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Rock Mechanics in Petroleum Industries and the Importance to Wellbore Stability

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ABSTRACT

The petroleum that also means "rock-oil" could not exist under the ground without reservoir rock be it sandstone, limestone, shale or granite. Therefore, understanding the rock characteristics and its behavior is primarily important before the designing phase of a petroleum field. Knowing that most of the petroleum fluid will situated in sandstone, the emphasation would focus on this type of rock. The basic properties such as porosity, permeability, density, compressive strength, tensile and shear strength are need to be defined and understood, and the relationship among them should be identified. In this research paper, all rock properties and behavior has been highlighted and the relationship between them has been explained. The problem related to the rock, e.g., shale swelling, drilling pipe stuck, wellbore stability and sand production problem also have been discussed. The wellbore stability then been focused and related experimental work results presented. The perforation parameter and wellbore geometry have been varied to see the effects of rock stress on the wellbore stability. The results show that the rock mechanics aspect must be considered in the designing phase of a petroleum field to avoid excessive money spending to threat the petroleum wells and to optimized the production. Therefore, the rock properties and behavior should be understood in details before the designing period. From experimental works, it was found that the perforation parameters have a great influence on the wellbore stability and sand production due to the stress redistribution depending upon the rock properties and behavior. The higher is the shot density, the lower will be the wellbore stability and increased sand production problem. The spiral pattern gave the best stability followed by inplane and inline patterns.

INTRODUCTION

Rock mechanics is a central component of many oil industry problems and can be considered as a "phase of intensive exploration." After the early days, petroleum related rock mechanics were mostly confined in a few specific topics such as hydraulic fracturing design and pore compressibility assessment, but for the last 15 years have seen the identification of most industrial aspects that have a rock mechanical content, as shown in Table 1.

For example, a perforation productivity has received only limited and recent attention from a rock mechanics point of view. It was understood that the perforation length strongly affects its flow capacity and that such a length depends upon the reservoir rock strength. The physical nature of the permeability impairment around the perforation was subsequently identified and related to rock mechanics phenomena. From an industrial point of view, the role of rock mechanics has thus been limited to feeding parameters into semi-empirical models for the optimum perforation flow performance. However, the margin for a larger rock mechanical involvement is quite large and this domain can be likened to a field that has been discovered but remains to be appraised.

Table 1 Domains with a Rock Mechanical Content in Petroleum Engineering

Phase/Aspect	Issues
Drilling	Wellbore stability, Coring, Mud losses, Casing collapse, Bit performance
Production	Sand production, Perforation, Hydraulic fracturing, Gravel packing
Surface	Site investigation, Subsidence, Seismicity, Waste management
Reservoir	Stress, Compressibility and Permeability vs Depletion; Water injection; Fracture identification; Capillary forces
Exploration	Hydrocarbon migration, Fractures, Seal efficiency, Basin modeling

Another example is a wellbore stability issue. The cost of wellbore instabilities has been delineated by most operators and the topic is now widely held as a domain where major savings could be achieved by a proper application of rock mechanically based technologies. These domains can be likened to a field that has been appraised but remains to be developed economically.

From this, it derives that the industrial challenge facing rock mechanics for the next decade is twofold. First, on the one end appraise the poorly investigated issues such as mud loss/leak off test interpretation, casing collapse, perforation, many reservoirs and exploration issues. Second, on the other end develop economically the topic such as wellbore stability, sand production prediction, hydrofracturing and subsidence. Whilst the first aspect can be treated from an essentially research based stand point, the second needs to be addressed from an industrial point of view where the use of existing technology is optimized to fit within the constraints posed by operations, such as timing, information availability, risk handling policy and economical return.

With low oil price and reserve depletion, steps must be taken by the industry to ensure all existing petroleum reserves can be produced as optimum as possible with minimal cost. Future activities will be centered around deep sea exploration and using cluster production systems in developing marginal fields. Hence, a cost effective technology and local technical alliances must be utilized or established to ensure that petroleum industry is growing and still an attractive investment to the investor.

As future petroleum operations will be concentrated at deep well, wellbore stability is one of main factors that should be emphasized in designing oil and gas fields. Wellbore stability analyses require rock mechanics inputs, and the understanding of the theory of rock mechanics is very important in the study of wellbore stability.

