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Application of the Finite Element Method in the study of local stresses at Recôncavo Basin, Northeast Brazil

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ABSTRACT

The Finite Element Method has been widely used in several fields. This paper reports an application of this method to the study of local stresses at Recôncavo Basin, Northeast Brazil. This basin has a half-graben structural framework and a complex stress distribution. Some geological information about the Recôncavo Basin is presented to highlight the correlation of the generated model with the geological context. Petrophysical data for several depth intervals of the model were generated by inversion using data from many well logs. The finite element program TECTOS was used to build the triangular mesh and to perform the numerical analysis. A present day analysis of the stress field of the basin was also performed. In conclusion, the Finite Element Mehod proved to be an important tool to be used in Structural Geology.

INTRODUCTION

Finite elements constitute the approach that has the greatest impact on the theory and practice of numerical methods during the twentieth century. Finite element methods have now been used in virtually every conceivable area of engineering that can make use models of nature characterized by partial differential equations. There are dozens of textbooks, monographs, handbooks, memoirs, and journals devoted to its further study. Numerous conferences, symposia, and workshops on various aspects of finite element methodology are held regularly throughout the world. There are easily over one hundred thousand references on finite elements today, and this number is growing exponentially with further revelations of the power and versatility of the method (Oden, 1991). Today, finite element methodology is making significant inroads into fields in which many thought were outside its realm, for example, Structural Geology and Tectonics

GEOLOGICAL ASPECTS OF THE STUDY AREA

Recôncavo Basin, located at Northeastern Brazil, is genetically related to the rifting process that affected the paleocontinent of Gondwana during the Eocretaceous (Neocomian). This basin constitutes a series of asymmetric grabens aligned in NE-SW direction, composing an intracontinental rift with N-S general direction. These grabens were filled with fluvial and lacustrine sediments with rich organic matter horizons. The tectonic activity of this region was aborted during the Eoaptian.

In its structural framework, the Recôncavo Basin acquires a half-graben shape, with a SE regional dip of the layers, in direction of the depocentre located near the east boundary. The distensive stresses originated normal faults, with steeply dipping planes, having N30°E as preferencial direction.

The description of the lithostratigraphic chart of the Recôncavo Basin is based principally at Viana et al. (1970) and Ghignone (1979). The pre-rift fase shows, from the bottom to the top, the followings lithostratigraphic units: Afligidos, Aliança, Sergi, Itaparica, Água Grande and the Member Tauá of the Candeias Formation. The Afligidos and Água Grande Formations until recently were considered as members of the Aliança and Itaparica Formations, respectively (Silva, 1993).

The sediments of the pre-rift phase were deposited in a period of relative tectonic stability, and they consist of continental sandstones and lacustrine shales with ages from the Upper Permian (Afligidos Formation), Upper Jurassic (Aliança and Sergi Formations) until the Lower Cretaceous (Itaparica and Água Grande Formations and Tauá Member of Candeias Formation).

The sin-rift phase started during the Neocomian, with the predominance of normal faults and the deposition of a great thickness of conglomerates near the border faults (Salvador Formation). A deeper lake was formed in the center of the basin, filled after with shales and turbiditic sandstones (Candeias Formation). Deltaic sandstones (Marfim Formation), ciclic intercalations of sandstones, shales and limestones (Pojuca Formation) and fluvial sandstones (São Sebastião Formation) filled the rift cavity.

The sin-rift phase finished in the Lower Aptian, being the basin recovered in a discordant form by the fluvial and alluvial sandstones from age of the Marizal Formation (pos-rift phase). Finally, during the Cenozoic, continental sandstones of the Barreiras Formation were deposited. The basement is formed by the Cinturão Granulítico Atlântico, constituted predominantly by granulites of arquean age (Santos et al., 1990).

FINITE ELEMENT METHOD

The advances in computational techniques have improved numerical modelling in Structural Geology and Tectonics. Basicaly, those numerical models aim to show the evolution of geological settings throughout the time and the relative rheological behaviour of rocks. Among a huge quantity of available numerical techniques finite elements have been the most used numerical method in tectonics (for example, Wiltlox, 1986 and Moraes, 1995). The facility in handling with complex geological shapes, anisotropy, heterogeneity and a variable range of non-linear rheological behaviour has brought finite elements to be the most popular numerical method in structural geology modelling.
Models showed in this paper have been built up by using the finite element program TECTOS, a joint product of PETROBRÁS and Rio de Janeiro Catholic University. The software TECTOS has been developed for specific application in structural geology and mechanical basin modelling, constituting an integrated environment of computational programs based on easy communication among pre-processor, analysis and visualisation codes. TECTOS builds up the models by using complex topological and mapping techniques turning easy to model complex geological features. The finite element analysis itself is done by a fast converging dynamic relaxation method code. The program can handle many different flow and rheological laws, material anisotropy and interface elements to simulate faults, among other facilities.

