Sudan University of science & Tecnology

College of petroleum Engineering & Technology

Departed of Petroleum Engineering

New Computer Program to Predict Sand Production with Case Study

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الاستهلال

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قال تعالى:

"اللَّهُ نُورُ السَّمَوَاتِ وَالْأَرْضِ مَثَلُ نُورِهِ كَمِشْكَاةٍ فِيهَا مِصْبَاحٌ الْمِصْبَاحُ فِي زُجَاجَةٍ الزُّجَاجَةُ كَأَنَّهَا كَوْكَبٌ دُرِّيٌّ يُوقَدُ مِنْ شَجَرَةٍ مُبَارَكَةٍ زَيْتُونَةٍ لَا شَرْقِيَّةٍ وَلَا غَرْبِيَّةٍ يَكَادُ زَيْتُهَا يُضِيءُ وَلَوْ لَمْ تَمْسَسْهُ نَارٌ نُورٌ عَلَى نُورٍ يَهْدِي اللَّهُ لِنُورِهِ مَنْ يَشَاءُ وَيَضْرِبُ اللَّهُ الْأَمْثَالَ لِلنَّاسِ وَاللَّهُ بِكُلِّ شَيْءٍ عَلِيمٌ" **النور** (35)

Dedication

Every challenging work, needs self-efforts as well as guidance of elders especially those who were very close to our heart

Our humble effort we dedicate to our sweet and loving Parents

Whose affection, love and encouragement make us able to get much success and honor. Along with all hard working and respected Teachers.

Acknowledgment

First of all, we want to thanks Allah, because he has graced our life with opportunities that we know are not in our hand or of any human hand, and shows us it's a scientific fact that gratitude reciprocates.

To our parents that who we are looking forward to, to our colleagues and friends and each one helps us through this part of life

To our supervisor Dr. Elham Mohammed Mohammed Khair who works with us hardly in this job to achieve high level of expectation.

Abstract

Sand production is a growing concern in petroleum industry due to its severe problems and the associated technical and operational challenges. In Sudan, due to the relatively high viscose fluids, and the poor consolidated formation, sand is supposed to produce massively from many reservoirs and many problems were found in the fields due to sand production. Predicting sanding onset production allows operators to effectively manage the oil recovery operation in most technical and economical manner. The prediction requires an accurate data and calculations to insure the field critical pressure for sanding; and the most important factor is the rock elastic properties which can be estimated from well logging using Acoustic logging and density logs. In the absence of the shear wave (which is too difficult to measure in unconsolidated sand), the problem is more complicated and the calculation need accurate tools.

A Computer program using MatLab programming language were developed to predict sand production through calculating the critical wellbore pressure based on In-situ stresses and rock mechanical properties using well logging data. The program estimating the shear wave based on Han, Brocher and Greenberg - Castagna empirical correlations. Also the properties can be calculated in the absence of shear wave using Anderson's formula.

The developed program was used to estimate the critical pressure for sanding through a well in Fula north oilfield; the result obtained from Anderson's formula were compared with results using the estimated shear waves and variation were found between the different methods.

التجريد

إنتاج الرمل مصدر للقلق المتزايد في الصناعة النفطية بسبب مشاكله المتعددة وما يرتبط بذلك من تحديات تقنية وتشغيلية. في السودان وبسبب اللزوجة العالية للنفط والتماسك الضعيف للتكاوين فإن الرمل يتم انتاجه بشكل هائل من العديد من المكامن, كما ان العديد من المشاكل وجدت في الحقول بسبب انتاج الرمل. يسمح التنبؤ ببداية انتاج الرمل للمشغلين بالإدارة الفعالة لعمليات استخراج النفط بمعظم الطرق التقنية والاقتصادية. يحتاج التنبؤ لبيانات وحسابات دقيقه للتأكد من الضغط الحرج لإنتاج الرمل في الحقل؛ أهم عامل هو الخواص المرنة للصخور والتي يمكن استنباطها من تسجيلات الآبار باستخدام التسجيل الصوتي والكثافة. في غياب موجة القص (والتي من الصعب جدا قياسها في التكاوين الغير متماسكه) فإن المشكلة معقدة جدا وتحتاج الحسابات الى معدات دقيقه.

برنامج حاسوبي باستخدام لغة برمجة الماتلاب تم تصميمه للتنبؤ بإنتاج الرمل من خلال حساب الضغط الحرج للبئر بناءا على الإجهادات الموضعيه وخواص الصخور الميكانيكية باستخدام تسجيلات الابار. البرنامج يستنبط موجة القص اعتمادا على (Han , Brother and Greenberg-Castagna) وايضا يتم حساب الخواص في غياب موجة القص باستخدام صيغة Anderson.

البرنامج المصمم تم استخدامه لاستنباط الضغط الحرج لإنتاج الرمل خلال بئر في حقل الفولة الشمالي ، النتائج التي تم الحصول عليها من صيغة Anderson , تمت مقارنتها مع النتائج المتحصل عليها باستخدام موجه المقص المستنبطة وتم ايجاد اختلاف بين الطرق المختلفة.

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Nomenclatures

μ = Poisson's Ratio

C_b = Bulk compressibility, Dimensionless

E = Young's Modulus, Psi

G = Shear Modulus, Psi

G_{Rmax}= Gamma ray for Shale

G_{Rmin}= Gamma ray for Clean Sand

K_B = Bulks Modulus

$ø_D$ = Density Porosity uncorrected for shale

$ø_e$ = Effective Porosity

$ø_N$ = Neutron Porosity uncorrected for shale

$ø_{Nsh}$ = Neutron Porosity of adjacent shale

$ø_S$ = Sonic Porosity uncorrected for shale

UCS = The Unconfined Compressive Strength

V_{SH} = Shale Volume, Fraction

Δt_c = Cornpressional Transit Time, µs/ft

Δt_s = Shear Transit Time, µs/ft

Δt_{sh} = Interval Transit Time of Adjacent Shale, µs/ft

ρ = Matrix Density g/cm^3

ρ_{sh} = Density of adjacent shale

$1.34*10^{10}$ is coefficient corrects for units when the transient time is measured in micro Sec/ft and the bulk density is measured in gm/cc.

Chapter 1

Introduction

Sand production (or sanding) is the production of the formation sand alongside with the formation fluids due to the unconsolidated nature of the formation; it refers specifically to sand produced from the load-bearing of the formation. Most of the world’s oil reserves is sandstone formation with heavy oil, where sand production is likely to become an issue during the life of the well. Sand production causes many troubles such as well plugging erodes equipment’s and settles in surface vessels. This problem occurs throughout the world in wells producing from the younger Tertiary Age reservoirs; older and more deeply buried formations are generally expected to be more consolidated. However, some formations have been found on the edge of the Mississippi Delta at 20,000 ft (6,100 m) that are completely unconsolidated.

In weakly consolidated formations, the stresses caused by fluids flowing into the wellbore are often sufficient to cause fine particles to be agitated. In turn, the throttling effect caused by these particles lodging in pore throats near to the wellbore redirects the fluid flow pattern, thereby altering the direction and magnitude of the stress fields. This leads to additional particles being dislodged. Once the destabilizing forces exceed the formation strength, increased sand production follows. As an example, a formation may produce sand-free when producing 100% oil. When water begins to flow through the matrix, the drag resistance of the water phase flowing past the water-wetted sand grains increases, causing the well to start producing sand. Water production also severely reduces a formation's strength due to the dispersion of amorphous bonding materials.

Controlling formation sand is costly and usually involves advanced techniques; and solutions ranging from conventional gravel packs to High Rate Water Packs to Frac Packs to a novel steam sand consolidation completion technique. therefore, field operators need to consider this phenomenon in the field development plans to detect the situations and the conditions of the sanding. The procedure followed by most, to consider whether sand control is required, is to determine the hardness of the formation rock; the rock’s compressive strength and the pressure difference between the reservoir and the well can be directly compared to determine the drawdown limits for specific wells as a first step for Predicting sanding potential.

Predicting sanding onset required to detect, whether conditions for wellbore collapse will be fulfilled in production situation or not. Sand prediction is usually done at the initial stage of reservoir development. It involves development of completion design, reservoir management strategy, perforation strategy, sand monitoring strategy, planning of the surface facilities and field economics. It involves development of laboratory data along with field data in order to understand the formation and knowledge the mechanisms involve in sand production.

1.1 Problem Statement

Sand Production associated with heavy oil was appeared as one of the most common challenges in many Sudanese oilfields sand it causes serious technical and economic problems. The early prediction of sanding potential can offer a good technique to avoid sanding and to manage oil production; the predicting techniques required many information and logging data which may not be available in unconsolidated formations; and this highly complicates the predicting procedures. This study introduces a local computer program for sand production prediction at different conditions using different predicting methodologies; also, case study for sanding potential in Fulla oilfield was discussed.

1.2 Objectives

The main objective of this study is to develop a computer program that calculate the sanding potentials critical pressure for sand failure in unconsolidated formations; which include:

1. To calculate the dynamic rock mechanical properties.
2. To estimate the mechanical properties in the absence of shear wave.
3. To calibrate the static properties with the dynamic one if static properties are available.
4. To predict the critical pressure for rock failure based on a failure criterion.

Chapter 2

Theoretical Background and Literature Review

Most materials have an ability to resist and recover from deformations produced by forces. This ability is called elasticity. The simplest type of response is one where there is a linear relation between the external forces and the corresponding deformations. When changes in the forces are sufficiently small, the response is (nearly) always linear. Thus the theory of linear elasticity is fundamental for all discussions on elasticity. The theory of elasticity rests on the two concepts stress and strain. When a body is subjected to loading it will undergo displacement and/or deformation. the force per unit area of a material is defined as stress; while the strain defined as the amount of deformation in the direction of the applied force divided by the initial length of the material. (Petroleum related rock mechanics,2008)

The rock strength parameters can be derived at specific depths directly from core measurements. Although this is the most accurate method for estimation of rock properties, it is generally expensive and covers small part of the interval while a measurement through the entire section of the reservoir is required to get continuous profiles of rock strength against depth. The geo-mechanical properties can be modeled based on well logging tools such as density and acoustic velocities Gamma Ray, Neutron. Wire-line measurements were converted to mechanical properties using the equations for homogeneous isotropic and elastic rock as follows.

2.1. Static Measurement of Rock Mechanical Properties:

When a stretching force (tensile force) is applied to an object, it will extend. We can draw its force - extension graph to show how it will extend. ***Note:*** that this graph is true only for the object for which it was experimentally obtained. We cannot use it to deduce the behavior of another object even if it is made of the same material. This is because extension of an object is not only dependent on the material but also on other factors like dimensions of the object (e.g. length, thickness etc.) It is therefore more useful to find out about the characteristic extension property of the material itself. This can be done if we draw a graph in which deformation is independent of dimensions of the object under test. This kind of graph is called stress- strain curve.