When hydrocarbon was extracted from a porous reservoir, the reservoir pressure will decrease, resulting in increasing of overburden pressure that reduces the reservoir bulk volume and space. This phenomenon may lead to reservoir compaction that may be transferred to the surface as a vertical displacement (ground surface subsidence), collapse of wellbore and surrounding formation, porosity and permeability reduction, instability of the area and reduction in the well productivity. Generally, the reservoir rock compressibility ranges from $3x10^{-6}$ to $23x10^{-6}$ pore space volume per psi. For every one million barrel of pore space and 1000 psi reservoir pressure reduction, there will be 3000 to 23000 barrel of reservoir volume reduction with higher reduction rate corresponds to higher production rate. In other words, the reduction rate depends on the development design, its implementation and operations, particularly during drilling and production phase. Therefore, the reservoir rock properties and behavior, including failure mechanism and their impact on the reservoir productivity, ground subsidence and area stability should be determined and understood and their impact controlled in order to ensure optimum productivity and stability.

In addition, instability of wellbore will lead to sand production where against more money is needed to be invested to control the problems. Therefore, avoiding and minimizing the problem would be a better solution rather then reacting on the problem. Thus, rock mechanics aspect and the wellbore instability need to be considered for enhancing the recovery of oil and minimizing the maintenance cost. Hence, a proper planning of reservoir development is needed. Sand controlled methods have to be used if the well is producing more than 15 lb/1000 bbl of sand. Sand production has become a serious problem in Malaysia, especially in East Malaysian oil fields, such as the Baram Delta Operation Field. Severe sand production problems occurred in Lutong Barat, Tembungo, Baronia, Baram, Bekok, Betty, Pulai and Tapis. For example, the Baronia field produced 100 lb/1000 bbl of sand. The sand production occurrence always associated with formation failure caused by excessive production rate or high overburden. Here, the rock mechanics aspect should be considered in the study of sand production problems.

LABORATORY WORKS

Understanding the problem only by literally is not very effective. Laboratory work must be done in order to understand the behavior of the rock and the effects to the petroleum wellbore as elaborated previously. As for this research purpose the laboratory work has been conducted to see the effects of certain parameter to the wellbore stability. Basically type types of wellbore models prepared i.e. block and 6" cylindrical models.

Preparation of wellbore model

Since most of the reservoir rocks are sandstone type formation, so the research was concentrated in understanding sandstone wellbore model behavior only. Sandstones were cored from X formation. Before preparing the wellbore models, basic mechanical properties has determined to ensure that the X formation sandstone can be used as wellbore model.

Block model

The sandstone block was cut into block shape with dimension of 6" length, 6" width and 6" height. Then a 2" borehole were cored at the center of the block correspondence to desired angle i.e. 0°, 10°, 20° and 30°. Then a 1" steel pipe representing casing mounted at the center of the borehole and cemented with G class cement (cement-water ratio of 2:1). The model then left over for 1 day to ensure that the cement is cured. Later the model was saturated with crude oil. Lastly the block model was perforated with shot density of 8 SPF with three different perforation patterns e.g. Spiral, Inplane and Inline.

Cylindrical model

The same process as block model was adopted and the only different with this cylindrical model is that borehole was not inclines, whereas the shot density was varied from 6 SPF, 8 SPF and 16 SPF maintaining the perforation patterns.

Wellbore stability testing.

Before the stability test was conducted to the design wellbore model, special platen has been fabricated and treated to minimize the flaws. The purposes of the platen was to ensure that load was only applied to sandstone material and not to the casing and cement.

The fabricated platens placed very carefully on the top of the wellbore model. Then the whole assembly was put at the center of Servo Controlled Compression Machine e.g. between top and bottom piston platens.

Then load was applied to the assemblies by the servo machine, where a simple program has been develop within the machine software that will automatically applied the load until it detects the failure. Apart from that the machine software also will collect data and can be plotted as required. The common plot is load vs. displacement.

RESULTS AND DISCUSSION

Generally it was found that all the wellbore model failed. The load of failure is depending on the wellbore model design and structure. The failure pattern also has been monitored very closely in order to understand the rock behavior. Table 2 summarized the basic rock mechanical properties.

Effect of borehole angle on wellbore stability

The borehole angle has a great influential on the wellbore stability. Figure 1 show that the wellbore stability decreases as the borehole angle increases regardless of the perforation pattern. This phenomenon is due to the stress concentration around the borehole increases as the borehole inclined.

