 2012



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Dissertation presented to the Programa de Pós-Graduação em Engenharia Civil of the Departamento de Engenharia Civil, PUC-Rio as partial fulfillment of the requirements for the degree of Mestre em Engenharia Civil.

Advisor: Prof. Eurípedes do Amaral Vargas Jr.  
Co-advisor: Prof<sup>a</sup>. Raquel Quadros Velloso

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## Resumo

Grainger, Phillip Afonso de Melo; Vargas Jr., Eurípedes do Amaral. **Análise numérica do comportamento mecânico de bainhas de cimento em poços através de formações salinas**. Rio de Janeiro, 2012. 134p. Dissertação de Mestrado - Departamento de Engenharia Civil, Pontifícia Universidade Católica do Rio de Janeiro.

Existem muitas formações no mundo hoje que armazenam uma quantidade significativa de petróleo, sendo um grande valor para a indústria petroleira. As bacias de Pré-sal da costa do Brasil atualmente estão em grande foco devido aos descobrimentos recentes de petróleo e os desafios que eles criam na perfuração. Ao contrário de muitas formações, a rocha salina exibe fluência, uma vez que, a perfuração seja realizada a rocha começa se realiviar das tensões geostáticas por fechamento com o tempo. A profundidade e os altos níveis de tensões induzidas pelo sal no revestimento requerem a cimentação para fornecer estabilidade adicional. Mesmo assim, um defeito no cimento complica a análise para os engenheiros a modelar e prever seu comportamento. Um revestimento bem cimentado não é sempre alcançado em águas profundas. A geometria e o tamanho têm uma grande influência nas tensões no defeito do cimento. A ovalização do revestimento pode reduzir as tensões máximas de compressão induzidas pelo sal dependendo da geometria do defeito. Excentricidade reduz os efeitos da ovalização enquanto muda o estado de tensões do cimento. Portanto, é importante que o cimento e o sal sejam entendidos inteiramente a fim de realizar decisões racionais em engenharia. O foco desta pesquisa é atingir um conhecimento mais profundo de poços de offshore mal cimentados sujeitos ao carregamento não uniforme. Um modelo de elementos finitos foi gerado pelo software *Abaqus* para implementar simulações e análise de vários cenários de falhas no cimento.

## Palavras-chave

Cimento; Fluência de sal; Pré-sal; Carregamento não uniforme; Abaqus.

## Abstract

Grainger, Phillip Afonso de Melo; Vargas Jr., Eurípedes do Amaral (Advisor). **Numerical analysis of the mechanical behavior of cement sheaths in wells through salt formations.** Rio de Janeiro, 2010. 134p. MSc. Thesis - Departamento de Engenharia Civil, Pontifícia Universidade Católica do Rio de Janeiro.

There exist several salt rock formations in the world today which store a substantial amount of oil, being a great asset to the petroleum industry. The pre-salt basins off the coast of Brazil have been a primary focus due to the challenges they provide in oil drilling. Unlike most formations, salt rock exhibits creep behavior where, once the drilling has been performed, the rock begins to relieve itself from the applied stress by closing gradually with time. This may lead to cases of well collapse and well abandonment, creating an economical issue to oil drillers. Well cementing is always sought to be performed with excellence, caution and thoroughness. Nevertheless, an unevenly distributed cement job complicates the analysis for engineers to model and predict its behavior. A well-cemented casing is not always achieved in deepwater wells. Geometry and size greatly influence the stresses on the defected area. Hence, it is important that the cement and salt formation be fully understood in order to make rational engineering decisions. The focus of this research study is to attain a deeper understanding of poorly-cemented offshore wells subjected to non-uniform salt loading. A finite element model was generated by the commercial software program *Abaqus* to implement simulations and analyses of various failure scenarios.

## Keywords

Salt creep; Brazil; Non-uniform loading, Cement, Abaqus.



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## Used Symbols

### *Roman Letters*

$A$	Cross-sectional area; reciprocal viscosity coefficient (creep)
$[B]$	Transformation matrix relating strains and displacements
$c$	Cohesive strength
$[C]$	Constitutive (strain-stress) matrix; general diagonal matrix
$d$	Diameter
$E$	Modulus of Elasticity (i.e., <i>Young's modulus</i> )
$G$	Shear modulus
$ID$	Inner Diameter
$[J]$	Jacobian matrix
$[K]$	Assemblage stiffness matrix
$k$	Stress concentration factor; spring constant
$n$	Stress power (creep); strain hardening exponent
$[N]$	Coefficient matrix for interpolation field variable (displacement) model
$OD$	Outer diameter
$p$	Pressure
$Q$	Activation energy
$r$	Radius
$t$	Time; thickness
$T$	Temperature
$\tau_o$	Octahedral shear stress
$\nu$	Poisson's ratio; displacement
$V$	Volume
$x, y, z$	Spatial coordinates

***Greek Letters***

$\varepsilon$	Normal strain
$\varepsilon_e$	Elastic strain
$\varepsilon_p$	Plastic strain
$[\varphi]$	Coefficient matrix for generalized coordinate model
$\varphi$	Angle of internal friction
$\sigma$	Normal stress at a point, or in a uniformly stressed member.
$\lambda$	Shear strain;
$\nu$	Poisson's ratio
$\psi$	Dilation angle; interpolation function

***Subscripts***

$c$	Creep
$e$	Elastic ( $\varepsilon_e$ )
$p$	Plastic ( $\varepsilon_p$ )
$max$	maximum
$min$	Minimum
$m$	Mean ( $\sigma_m$ )
$x, y, z$	Direction ( $\sigma_x$ ); axis ( $I_y$ )
$xy, yz, zx$	Plane ( $\tau_{xy}$ )
$1, 2, 3$	Principal direction ( $\sigma_1$ )

**Abbreviations**

bwow	By weight of water
w/c	Water-cement ratio
ppg	Pounds per gallon
SMYS	Specified minimum yield stress