The application of a force to an object is known as loading. Materials can be subjected to many different loading scenarios and a material's performance is dependent on the loading conditions. There are five fundamental loading conditions; tension, compression, bending, shear, and torsion. Tension is the type of loading in which the two sections of material on either side of a plane tend to be pulled apart or elongated. Compression is the reverse of tensile loading and involves pressing the material together. Loading by bending involves applying a load in a manner that causes a material to curve and results in compressing the material on one side and stretching it on the other. Shear involves applying a load parallel to a plane which caused the material on one side of the plane to want to slide across the material on the other side of the plane. Torsion is the application of a force that causes twisting in a material.

If a material is subjected to a constant force, it is called static loading. If the loading of the material is not constant but instead fluctuates, it is called dynamic or cyclic loading. The way a material is loaded greatly affects its mechanical properties and largely determines how, or if, a component will fail; and whether it will show warning signs before failure actually occurs. Stress is defined as the force per unit area of a material.

Stress = force / cross sectional area

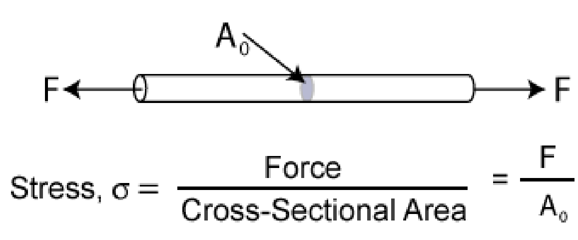
$$\sigma = \frac{F}{A} \quad (N/m^2) \tag{2.1}$$

Where: -

σ = stress

F = force applied.

A= cross sectional area of the object.



Strain is the fractional deformation produced in a solid body when it is subjected to a load. Or is the ratio of the change in length to the initial length

$$\varepsilon = \frac{\Delta L}{L} \tag{2.2}$$

It is the response of a system to an applied stress. When a material is loaded with a force, it produces a stress, which then causes a material to deform. Engineering strain is defined as the amount of deformation in the direction of the applied force divided by the initial length of the material. This results in a unit less number, although it is often left in the unsimplified form, such as inches per inch or meters per meter. For example, the strain in a bar that is being stretched in tension is the amount of elongation or change in length divided by its original length. As in the case of stress, the strain distribution may or may not be uniform in a complex structural element, depending on the nature of the loading condition.

In a conventional triaxial compression test, a cylindrical core sample is loaded axially to failure, at constant confining pressure. Conceptually, the peak value of the axial stress is taken as the confined compressive strength of the sample. In addition to axial stress, axial and radial strains may be monitored during this test, to determine basic elastic constants (Young’s Modulus, E, and Poisson’s ratio, ν). In view of the variability of rock properties, when adequate samples are available, repeat testing may be merited to determine average values. If triaxial testing is performed at several confining pressures, and preferably if unconfined compression and tensile test data are available, a representative failure locus can be constructed. The selected confining pressures for triaxial testing are generally spread over a range from very low to beyond the maximum anticipated in-situ effective stress conditions. Measurements can be performed at in-situ temperature and pore pressure can be applied. Testing Equipment and Setup consist of a triaxial compression system which is used to perform this type of testing. Axial load is applied with a servo-controlled actuator. Confining pressure and pore pressure are hydraulically generated. Axial force up to 1.5 x 106 lbf can be applied to samples up to ten inches in diameter. Axial stress is monitored with a load cell. Confining pressure and pore pressure are monitored with conventional pressure transducers. Axial and radial strains are measured using cantilever type strain transducers. When a rock is brittle, or large deformation is expected, LVDTs may be used instead of cantilever devices. Occasionally, strain gages are attached directly to the sample. Tests can be conducted at temperatures up to 500° F. Inflow or outflow of pore fluid is measured with accumulators (or burettes with pressure transducers, if the test is drained to atmosphere). Uniaxial test includes the following steps:

In an unconfined compression test, a cylindrical core sample is loaded axially to failure, with no confinement (lateral support). Conceptually, the peak value of the axial stress is taken as the unconfined compressive strength of the sample. In addition to axial stress, axial and radial strains may be monitored during this test, to determine elastic constants (Young's Modulus, E, and Poisson's ratio, v). In view of the variability of rock properties, when adequate samples are available, repeat testing may be merited to determine average values. Testing Equipment and Setup consist of loading frames which and can be used to perform this type of testing. Axial load is applied with a servo-controlled hydraulic actuator. Available actuators can deliver up to 1.5 x 106 lbf. Axial stress is monitored with a load cell. Axial and radial strains are measured using cantilever type strain transducers. When a rock is brittle, or large deformation is expected, LVDTs may be used instead of cantilever devices. Occasionally, strain gages are attached directly to the sample. Tests can be conducted at representative reservoir temperatures.

Young’s modulus is the ratio of the longitudinal stress to the longitudinal strain when a solid body is loaded by longitudinal stress within the elastic limit.

This is because stress is proportional to strain. The gradient of the straight-line graph is the Young's modulus, E

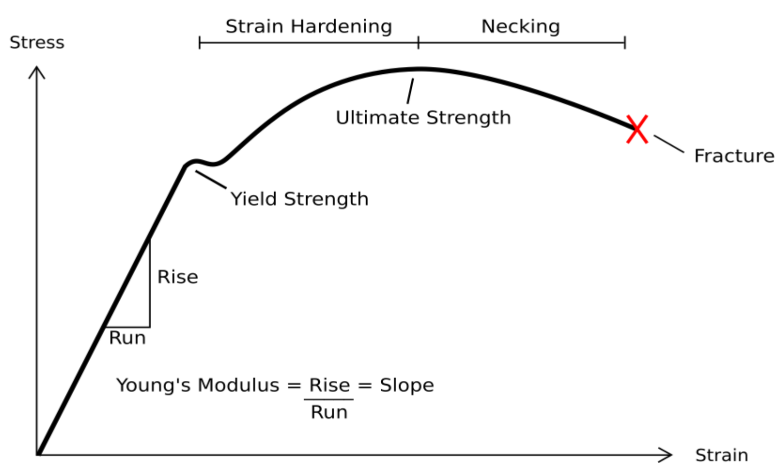


Figure 2.1 Strain VS Stress

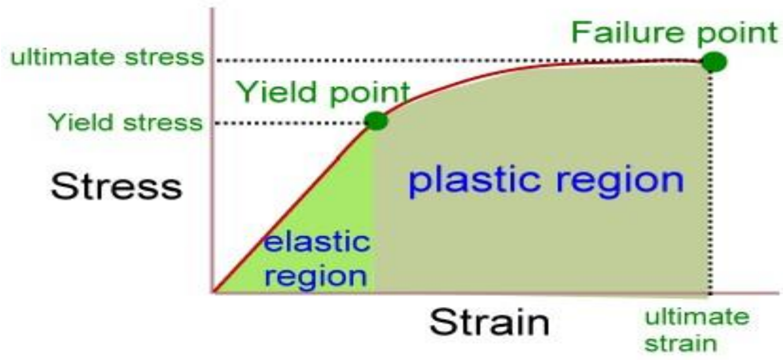


Figure 2.2 Strain VS Stress

The linear relationship between applied stresses and resulting strains is known as Young's modulus:

$$E = \frac{\text{strees}(\sigma)}{\text{strain}(\varepsilon)} \quad (\text{N/m}^2) \tag{2.3}$$

Poisson's ratio is the ratio of lateral strain to axial strain, that is:

$$\mu = \frac{\text{lateral strain}}{\text{longitudinal strain}} \quad 0 \leq \mu \leq 0.5 \tag{2.4}$$

Shear modulus is the ratio of shear stress to shear strain.

$$G = \frac{\text{shear stress}}{\text{shear strain}} \tag{2.5}$$

On the other hand, Bulk modulus is the ratio of the applied stress to the volumetric strain when a solid body is subjected to uniform stress throughout its surface, that is:

$$K = \frac{E}{3(1-2\mu)} \quad (\text{N/m}^2) \tag{2.6}$$

2.2 Laboratory Testing:

2.2.1 Uniaxial compression strength (UCS):

The uniaxial compression tests provide a simple and effective way to characterize a material's response to loading. By subjecting a sample to a controlled tensile or compressive displacement along a single axis, the change in dimensions and resulting load can be recorded to calculate a stress-strain profile. From the obtained curve, elastic and plastic material properties can then be determined.

For uniaxial tests, the displacement is typically held at a constant rate, and displacement and resulting load are recorded. The load is measured by a series of strain gages, or “load cell,” while the displacement can be recorded as displacement of the crosshead

With the sample geometry, a stress-strain curve can then be generated from the recorded load and displacement. A typical stress-strain profile for a ductile metal resembles the following.

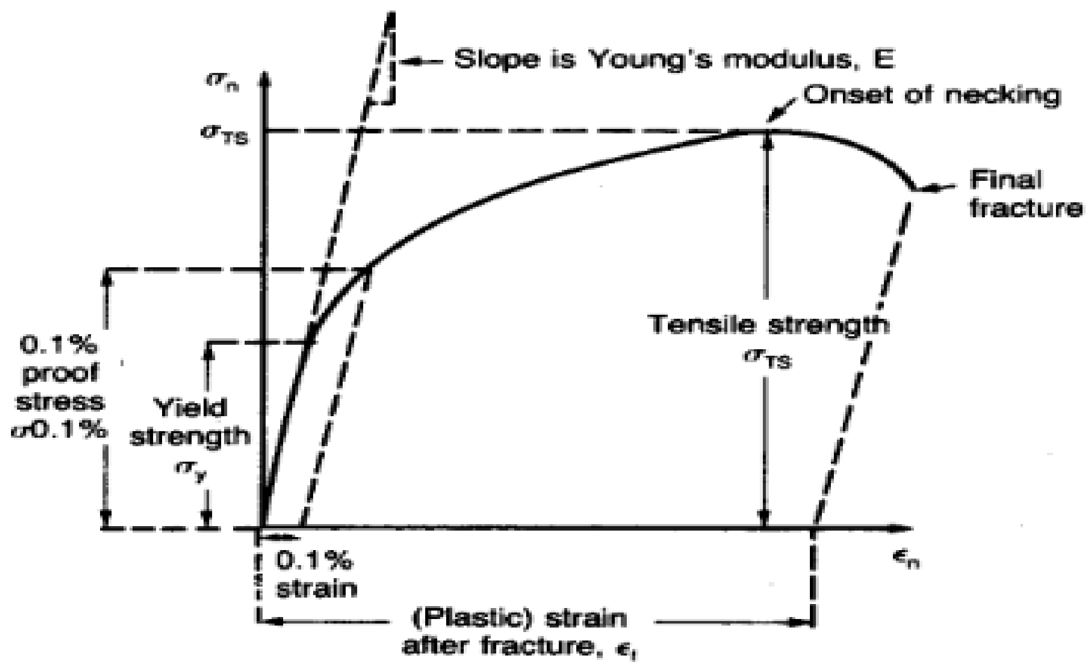


Figure 2.3 UCS

(Uniaxial Tension and Compression Testing of Materials, lab report, 2013)

2.3 Sand Production Prediction Methods

It is important to know under what conditions a well produces sand to predict if the well will require a method of sand control.

The most critical factors to determine the sand production potential of a reservoir formation are:

(1) Formation strength.