Furthermore, the shear stress around the borehole increases tremendously as the loads were applied on the top. Simple stress calculation has been done (Surej. K.S. 1997) and show that for inclination of 30^0 , 20^0, 10^0 and 0^0 the shear stress was 17.32 MN/m2, 12.86 MN/m2, 6.84 MN/m2 and 0 MN/m2 respectively for an overburden of 20 MN/m2. Thus, it can be stated that, when the wellbore inclination angle increases, there is tendency to shear or slide along the inclination since the concentration of the shear stress is greatest. Therefore, the instability of a wellbore is greater for higher inclination angles.

Effects of shot density on wellbore stability

Known that perforating the casing into the formation is one of the important activities in petroleum production engineering.The more we perforate the more oil/gas is produced. Anyway there is limitation in perforating a wellbore since it can lead to casing collapse and wellbore instability.

In the study, it was found that as the shot density is increased the wellbore stability is decreased regardless of the perforation pattern. Figure 2 shows the relationship between shot density and stress at failure.

The phenomenon of this disaster is due to reduction of rock mass around wellbore. Thus more stresses have to be redistributed along the perforation system. This redistributed load/stress must be carried by the surrounding rock grains. As the result, the rock mass strength is reduced tremendously as the shot density increases. Moreover, greater concentrations within the rock between perforation tunnels are experienced as the number of shot density increases.

Effects of perforation pattern on wellbore stability

As mentioned earlier, three types of perforation pattern tested to identify the most stable pattern. Figure 3 and Figure 4 shows the relationship between perforation pattern and stress at failure for block (borehole inclined) and cylindrical (shot density varied) model respectively.

From the result, it can be seen that spiral pattern gives the most stable wellbore model and followed by inplane and inline pattern regardless of model types. The spiral pattern failed at higher stress compared to inplane and inline pattern due to the arrangements of the perforation tunnels. The perforation tunnels were deviated to the maximum stress (axial load) and produces the greatest distance between each successive perforation. Therefore the perforated structure is stronger. As for the inplane pattern the perforation tunnels were arranged in perpendicular or in horizontal line to maximum stress and this gives the rock mass strength higher than inline pattern. Whereas, for inline pattern the tunnels were arranged parallel to the maximum stress or in one vertical line and this lead to the rock mass strength being minimum level and as the result, it failed under a minimum load/stress.

CONCLUSIONS

From experimental works, it can be conclude that the perforation parameters have a great influence on the wellbore stability and sand production due to a stress redistribution depending upon the rock properties and behavior. Wellbore stability decreased as the

wellbore angle and shot density increased and the perforation pattern changed from spiral to inplane and inline.
Therefore, the rock mechanics application to petroleum engineering must be considered in the designing and development phases of petroleum field to avoid excessive money spending to threat the petroleum wells and to optimized production.

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Table 2 Summary of Basic Rock Mechanical Properties

Properties	Value
Density	2.03 g/cc
Porosity	7 - 18 %
Permeability	1.2 - 7.3 mD
Compressive strength	32 MN/sq.m.
Tensile strength	1.82 MN/sq.m.
Modulus of elasticity	6.95 GN/sq.m.
Triaxial shear strength	12.90 MN/sq.m.
Angle of internal friction	39.39 deg.
Poisson ratio	0.3