ELASTIC MODULI AND GEOLOGICAL MODEL GENERATION

In order to generate the average elastic moduli for each depth interval, using the expressions of elasticity theory, density as well as compressional and shear wave velocities (VP and VS) data, were necessary. All these data were obtained from some well logs of the Recôncavo Basin. The lack of one or more of these well logs, led us to try to generate them from the available data. The pseudo-VS logs, for instance, were generated from VP logs, porosity and pore fluid data, using the model proposed by Greenberg and Castagna (1992). Where there were no density logs, the density data were generated using Gardner Equation (Gardner et al.,1974). Porosities were estimated from sonic logs.
A geological model constructed through a tranverse regional NW-SE geological section of the Recôncavo Basin (Azevedo et al., 1994), was used to perform the finite element analysis. Figure 1 shows the triangular finite element mesh and boundary conditions applied in this geological model. Some lithostratigraphic units are mentioned in the model.

RESULTS

The analysis perfomed in this paper yields very instructive results to study present stresses and deformation fields in Recôncavo Basin. Figure 2 shows the shear stress field distribution in the modeled section. This map enhances the areas most suitable to yielding. As is evident from this figure, the complexity of geometric boundaries and rheological behavior of geological units yields an also complex stress field, with large values being most frequent close to the most proeminent shapes of the basement. Figure 3 shows volume change through the model. The sedimentary core attains most of the loss of volume, mainly inside those units having low values of Poisson's ratios. By comparing models generated with more simplistic physical parameters obtained from literature, our work shows that this kind of analysis is best achieved by using mechanical parameters from well geophysical inversion techniques as is performed here. Focusing on reservoir scale, this kind of work can bear a very important role in production and development of petroleum fields.

CONCLUSIONS

Numerical models using finite element modeling coupled with geophysical inversion to obtain mechanical parameters of rocks have proved to be very important tools to investigate local stress distribution related to the complex structural framework as that ocurring at Recôncavo Basin.

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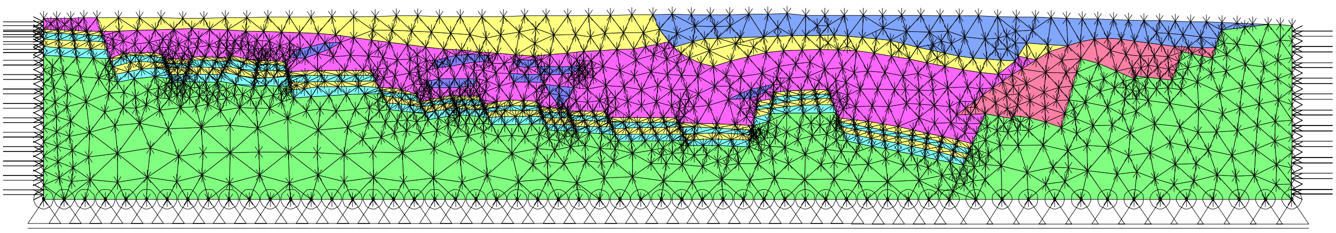


Figure 1 – Triangular finite element mesh and boundary conditions applied to the geological model of the Recôncavo Basin. The blue, yellow, pink, and red colors correspond to São Sebastião, Pojuca, Candeias and Salvador geological formations, respectively. The green color is the cristaline basement.