(2) In-situ stresses.

(3) Production rate.

Sand prediction is usually done at the initial stage of reservoir development. Some technique uses a correlation between sand production well data and field operational parameters in prediction. usually one or a couple of parameters (such as Porosity, drawdown or flowrate, compressional slowness etc.) are used to show the potential of producing sand.

It was presented in the literature that sonic measurements are conveniently used to determine the elastic properties, which are called dynamic elastic properties. Logging models are typically too high and have a very little success; hence calibration to static measurements on selected core samples is required. The calibrated log properties can be used with some correlations to estimate formation strength and failure conditions. The way to calculate the dynamic elastic modulus is to use the dipole sonic and density log; when these variables are available, the solution is at hand; however, share velocity is difficult to evaluate in unconsolidated sand and an alternative approach is necessary to estimate rock properties. Historically many methods are available for calculating share velocity depending on compressional velocity. Gardner and Harris (1968) showed that Vp/Vs values > 2.0 are characteristic of water saturated unconsolidated rocks, and values < 2.0 indicate either well-consolidated rock or the presence of gas in unconsolidated sands. Gregory (1976) confirmed this relationship between the velocity ratio and consolidation and suggested the dependence of velocity ratio on porosity. Hornby and Murphy (1987) and Murphy et al. (1993) showed that (1) the velocity ratio increases as the clay content increases; (2) the Biot-Gassmann theory (BGT) accurately predicts the velocity ratio of unconsolidated water-saturated sand with respect to effective pressure. Han et al. (1986) showed that the velocity ratio increases linearly with clay content and porosity the above mentioned method can be summarized as follows:

Pickett et al. (1963):

$$\frac{Pwave}{Swave} = 1.6 \quad (\text{for low sand porosity})$$
$$\frac{Pwave}{Swave} = 1.8 \quad (\text{for high sand porosity}) \qquad (2\text{-}7)$$

Gardner and Harris (1968):

$$\frac{Pwave}{Swave} \succ 2.0 \quad (\text{for Water saturated unconsolidated rock})$$
$$\frac{Pwave}{Swave} = 2 \quad (\text{Water saturated consolidated or Gas saturated unconsolidated rock}) \qquad (2\text{-}8)$$

Han (1986) for clean sand:

$$Vs = 0.79Vp - 0.79$$
$$Vs = 5.97 - 7.85\phi \qquad (km/s) \qquad (2\text{-}9)$$
$$Vp = 4.03 - 5.85\phi$$

Han (1986) for shaly sand

$$Vs = 0.7197Vp - 0.3235$$
$$Vs = 3.57 - 4.57\phi \qquad (km/s) \qquad (2\text{-}10)$$
$$Vp = 5.41 - 6.35\phi$$

Other correlations are available in the literature for other cases; (Castagna et al. (1985, 1993),Mavko et a. (1998),Brocher et al, (2005), (2008)).

It is clear that the only tool that responds to the elastic properties of the formation is the dipole sonic log, unfortunately the share wave is not available for most of the friable sediments, hence alternate approach has been to determine indirectly by a correlation to other parameter.

Poisson’s Ratio was related to shaleness by Anderson et al. (1973), Poisson’s Ratio was calculated as:

$$\mu = 0.125q + 0.27 \qquad (2.11)$$

$$q = \frac{\phi_S - \phi_D}{\phi_S} \qquad (2.12)$$

This is empirical correlation is valid only for un-compacted Gulf Mexico sand, more studies are required to confirm the applicability of this method in other area, however the equation was widely used to calculate the formation strength and predicting sanding in Gulf of Mexico sands

(Tixier el At (1975), Ghalambor el At (2002)), it was also used in Gulf of Suez Basin in Egypt (Walid et al (2006)).

Experimental methods were presented in literature for modeling rock strength with the empirical core loge correlations [Henry et al, 2003; Morales et al, 1993]. Unfortunately, the application of those models is only valid on the conditions in which they are derived. Application for any other conditions need verified before it used

Empirical methods have the advantage of being directly related to field data and can use easily measurable parameters to provide routine and readily understandable method to estimate sanding risk on a well by well basis.

Veeken et al, (1991) gave a relationship between the near-wellbore vertical effective stress (σv,w) and the TWC collapse pressure (σtwc) from many experiments carried out on friable-consolidated sandstone.

$$\sigma_{v,w} = 0.86 \times \sigma_{twc} \qquad (N/m^2) \qquad (2.13)$$

The results from TWC can however be influenced by sample size/hole size ratio of the hollow cylinder.

Flow rate only plays a role in weak and unconsolidated rocks and rocks under excessive stresses, increase in drawdown causes sand production increase, due to changes in boundary conditions (i.e., stresses of fluid flow rate).

Exxon 1970s, conducted an experiment to establish the relationship between the rock compressive strength and sand production potential of the rock.

The studies revealed that the rock failed and began sand production when the fluid flow stresses exceeded the formation compressive strength.

Sand production or rock failure will occur when the drawdown pressure is 1.7 times the compressive strength. This relationship holds for consolidated formations. Non-destructive test like impact and scratch test are also used for measuring the strength properties of a rock.

The main disadvantage of this approach is the amount and availability of core samples needed, time and cost for preparing the core, conducting the experiments, processing and analyzing the data from the test.

Yin et al. (2004) established an analytical solution for shear failure sanding criterion in a perforation tunnel by assuming Mohr-Coulomb failure criterion and linear elastic–perfectly plastic material.

$$\frac{P}{C} = (1 - \upsilon)\left[\frac{2\sigma H}{C} - \frac{(1-2\upsilon)P}{(1-\upsilon)C} - 1\right] \quad (2.14)$$

Sanding occurs when the left-hand side is less than the right-hand side. Yin et al. (2004) also derived a pore elastic solution for perforation tip failure that results in higher allowable drawdown, so we ignore them. Sanding occurs when the left-hand side is less than the right-hand side.

Zhang et al., 2000 developed a simple and efficient approach to evaluate formation strength. They found out to construct a universal failure envelope the only parameter needed is the critical pressure. Conventional logs data (compressional wave velocities) can be used to obtain the failure envelope of a sandstone formation. The generality of their observation is still explored. The failure envelope is constructed from the Pc determined.

$$\mathrm{P_c} = 10.086 \times \ln \frac{(6.789)}{12.322 - \mathrm{V_p}} \qquad \text{(psi)} \quad (2.15)$$

Kim, (2010) developed a predictive model to provide an assessment of the sanding potential of a well based on reservoir properties, completion geometry as well as operational parameters.

Several experimental cases, taken from the literature, were simulated. The model-generated results were compared with the experiments. It was found from sensitivity studies that material and reservoir property changes can have different implications in sand production behavior. As expected, increasing mechanical stresses resulted in a more sand production. This is due to the enlargement of the failed sand region at a higher stress level, making more material available for erosion. An increase in flow rate or pore pressure gradient increases the hydrodynamic force allowing it to overcome the force holding the disaggregated sand in place.

Mohammadreza et al., (2014) assumed that sand production initiates due to formation shear failure around the wellbore, an analytical sand prediction model using Mogi-Coulomb failure criterion was presented for determination of maximum sand free drawdown. In this model, by changing the drawdown and wellbore trajectory, sand failure will be predicted by comparing the sand strength to the failure criteria. Then a computer program is developed to obtain the critical bottom hole pressure that cause wellbore collapse. This program using several input parameters, including: in situ stresses, rock strength parameters (cohesion, friction angle and Poison ratio), initial and current formation pressure and Biot's pyroclastic constant. In production condition wellbore pressure decrease from initial formation pressure until the condition for wellbore collapse satisfied. These analyses have been done for different well inclination ($i = 0$ to $i = 90$) and azimuth ($\alpha = 0$ to $\alpha = 180$) in several cases of in situ stress regimes. The results show that in different in situ stress regimes the inclination and azimuth have a significant role in wellbore stability during production.

M. P. Tixier et.al 1975 provides a mechanical-properties log method which provides a quantitative means for identifying sands that are strong enough to produce oil and gas without any form of sand control. The method is based on a correlation of in-situ strength with the dynamic elastic moduli computed from sonic and density logs.

There is a considerable evidence (gather from laboratory measurement) showing a good correlation between intrinsic formation strength and the dynamic elastic constant determined from sonic and density measurement using alternative techniques.

Most of their experience has been in Tertiary sediments in the Gulf of Mexico at depth between 7000 and 13000 ft. A good correlation exists between the computed dynamic elastic module and sands ability to withstand production without any form of sand control.

Using the stress-strain relationships, elastic constants may be determined from a specimen of the rock under load in a testing machine from the practical standpoint of evaluating friable sands, several important considerations favor the use of the dynamic measurements obtained from the well logs. First, the measurements are made in situ and, therefore, should be fairly representative of the con- fining stress the formation will experience at completion. Conversely, the static measurement requires the recovery of an unaltered core, presumably representative of the formation, and the restoration of the core to an in-situ stress state. Second, the dynamic measurements obtained from well logs provide continuous curves that reveal changes and trends. There- fore, even though the absolute value of a dynamic elastic constant may appear high, its relative values from one sand to the next should have interpretative value.

In the presence of sonic-compressional and shear transit times with the bulk density, the elastic constants can be obtained from the basic relationship for homogeneous, isotropic water-bearing formations. However, in soft Tertiary formations the value of Δts is difficult to evaluate, and an alternative approach is necessary. Anderson et al. have previously presented an empirical relationship, discussed in Appendix A, relating Poisson's ratio to shaliness for unconsolidated Gulf Coast sands. This relationship suggested that a workable approach might be to write the equations for the elastic constants in terms of Poisson's ratio in a form independent of Δts.

The other modules or mechanical properties can then be calculated in the absence of shear wave from the various equations.

The empirical relation between μ and q may or may not be apply to condition other than those for which it was derived (uncompact Gulf coast sands). Most studies are needed to confirm the applicability of the relation in other areas.

The presence of hydrocarbons, particularly gas, increases the compressional transit time (Δtc) of a compacted formation. Hydrocarbons also reduce formation density The combined effect is to decrease the value of the shear modulus and increase the value of the bulk compressibility that would be computed from the uncorrected logs. These hydrocarbon effects have no relation to for-motion strength. It is therefore important that and values in uncompact formations be corrected for the presence of gas or light hydrocarbons. This is done to ensure Measuring Mechanical Properties is accurate.

Karl A. Lehne 2011Calculation of geomechanical elastic rock parameters based on the petrophysical logs by addressing two main parts. The first part describes the petrophysical evaluation of well 7121/4-F-2 H drilled in Snøhvit field using Interactive Petrophysics version 3.4 from Schlumberger. A numerical MATLAB code is also developed and explained in the second part to demonstrate the application of well logs and failure model for prediction of sand production and calculation of critical well bore pressure. Two sets of well log data from Snøhvit and Goliat fields are used to show the applicability of the generated code

The quality of pure well log data is assessed based on calliper log and consistency between density, neutron, sonic, resistivity and gamma ray logs. The well log data are not affected by well bore conditions (wash out) and the quality are good. A numerical MATLAB code is also developed and explained to demonstrate the application of well logs and failure model for prediction of sand production and calculation of critical well bore pressure. A numerical

MATLAB code has been developed using Mohr-Coulomb failure model and calculated rock elastic parameters to predict the critical well bore pressure at which sand production is less probable. The difference of the critical well bore pressure at any depth from the formation pore pressure refers the allowable draw down pressure that can be imposed for the production without sand production. The negative values of P_c show the well will not affect by sand production at any draw down pressure and production rate.