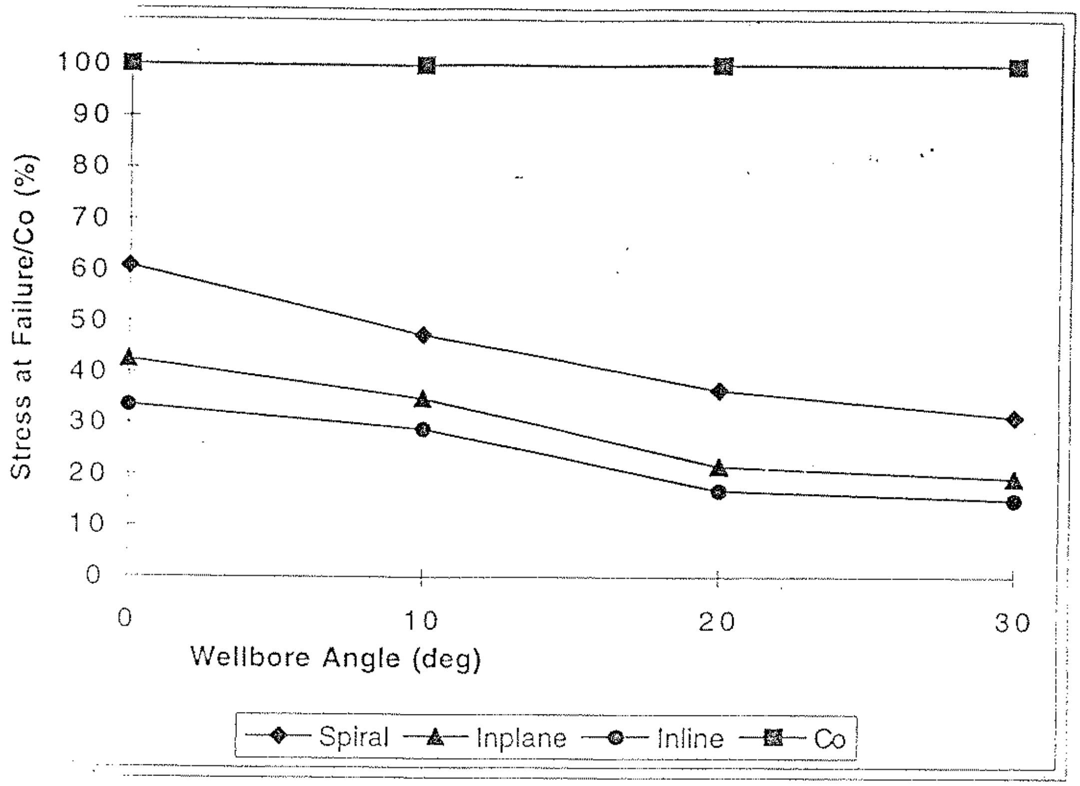

Figure 1a - The effects of wellbore angle on wellbore stability for various perforation patterns