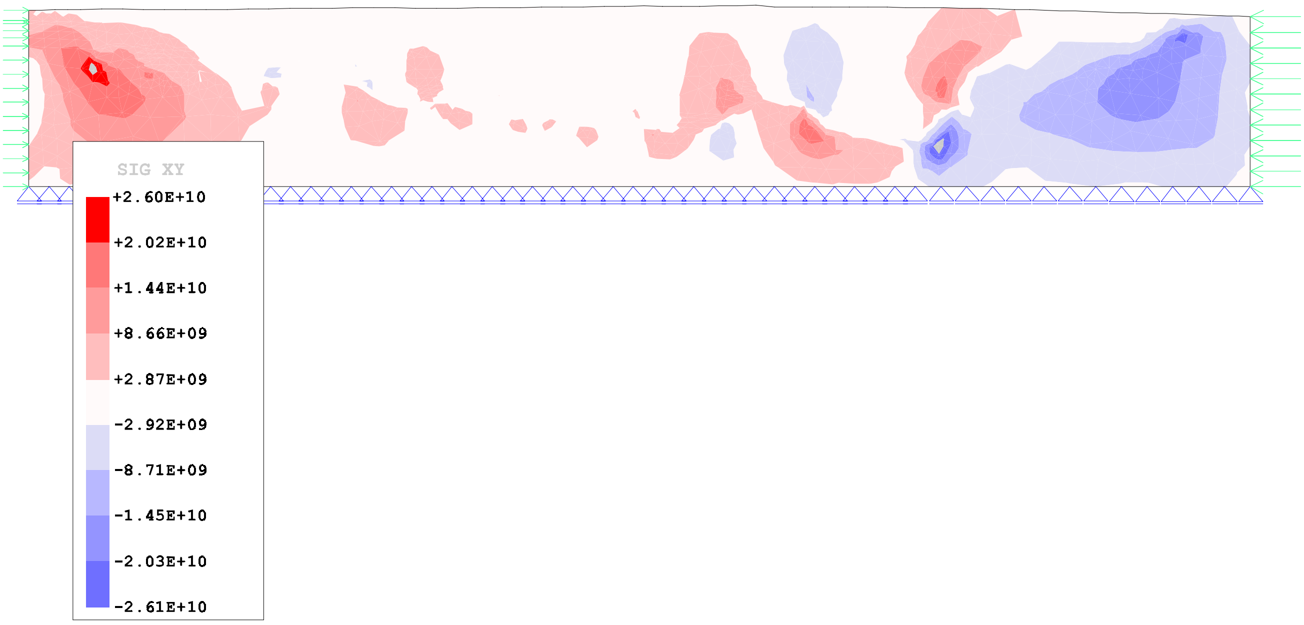
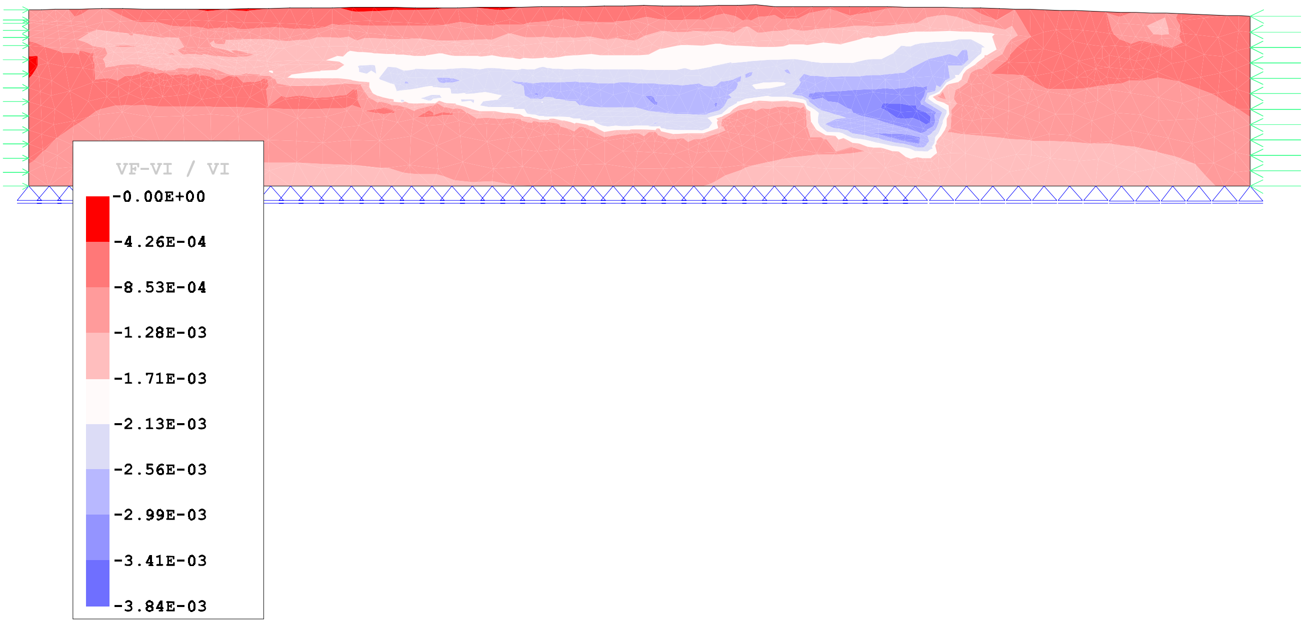


Figure 2 – Shear stresses distribution in the model. Red colors representing counter-clockwise sense and blue colors representing clockwise sense. Values in KPa.



Figue 3 – Volume change factor in the model. Blue colors represent large values in negative dilation.