Find out that The sanding problem can be happened in production wells as well as injection wells. The dynamic of reservoir parameters strongly affects the failure model and prediction of sanding problem onset. Parallel computing and coupling of failure model and reservoir rock and fluid behaviors should be implemented for field development planning in enhanced oil recovery methods such as CO2 injection.

Recommended to use non-linear failure model as a base for prediction of sand production. Because The certainty of the discussed model is highly dependent to the linear assumption of failure envelope model. snice Mohr-coulomb linear failure model is coupled to the elastic rock parameters calculated from well log data and sand failure situation is predicted. It is necessary to calibrate the log data and model to the uniaxial and triaxial rock strength laboratory results.

Hossein Rahmati et al (2013) Many researchers have used sanding criteria based on erosion mechanics to build models that predict the sand production phenomenon. This approach usually requires constitutive laws to be calibrated against laboratory tests to provide accurate results. It has been shown that these models are more suited for weakly consolidated rocks since the erosion mechanism dominates sand production in this situation. For well-consolidated rocks it is thought models based on shear or tensile failure coupled with an erosion criterion could provide useful results.

The literature possibly concludes that the best performing constitutive law is a combined isotopic and kinematic hardening model since this can predict failure by compression, shear and tension but also accounts for the hysteresis effect of fluctuating production rates and routine start-up/shut-down procedures.

Continuum models have been shown to require fine meshes around well perforations in order to accurately model the mechanical processes; this is very demanding for 3D models to achieve due to computing limitations. The bulk of modeling is completed in 2D for this reason, using axisymmetric and plane strain assumptions. The 2D approach has had very limited success in producing reliable results. A model that accurately captures the sand-arch phenomenon at the well perforation is yet to be developed. This is due to the complex geometry involved and is thought to be best suited to DEM modeling. The literature has indicated that more research into the micro-material parameters and the calibration procedures of DEM models requires better understanding in order to model the rock in situ. Current models have not taken into account possible chemical effects and de-bonding of the cementation due to the wash out effect from the fluid.

Chapter 3

Mathematical Models

In order to achieve the objectives of this study based on the available logging data, a new computer program with Matlab programming Language was performed; various techniques were applied and the required field parameters were estimated following the methodologies and procedures described in the following sections

3.1 Shear Wave Calculations

The essential data is shear wave value came from sonic log, however it is often un available in most unconsolidated formation. This program uses many alternative methods to estimate shear wave or to calculate the rock mechanical properties in the absence of shear wave.

3.1.1 Greenberg-Castagna Formula

A. Greenberg-Castagna formula (1992) combined relations for various lithologies to provide a unified empirical transform in multi mineral brine-saturated rock composed of sandstone, limestone, dolomite, and shale, that related the Compressional and Shear wave velocities as follows:

$$Vs = 0.8042 \times Vp - 0.85 \qquad \text{(Km/s)} \qquad (3.1)$$

3.1.2 Brocher (2008)

derived a non-linear empirical correlation for prediction of shear wave velocity in sandstone, carbonate and shale rocks

$$Vs = 0.7858 - 1.2344 \times Vp + 0.7949 \times Vp^2 - 0.1238 \times Vp^3 + 0.0064 \times Vp^4$$

(Km/s) (3.2)

3.1.2 Han's Relationship (1986):

Han used an extensive sandstone experimental dataset with large ranges of porosity and clay content variation to obtain Shear wave velocities as follows:

$$Vs = 07197 \times Vp - 0.3235 \ \text{(Km/s)} \qquad (3.3)$$

3.2 Sanding Potential Calculations

To detect the sanding potential of the formation, various methods can be followed and all are depending on Rock Mechanical properties.

3.2.1 Shear Modulus (G) and Bulk Compressibility

Sand production will occur if the ratio between Shear Modulus (G) and Bulk Compressibility (CB) become less than $(7 \times 10^{11})\ psi^2$(Tixier et al, 1975)

$$G = 1.3 \times 10^{10} \left(\frac{\rho b}{\Delta ts^2}\right) \tag{3.4}$$

$$K = 1.34 \times 10^{10} \times \rho b \times \left(\left(\frac{1}{\Delta tc^2}\right) - \left(\frac{4}{3\Delta ts^2}\right)\right) \tag{3.5}$$

$$CB = \frac{1}{Kb} \tag{3.6}$$

3.2.2 B-Index

(Application of Logging Data in Predicting Sand Production in Oilfield

,2013)**:**

Sand production will occur if the value of B-Index become less than (2×10^4) Mpa

$$B = \left(\frac{Ed}{(3\times(1-\mu d)}\right) + \frac{4}{3} \times \left(\frac{Ed}{2\times(1-\mu)}\right) \tag{3.7}$$

$$Edynamic = \frac{\rho b \times \Delta ts\left(3\Delta tc^2 - 4\Delta ts^2\right)}{\Delta tc^2 - \Delta ts^2} \tag{3.8}$$

$$Vdynamic = \frac{\Delta tc^2 - \Delta ts^2}{2\times(\Delta tc^2 - \Delta s^2)} \tag{3.9}$$

3.2.3 Schlumberger Sand Production Index (SR)

(Application of Logging Data in Predicting Sand Production in Oilfield,2013)**:**

Sand production will occur if the value of (SR) become less than 5.9×10^7 Mpa

$$SR = K \times G = \frac{Ed}{3\times(1-\mu d)} \times \frac{Ed}{2\times(1+\mu d)} \tag{3.10}$$

3.2.4 Combined Modulus

Combined Modulus was appeared as an active tool for sand production prediction (Stein and Hilchie -1972).

$$Ec = \frac{9.94\times10^{8}\rho r}{\Delta tc^{2}} \quad (3.11)$$

Stein and Hilchie stated that if the combined modulus is less than or equals to 1.5*106 Psi, the well will produce sand under any flow rate; for K value between 1.5*106 – 3*106 Psi the well cannot produce sand blew specific flow rate; however, if the modulus is greater than 3*106 Psi the well can produce the fluid at any desirable rate without sanding.

3.3. Rock Mechanical Properties Calculations

Using Anderson formula Rock Mechanical Properties was Calculate in the absence of shear wave as follows:

$$\mu = 0.125q + 0.27 \quad (3.12)$$

$$q = \frac{\emptyset s - \emptyset d}{\emptyset s} \quad (3.13)$$

$$G = 1.34*10^{10} \frac{A\rho_B}{\Delta t_c^{\,2}} \quad (3.14)$$

$$K = \frac{B\times\rho b}{\Delta tc^{2}} \quad (3.15)$$

$$A = \frac{1-2\mu}{2\times(1-\mu)} \quad (3.16)$$

$$B = \frac{1+\mu}{3\times(1+\mu)} \quad (3.17)$$

$$E = 2\times G\times(1+K) \quad (3.18)$$

When the acoustic waves and density log is available the calculation was done using the general following formula:

$$E = \frac{\rho\ 3\Delta t_s^{\,2} - 4\Delta t_c^{\,2}}{\Delta t_s^{\,2}(\ \Delta t_s^{\,2} - \Delta t_c^{\,2}}\times 1.34\times10^{10} \quad (3.19)$$

$$K = \rho\times\frac{3\Delta t_s^{\,2} - 4\Delta t_c^{\,2}}{(\ 3\Delta t_s^{\,2} - \Delta t_c^{\,2}}\times 1.34\times10^{10} \quad (3.20)$$

$$G = \frac{\rho}{\Delta {t_s}^2} \times 1.34 \times 10^{10} \tag{3.21}$$

$$\mu = \frac{1}{2}\left[\frac{\Delta {t_s}^2 - 2\Delta {t_c}^2}{\Delta {t_s}^2 - \Delta {t_c}^2}\right] \tag{3.22}$$

3.4 In-situ Stresses Calculations

Calculation of stresses around the wellbore

$$\sigma_v = g\int_0^D \rho dz \tag{3.23}$$

$$\sigma_v^{/} = \sigma_v - \alpha P \tag{3.24}$$

σ_1, σ_2 are the maximum and minimum horizontal stresses respectively and can be calculated as:

$$\sigma_H{}^{/} = \frac{v}{1-v}\sigma_v{}^{/} \tag{3.25}$$

$$\sigma_H = \frac{v}{1-v}(\sigma_v - \alpha p) + \alpha p \tag{3.26}$$

$$\sigma_H = \frac{v}{1-v}\sigma_v + (\frac{1-2v}{1-v}\alpha P) \tag{3.27}$$

The effective rock stress (stress that produces a deformation in the rock skeleton) can be obtained for Non-Penetrating fluid as follows:

$$\sigma_z = \sigma_V + 2\mu(\sigma_1 - \sigma_2) - \alpha P \tag{3.28}$$

$$\sigma_\theta = 3\sigma_1 - \sigma_2 - P_{wf} - \alpha P \tag{3.29}$$

$$\sigma_r = P_{wf} - \alpha P \tag{3.30}$$

Unconfined compressional strength can be calculated from:

$$UCS = (0.008 \times E \times Vcl) + \left(0.0045 \times E \times (1 - Vcl)\right) \tag{3.31}$$

Initial shear strength can be calculated by:

$$\tau i = \frac{0.025 \times UCS}{10^6 \times Cb} \tag{3.32}$$

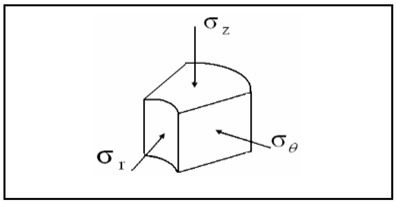


Figure 3.1 Principal Stresses on a Rock Element at the wellbore Interface

Biot's constant is factor relating the extent of the compressibility of the dry skeletal frame to the rock material (Biot, 1941), it is defined as:

$$\alpha = 1 - (K_{sk} / K_s) \tag{3.33}$$

The Biot's constant can be obtained experimentally, one approach to determine Biot's constant is that presented by Krief et al (1991)

$$\alpha = \left[1 - \frac{(1-\phi)^3}{(1-\phi)} \right] \tag{3.34}$$

3.5 Failure Envelope and Strength Parameters

According to the Mohr Coulomb failure criterion

$$\sigma_1 = \mathrm{C}_0 + \sigma_3 \tan^2 \beta \tag{3.35}$$

The Cohesion strength [C_0] is defines as follows:

$$C_o = \frac{1}{2} UCS \cos \beta \tag{3.36}$$

$$\beta = \frac{\pi}{4} + \frac{\theta}{2} \tag{3.37}$$

The Mohr's Circle Theory, as applied to rock failure assumes that the key stresses are the radial (σ_r) and tangential (σ_θ) stresses, which are in the horizontal plane. The technique assumes that the effect of vertical stress is negligible. Applying this theory and solving failure equation for wellbore critical pressure, Henry et al, 2003 presented the following formula:

$$P_{wc} = \frac{\sigma_H - \alpha / 2P_o \left[1 - \left(\frac{v}{1-v} \right) \right] - \tau_i * \cot \beta}{\left[1 - 0.5\alpha \left(1 - \frac{v}{1-v} \right) \right]} \tag{3.38}$$