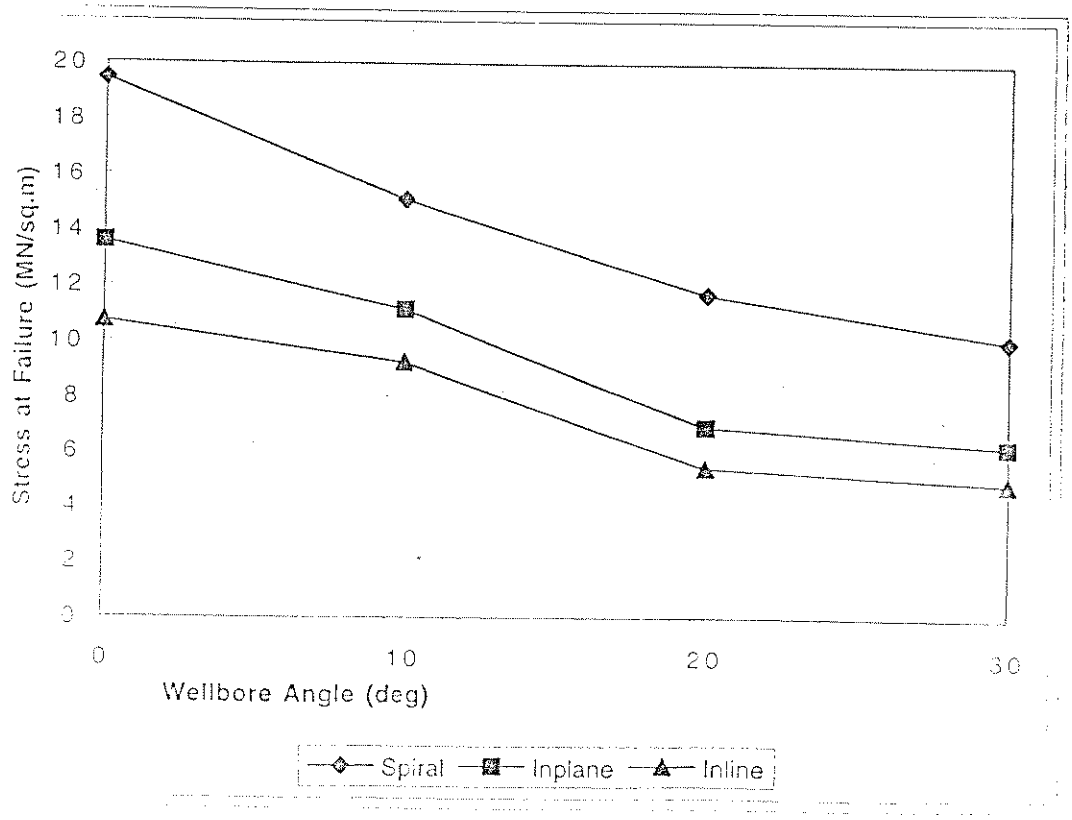

Figure 1b - The effects of wellbore angle on wellbore stability

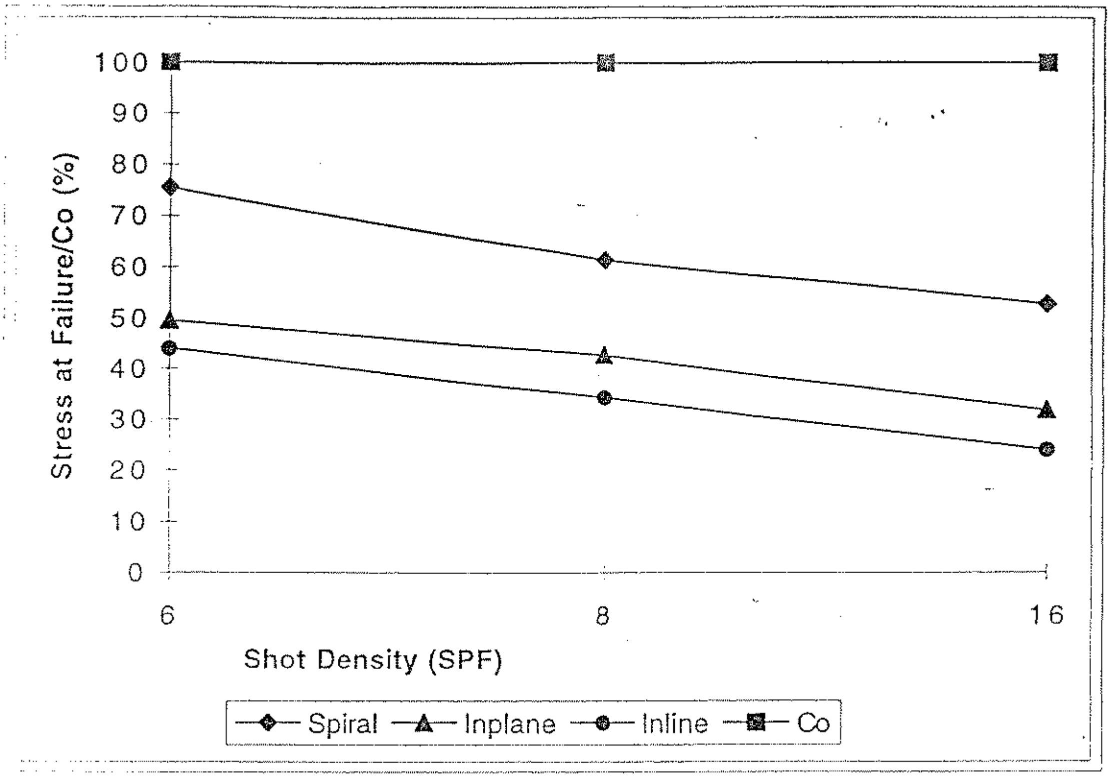

Figure 2a - Overall view of the effects of shot density on wellbore stability

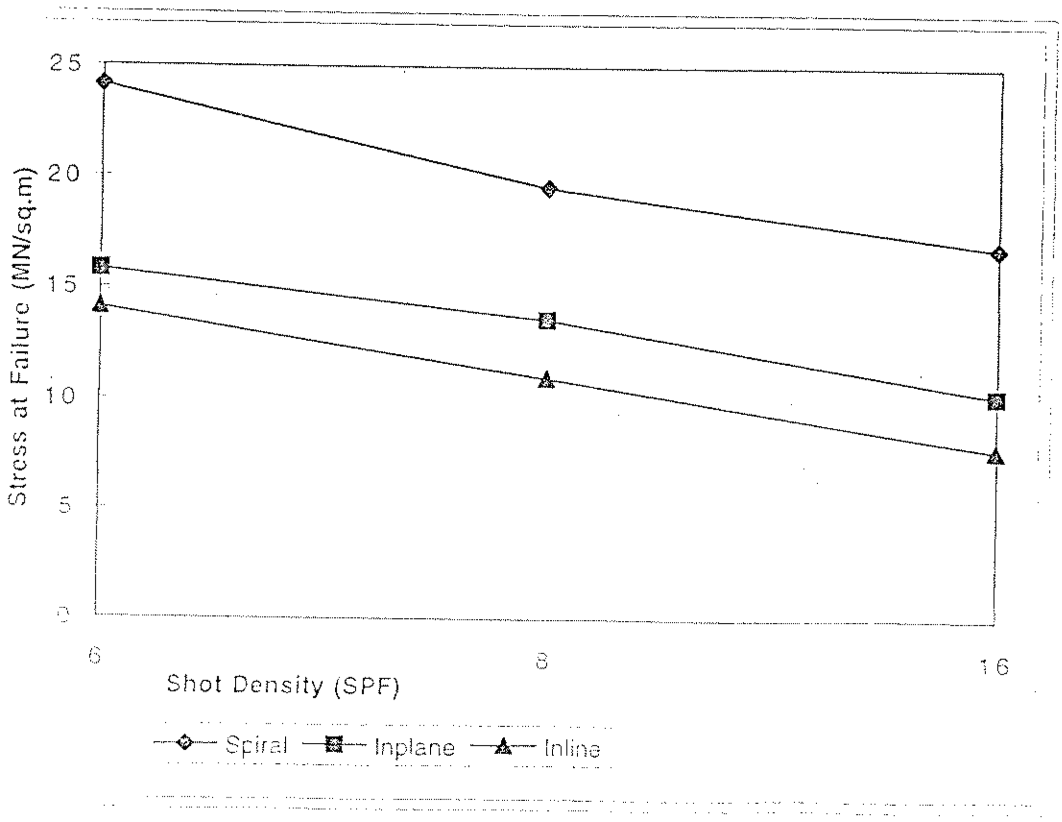

Figure 2b - Relationship between shot density and wellbore stability

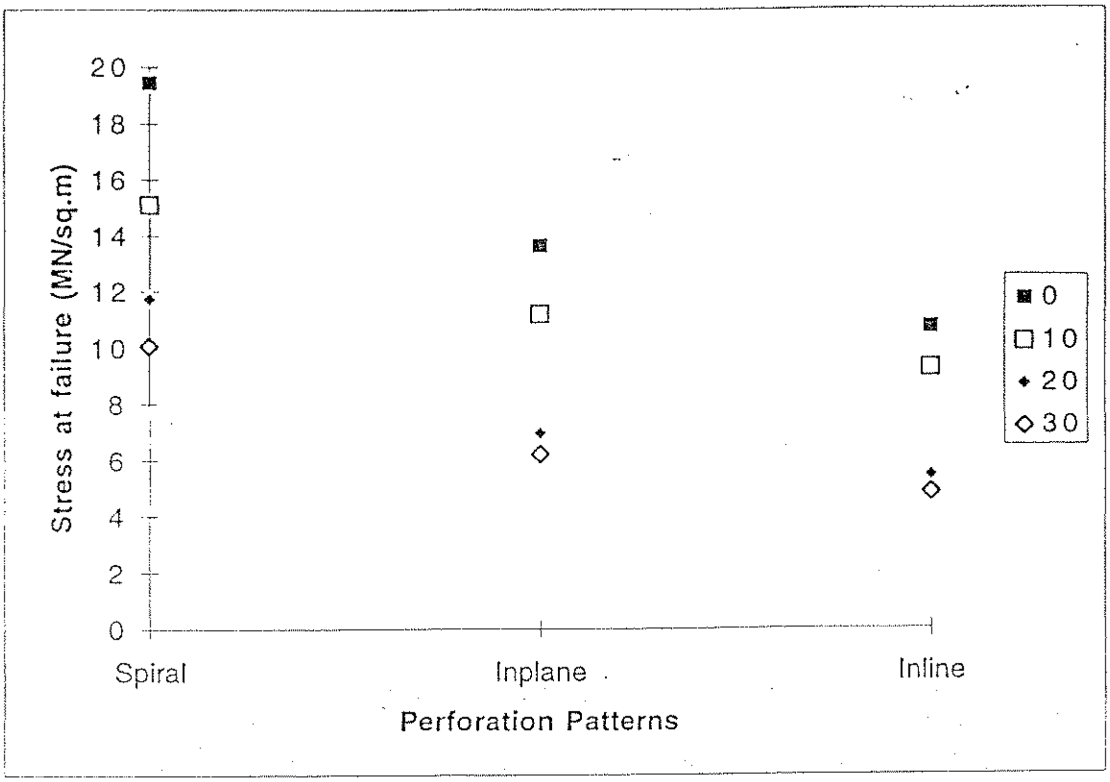

Figure 3a The effects of perforation patterns on wellbore stablity for various wellbore angle