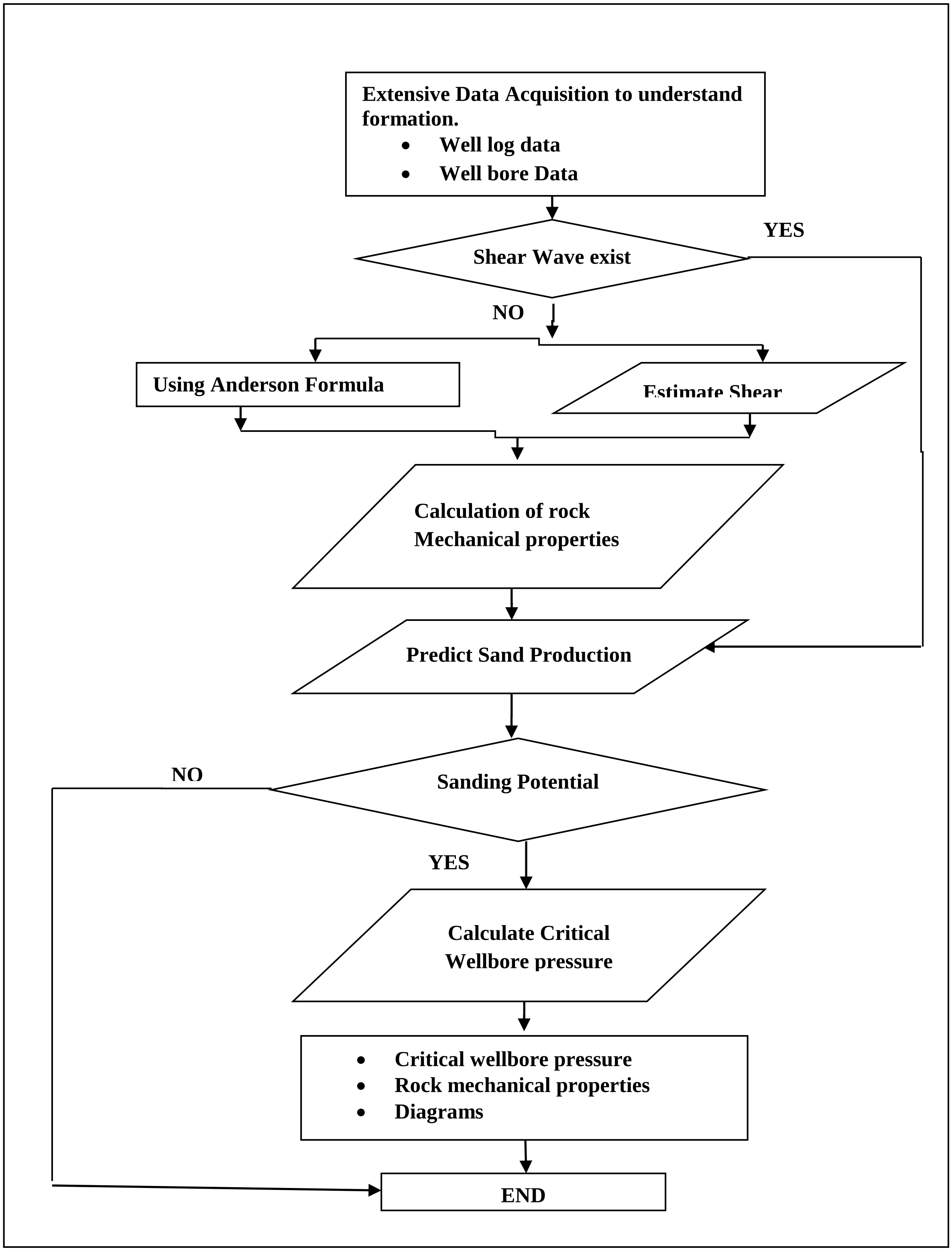


Fig 3.2 Flow Chart of the Computer Program

Chapter 4

Results and Discussion

Using the mathematical models and the procedures described in chapter 3, a new Sand Production Prediction Software (SPPS) was developed with different user interface to help the user in getting result as quick as possible. The designed program uses well logging information to calculate the dynamic properties for the rock; full data set are required including density, sonic, Gama ray and caliper. The program has been used to calculate the rock elastic parameters and the critical pressure for sand production through an oil well in Fula North oil field. Different models were used to estimate elastic parameters as no shear wave available in the well logging data; the analysis was presented through the following sections:

4.1 General Information about the field

Muglad basin is an interior Mesozoic-to-Cenozoic rift basin located in the south of the Republic of Sudan, covering an area of 112,000 sq.km. Its tectonics is complicated by faulting and continuous fault movement. Seismic data suggested large numbers of tensional faults in this area, and defined several sub-basins; structures within these sub-basins show significant variations in age of formation, complexity and size (RIPED -2003). Block VI is located in the southwest of Sudan, tectonically in the northwest of the Muglad basin, and covers an area of 59,000 sq. km. Fula sub-basin is located in the northeast of Block VI concession area, and consists of 5 structure belts namely south step-faulted belt, south sub-basin, central structure belt, north sub-basin and north step-faulted belt. Fula oilfield is located just in the Fula central structure belt. The main Blocks in Fula oilfield can be divided into 3 blocks, i.e. Fula-1 Block, Fula North Block, and Fula Central Block; the main pay zones of heavy crude (RIPED -2003) are Bentiu and Aradeiba reservoirs:

1) Bentiu Formation (Pan et al 206) is a major oil bearing sandstone reservoir in the Muglad rift basin of interior Sudan, with thick massive loose sand. The reservoir has an average reservoir thickness of 83m; it has high porosity ranging from 24.2% to 31.6%, averaging 29.1% and high permeability from 561.5 to 2926×10-3μm2, at an average of 2041.2×10-3μm2. The reservoir is

composed of thick beds of sands interbedded with thinner beds of clays with a thickness of 1 to 2 meters or less. The average oil viscosity is about 1536.39 cp at 50 ^{o}C.

2) Aradeiba (Pan et al 206) is the second reservoir with stratified unconsolidated pay sand; the reservoir has an average reservoir thickness of 15.5m. It has higher porosity and permeability than Bentiu reservoir, at averages of 32.3% and 3261×10-3μm2 respectively. The average oil viscosity is 400cp; viscosity is up to around 450 cp at 50 ^{o}C

According to the RFT data from wells, initial pressure at Bentiu formation is 1609.5Psi, and 1502Psi at Aradeiba formation. Initial pressure shows a linear relation with depth with a pore pressure gradient of 125.1 Psi/100m. According to the logging and testing data acquired from different wells, the temperature of Aradeiba formation at the depth of 1,196.9mKB is 62.55°C with a gradient of 2.76°C/100m, and the temperature of Bentiu formation (at the depth of 1,271.6mKB) is 64°C with a gradient of 2.81°C/100m.

Due to the relatively high viscosity of the crude, and the poor consolidation of formation, reservoirs may predictably produce massive amounts of sand. Although sand production problems in Fula Field have been relatively small when compared to other sand producing areas in the world, many problems were found in the field due to sand production, and sand cut reached a value of 6% in some wells. Hence many sand-control methods are proposed to be tested at the field. Technologies of sand removal downhole and sand separation from blending fluid with sand were proposed and generalized in the field; surface sand traps were generalized after detailed study and testing. The analysis and optimization of sand traps indicated that all the sand of a size greater than 0.45mm can be settled in wellhead sand trap. The general sand removal is greater than 95% as demonstrated by RIPED (2001).

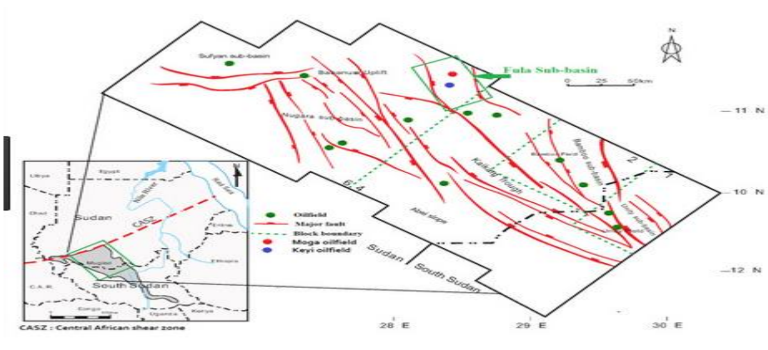


Fig 4.1 Fula oilfield Map (Yousif et. al 2016)

The technique of Cold Heavy Oil Production with Sand (CHOPS) was selected as the strategy to develop the field; the recovery factor of cold production with sand may amount to 12-20% (RIPED, 2003). Other research (Li et al., 2006) was carried out to study the equivalent wormhole module and to optimize the critical parameters, such as reasonable pressure drawdown and production rate for CHOPS. In order to prevent sand production from the formations, and to delay water production from Bentiu formation, the operator decided to drill horizontal wells in state of the conventional vertical wells as the recent technology recommended. As reported by Pan et al. (2006), the horizontally drilled wells have a good performance on controlling sand production and increasing the productivity of the well also extending the water free production.

4.2 Sand Production Prediction Software (SPPS) Screens:

The program starts with the first User-Interface which allow the user to start a new operation or to resume previous one (Fig 4.2).

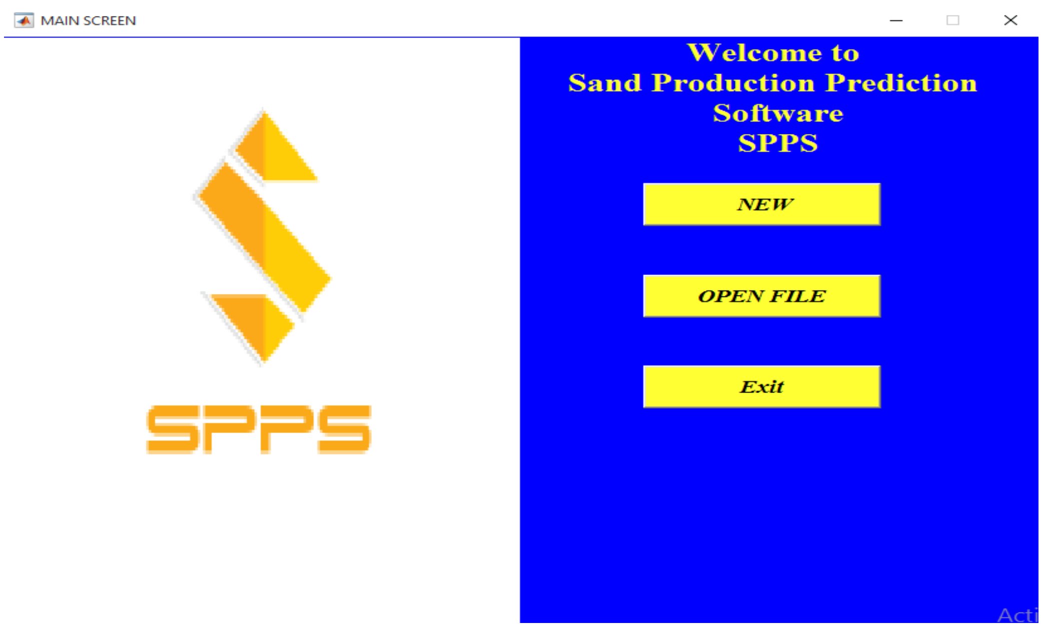


Fig 4.2 First Screen of Sand Production Prediction Software (SPPS)

When selecting New Operation command, the General Information Screen will appear; through which the user has to enter and save the job information in order to proceed. The program also allows the user to rest the information; if any field was remains empty; an error message will appear Fig 4.3.