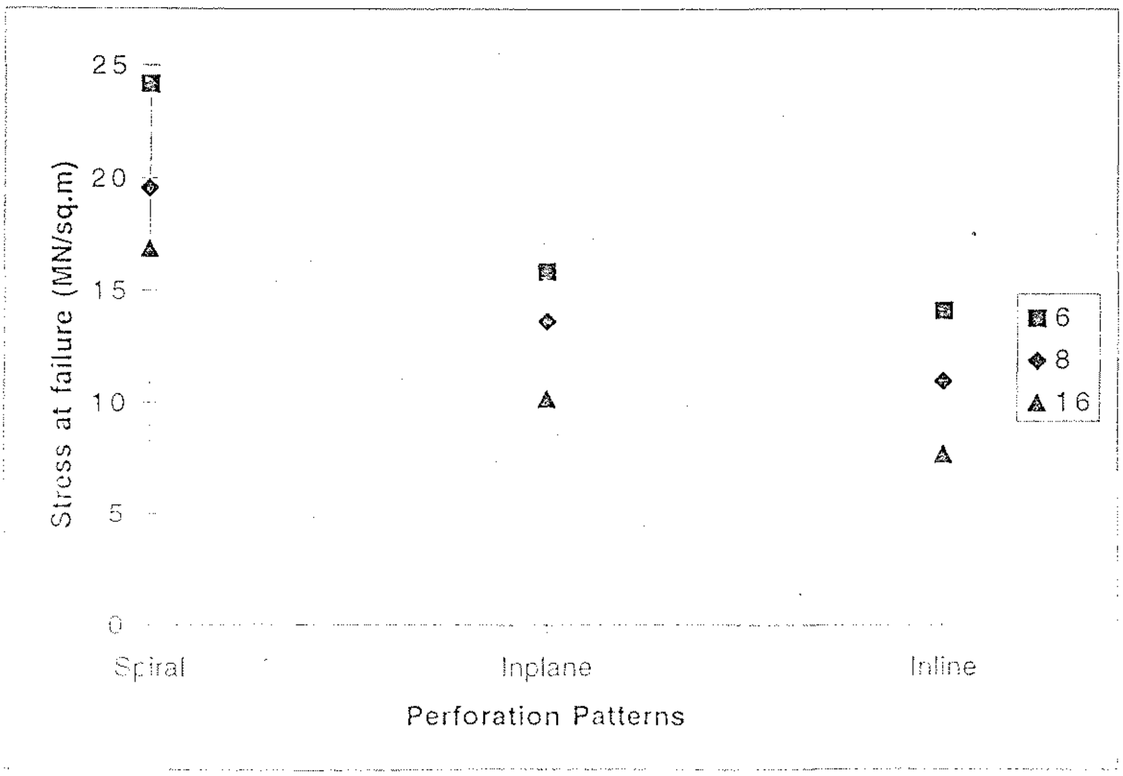

Figure 3b - The effects of perforation patterns on wellbore stablity for various shot densities