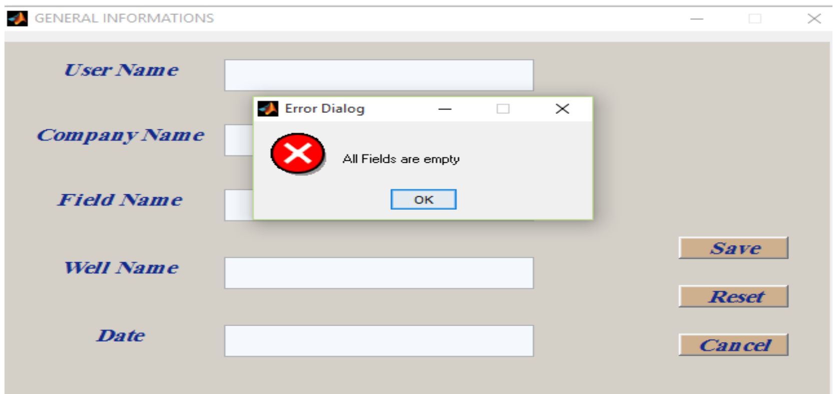


Fig 4.3 General Information Screen of the SPPS

Continue to the next screen is available for the user when the general information was saved. Then the Input data screen will appear, which allow the user to inter Well log-data and the other required data. When shear wave data is not available, a question dialog appears to detect whether to continue or to reset data as shown in Fig 4.4.

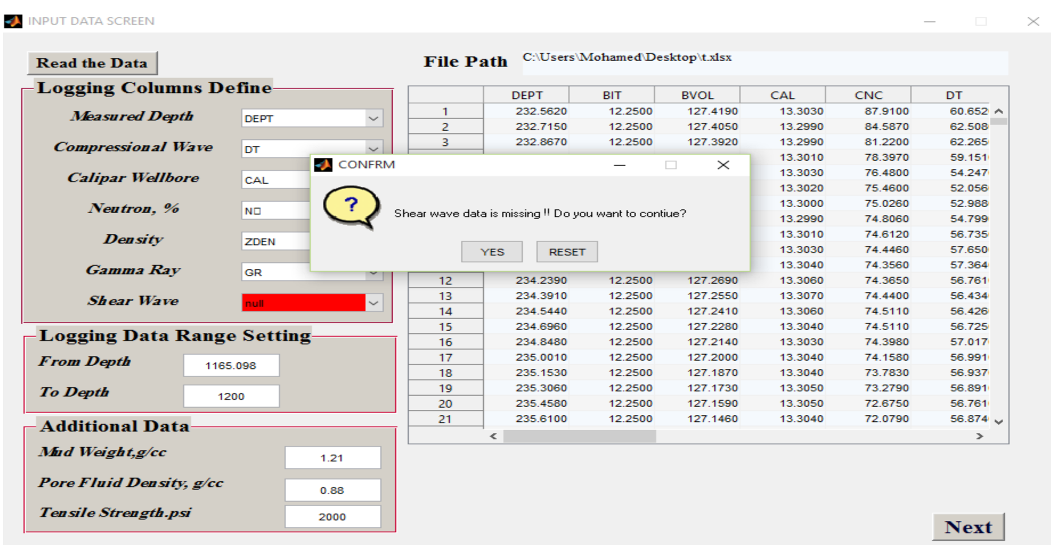


Fig 4.4 Input Data Screen of the SPPS

When the use selects Yes to continue to the next step, another screen will appear that allow calculating the Rock Mechanical Properties either independent of shear wave (Anderson formula) or using the available shear wave calculation method from various relationships, and then calculate the properties; the secreted method will result in either shear wave or elastic modulus, Fig 4.5.

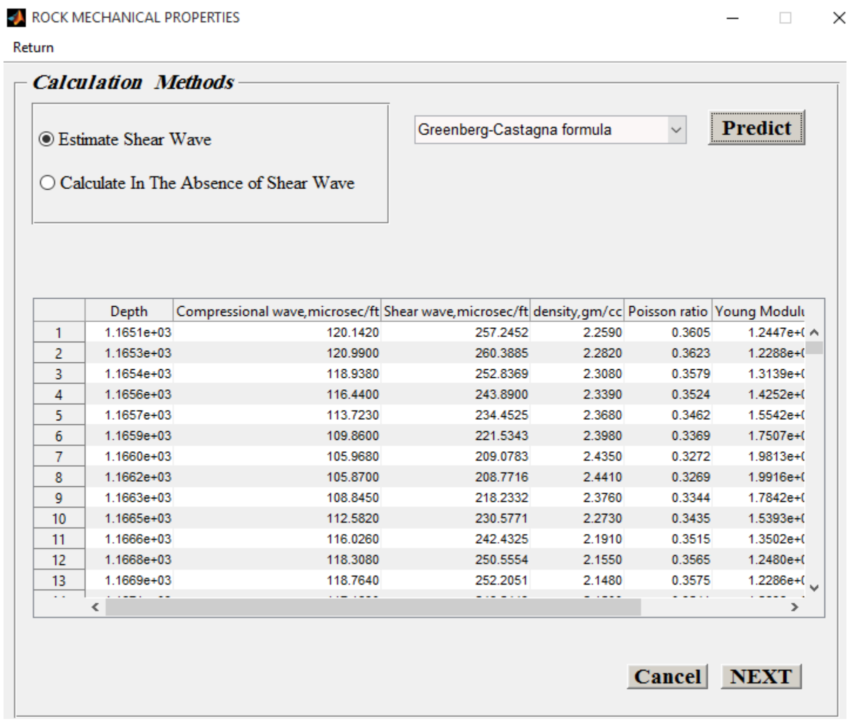


Fig 4.5 Rock Mechanical Properties Calculation Methods Screen

The next user-interface screen allows the user to calculate the Sanding Potential of the well by different methods; the user can continue to details calculation or not, based on the obtained result as presented through Fig 4.6.

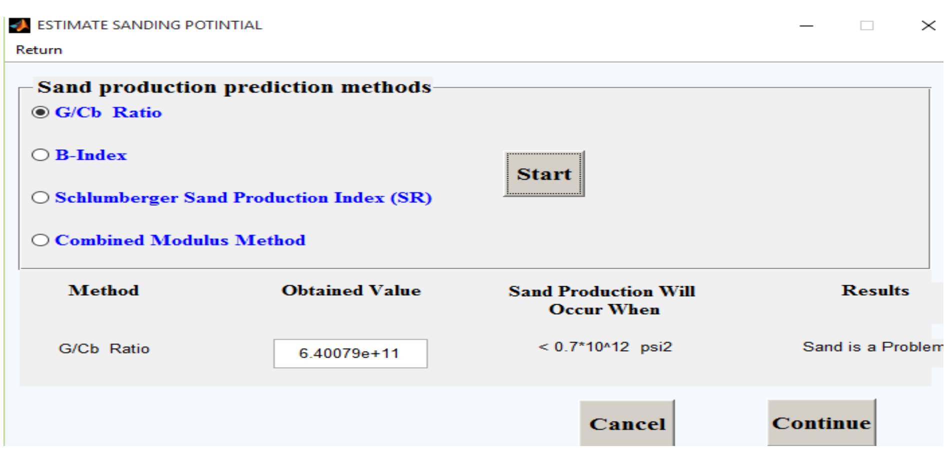
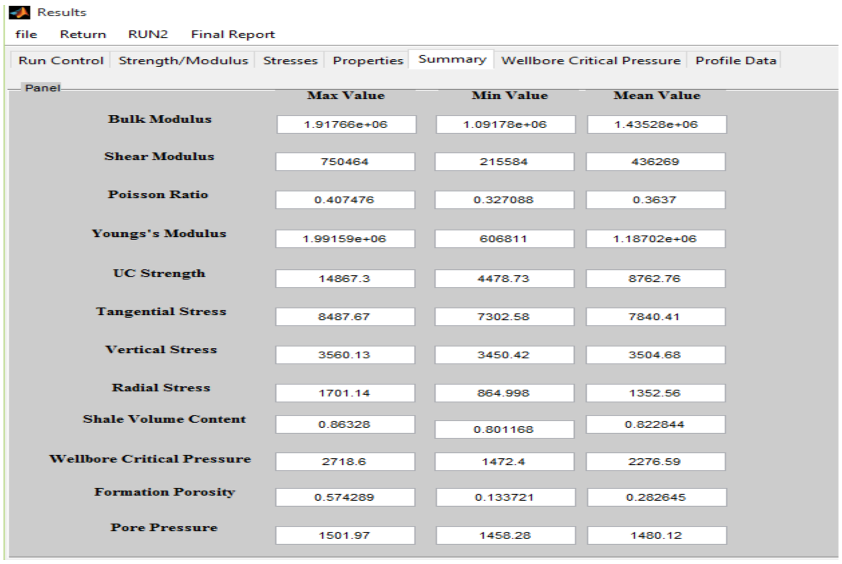


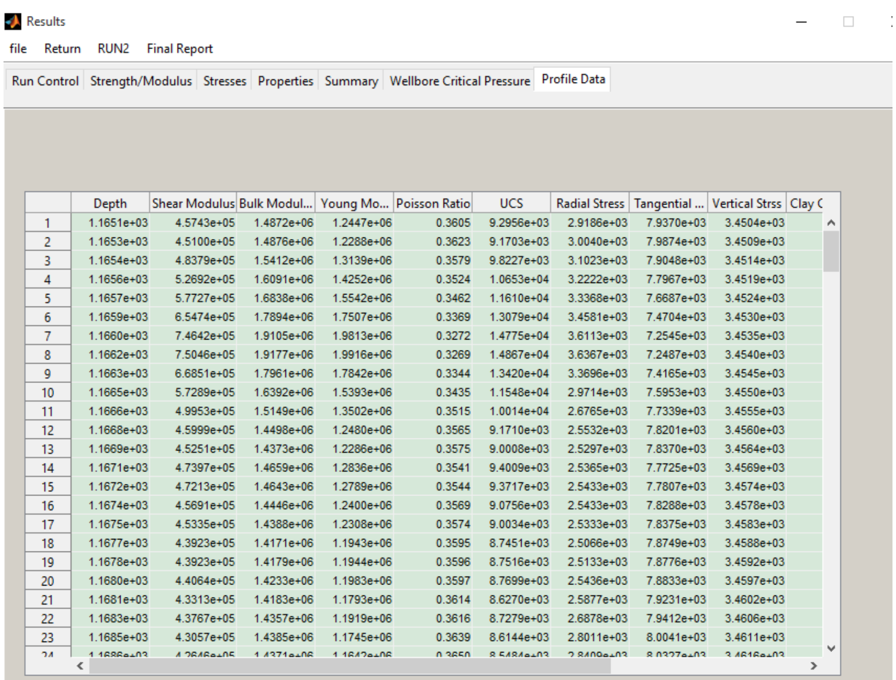
Fig 4.6 SPPS Sanding Potential Screen

The Final calculation results when the rock mechanical properties and the critical wellbore pressure estimated based on the shear wave can dispalied as a summary result as shown in Fig 4.7. Also, contiuse digital and graphical profile through the entire depth can be obtained as shown through Fig 4.8.



	Max Value	Min Value	Mean Value
Bulk Modulus	1.91766e+06	1.09178e+06	1.43528e+06
Shear Modulus	750464	215584	436269
Poisson Ratio	0.407476	0.327088	0.3637
Youngs's Modulus	1.99159e+06	606811	1.18702e+06
UC Strength	14867.3	4478.73	8762.76
Tangential Stress	8487.67	7302.58	7840.41
Vertical Stress	3560.13	3450.42	3504.68
Radial Stress	1701.14	864.998	1352.56
Shale Volume Content	0.86328	0.801168	0.822844
Wellbore Critical Pressure	2718.6	1472.4	2276.59
Formation Porosity	0.574289	0.133721	0.282645
Pore Pressure	1501.97	1458.28	1480.12

Fig 4.7 Summery Result Screen



	Depth	Shear Modulus	Bulk Modul...	Young Mo...	Poisson Ratio	UCS	Radial Stress	Tangential ...	Vertical Strss	Clay C
1	1.1651e+03	4.5743e+05	1.4872e+06	1.2447e+06	0.3605	9.2956e+03	2.9186e+03	7.9370e+03	3.4504e+03	
2	1.1653e+03	4.5100e+05	1.4876e+06	1.2288e+06	0.3623	9.1703e+03	3.0040e+03	7.9874e+03	3.4509e+03	
3	1.1654e+03	4.8379e+05	1.5412e+06	1.3139e+06	0.3579	9.8227e+03	3.1023e+03	7.9048e+03	3.4514e+03	
4	1.1656e+03	5.2692e+05	1.6091e+06	1.4252e+06	0.3524	1.0653e+04	3.2222e+03	7.7967e+03	3.4519e+03	
5	1.1657e+03	5.7727e+05	1.6838e+06	1.5542e+06	0.3462	1.1610e+04	3.3368e+03	7.6687e+03	3.4524e+03	
6	1.1659e+03	6.5474e+05	1.7894e+06	1.7507e+06	0.3369	1.3079e+04	3.4581e+03	7.4704e+03	3.4530e+03	
7	1.1660e+03	7.4642e+05	1.9105e+06	1.9813e+06	0.3272	1.4775e+04	3.6113e+03	7.2545e+03	3.4535e+03	
8	1.1662e+03	7.5046e+05	1.9177e+06	1.9916e+06	0.3269	1.4867e+04	3.6367e+03	7.2487e+03	3.4540e+03	
9	1.1663e+03	6.6851e+05	1.7961e+06	1.7842e+06	0.3344	1.3420e+04	3.3696e+03	7.4165e+03	3.4545e+03	
10	1.1665e+03	5.7289e+05	1.6392e+06	1.5393e+06	0.3435	1.1548e+04	2.9714e+03	7.5953e+03	3.4550e+03	
11	1.1666e+03	4.9953e+05	1.5149e+06	1.3502e+06	0.3515	1.0014e+04	2.6765e+03	7.7339e+03	3.4555e+03	
12	1.1668e+03	4.5999e+05	1.4498e+06	1.2480e+06	0.3565	9.1710e+03	2.5532e+03	7.8201e+03	3.4560e+03	
13	1.1669e+03	4.5251e+05	1.4373e+06	1.2286e+06	0.3575	9.0008e+03	2.5297e+03	7.8370e+03	3.4564e+03	
14	1.1671e+03	4.7397e+05	1.4659e+06	1.2836e+06	0.3541	9.4009e+03	2.5365e+03	7.7725e+03	3.4569e+03	
15	1.1672e+03	4.7213e+05	1.4643e+06	1.2789e+06	0.3544	9.3717e+03	2.5433e+03	7.7807e+03	3.4574e+03	
16	1.1674e+03	4.5691e+05	1.4446e+06	1.2400e+06	0.3569	9.0756e+03	2.5433e+03	7.8288e+03	3.4578e+03	
17	1.1675e+03	4.5335e+05	1.4388e+06	1.2308e+06	0.3574	9.0034e+03	2.5333e+03	7.8375e+03	3.4583e+03	
18	1.1677e+03	4.3923e+05	1.4171e+06	1.1943e+06	0.3595	8.7451e+03	2.5066e+03	7.8749e+03	3.4588e+03	
19	1.1678e+03	4.3923e+05	1.4179e+06	1.1944e+06	0.3596	8.7516e+03	2.5133e+03	7.8776e+03	3.4592e+03	
20	1.1680e+03	4.4064e+05	1.4233e+06	1.1983e+06	0.3597	8.7699e+03	2.5436e+03	7.8833e+03	3.4597e+03	
21	1.1681e+03	4.3313e+05	1.4183e+06	1.1793e+06	0.3614	8.6270e+03	2.5877e+03	7.9231e+03	3.4602e+03	
22	1.1683e+03	4.3767e+05	1.4357e+06	1.1919e+06	0.3616	8.7279e+03	2.6878e+03	7.9412e+03	3.4606e+03	
23	1.1685e+03	4.3057e+05	1.4385e+06	1.1745e+06	0.3639	8.6144e+03	2.8011e+03	8.0041e+03	3.4611e+03	
24	1.1686e+03	4.2646e+05	1.4371e+06	1.1642e+06	0.3650	8.5484e+03	2.8409e+03	8.0327e+03	3.4616e+03	

Fig 4.8 Continues Digital Profile Through the Entire Depth

4.3 Case Study

The designed program was used to evaluate the sanding potential of an oil field with targeting Bentiue formation with a depth of 1165 to 1200 m; no shear waves are available through the given information; therefore, the dynamic elastic modulus was first calculated using Anderson concept; The dynamic elastic modulus and critical pressure through the entire interval was presented through Fig 4.9 to Fig 4.12. The report is shown in Fig 4.13.