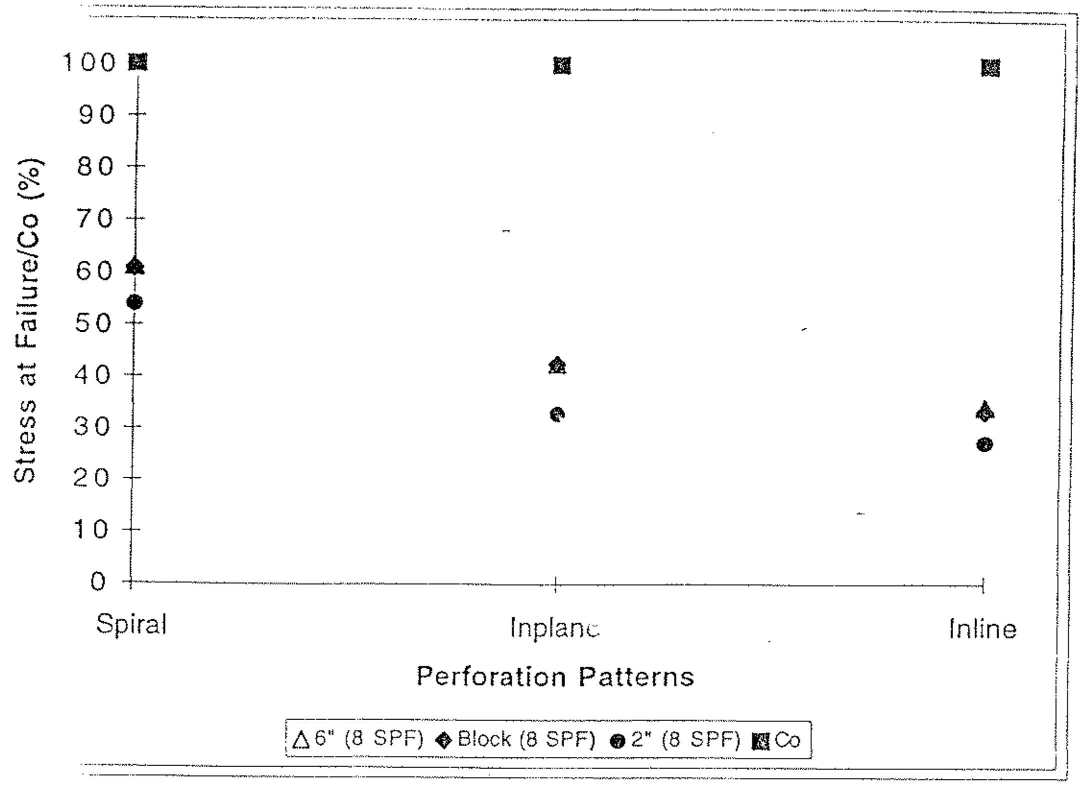

Figure 4a - The effects of perforation pattern on wellbore stability for various model gemetry

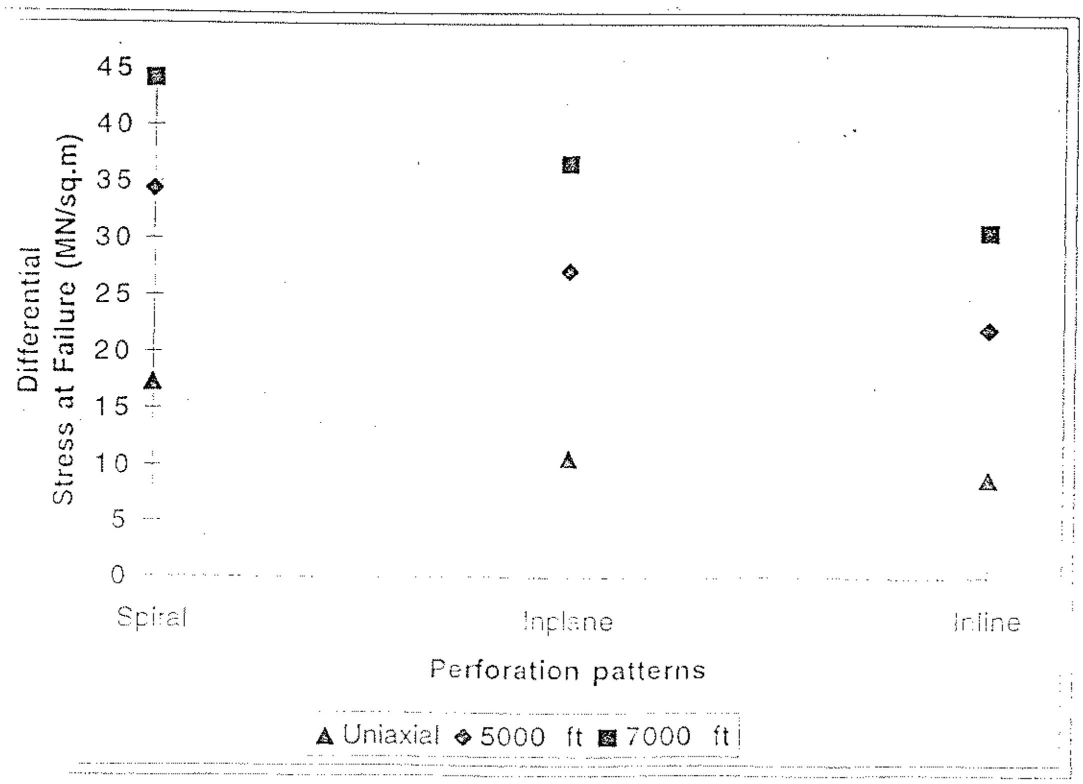

Figure 4b - The effects of perforation pattern on wellbore stability for different confining pressure