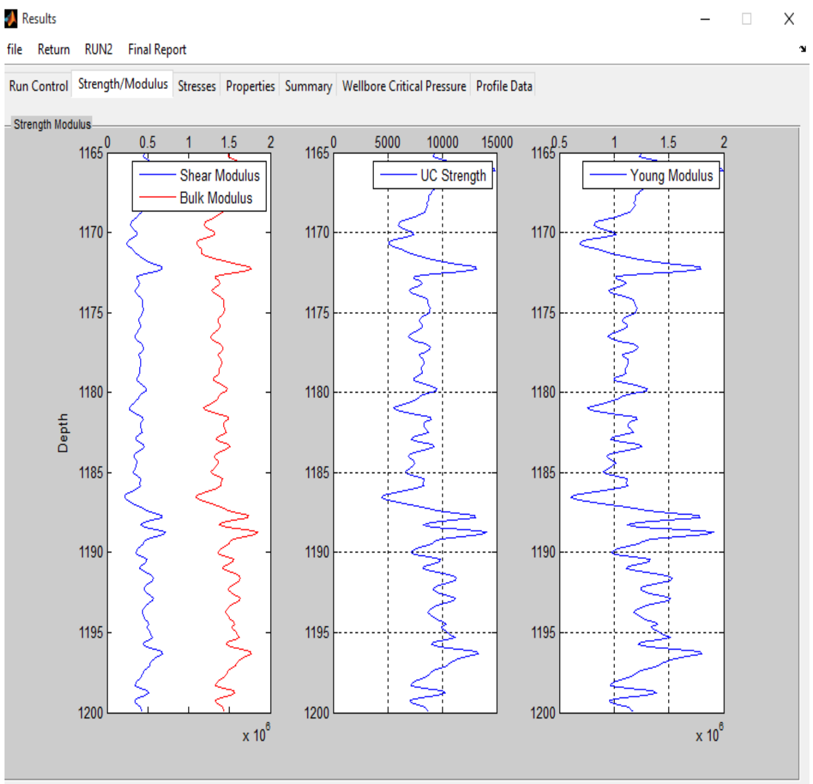


Fig 4.9 Elastic Modules Diagrams using Anderson Concept

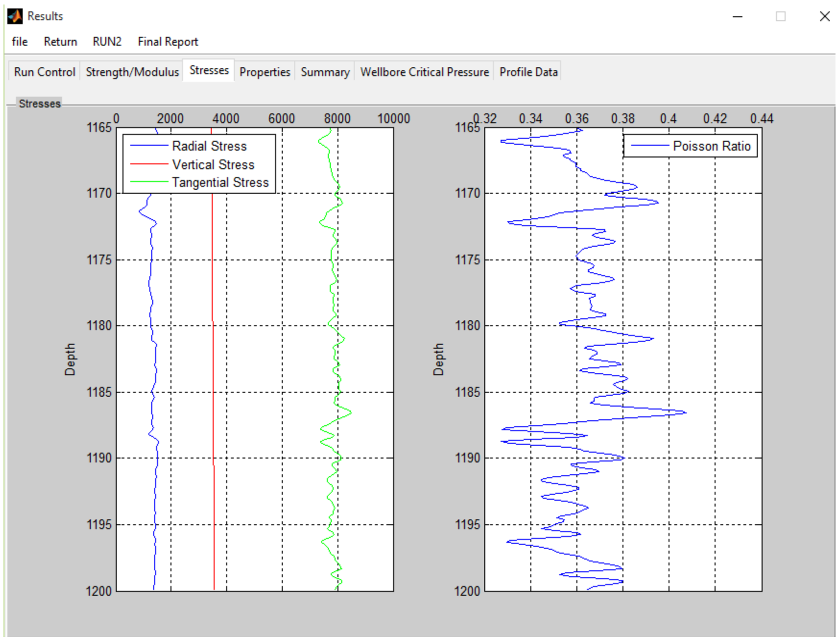


Fig 4.10 Poisson's Ration and Stresses Diagrams using Anderson Concept

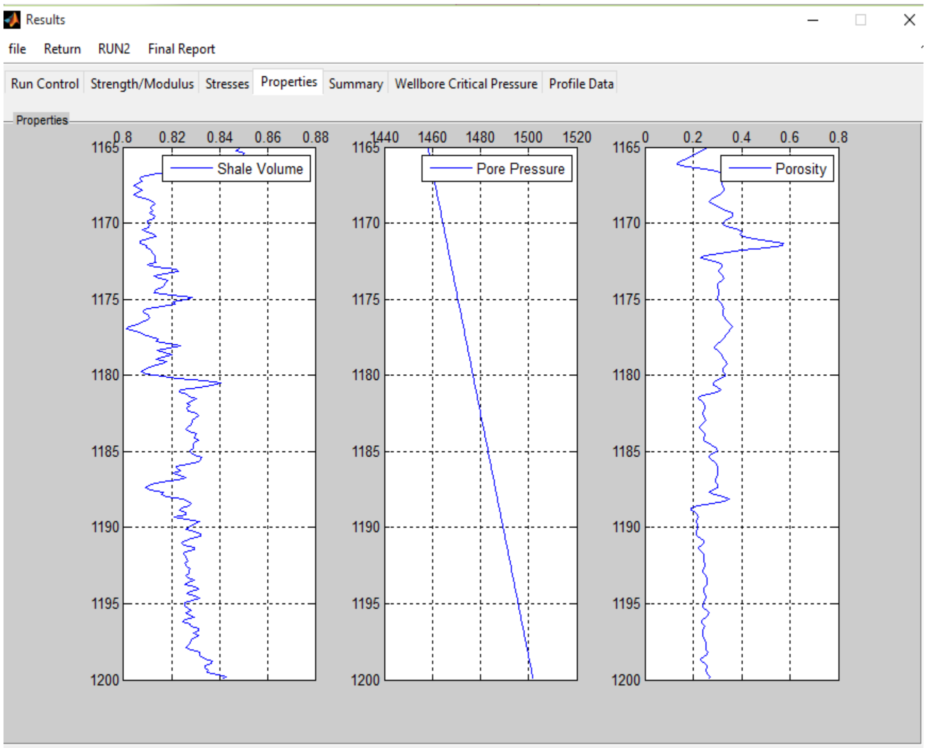


Fig 4.11 Shale Volume, Pore Pressure and Porosity Diagrams using Anderson Concept

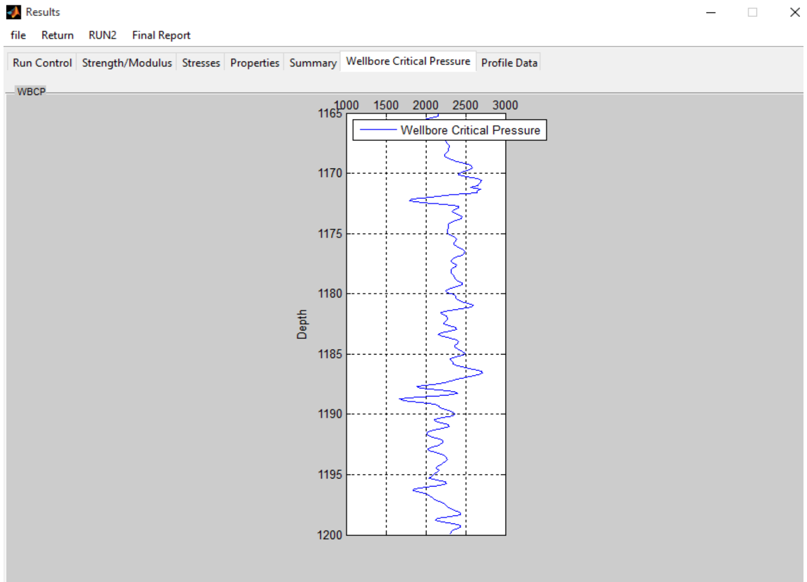


Fig 4.12 Wellbore Critical Pressure Diagram using Anderson Concept

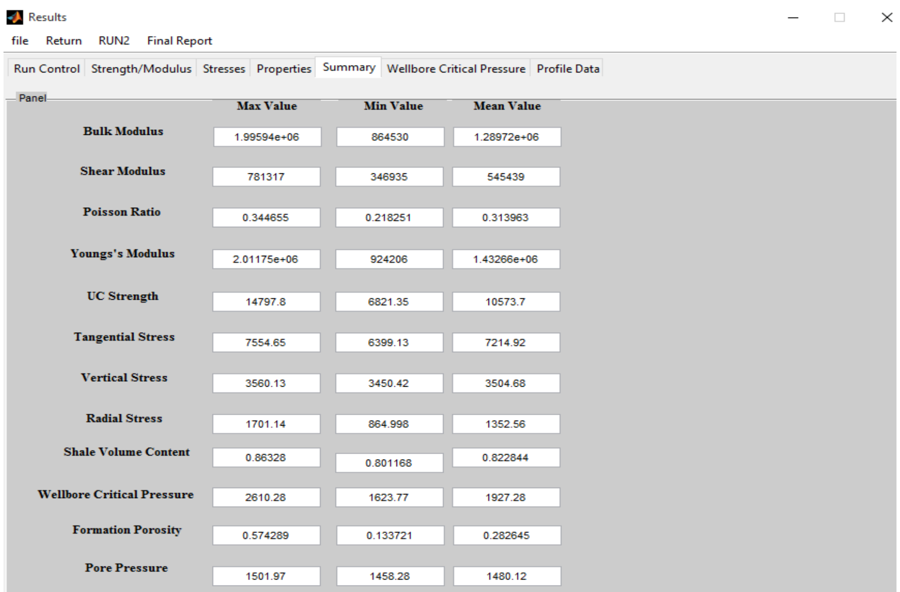


Fig 4.13 Summery of All the Calculated Properties and Stresses using Anderson Formula

The dynamic elastic modulus and critical pressure were also calculated based on the shear wave; the shear waves were calculated using the three programmed method (Han, Brocher and Greenberg - Castagna Equations) the results is shown in Fig 4.15; The calculated shear waves are varying from method to other however, Han and Greenberg - Castagna Equations have shear waves value approximately equals; while Brocher values are greater than the two other methods.

The dynamic elastic modulus and critical pressure using the shear wave's equation were presented through Fig 4.15 to Fig 18. Variations were observed between the dynamic elastic modulus and critical pressure from method to other. The calculated properties were also differing from that one calculated with Anderson.

Fig 4. 19 presented the critical pressure using the different concepts and equations; it is clear that critical pressure when using Brocher equation to estimate the shear waves is greater than the methods; also variation was observed between Han and Greenberg - Castagna Equations.

The critical pressure is a critical value through it the well will produces; therefore, an accurate value need to be estimated. The variation in this method indicates that the shear waves is a very important factor for predicting sand production; and as there is no any shear waves data the result cannot be trusted, till validations of these methods was performed.

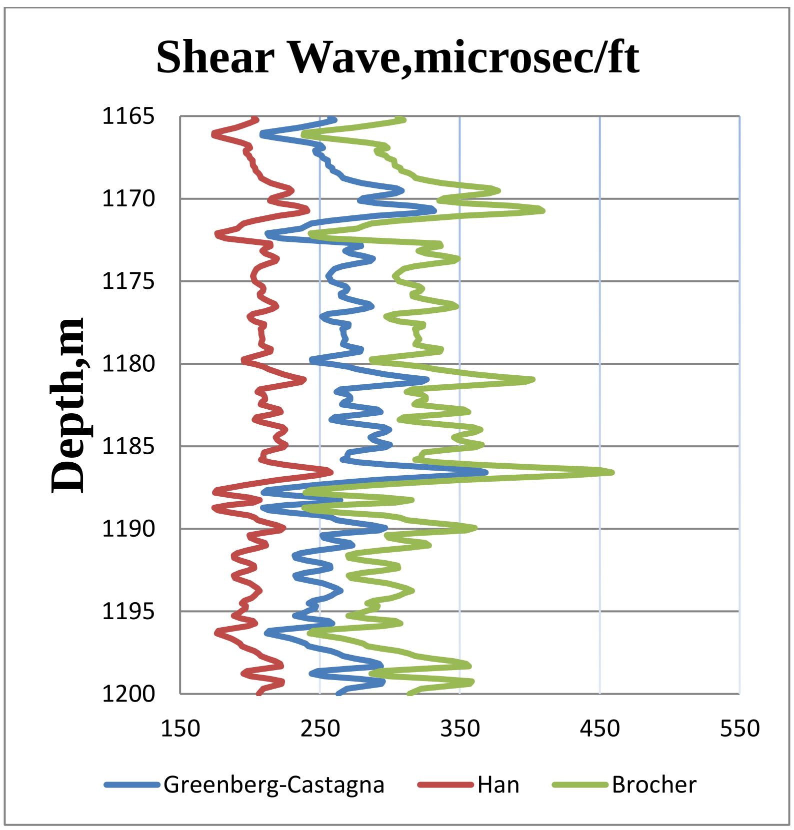


Fig 4.14 Comparison Between Shear Waves Calculated Using Different Relationships

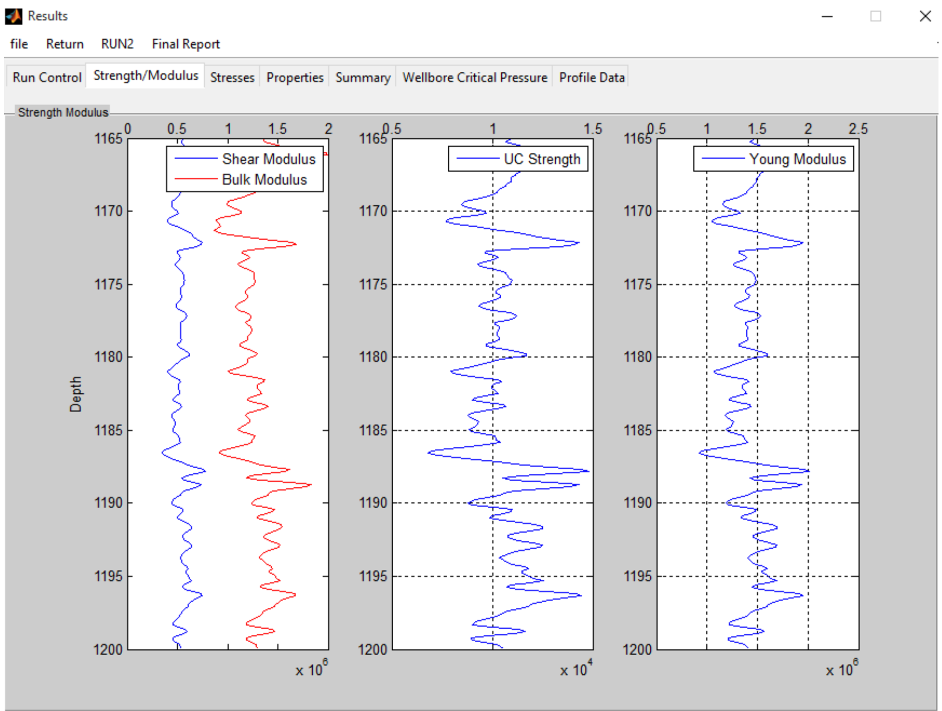


Fig 4.15 Elastic Modules Diagrams Greenberg-Castagna Equation

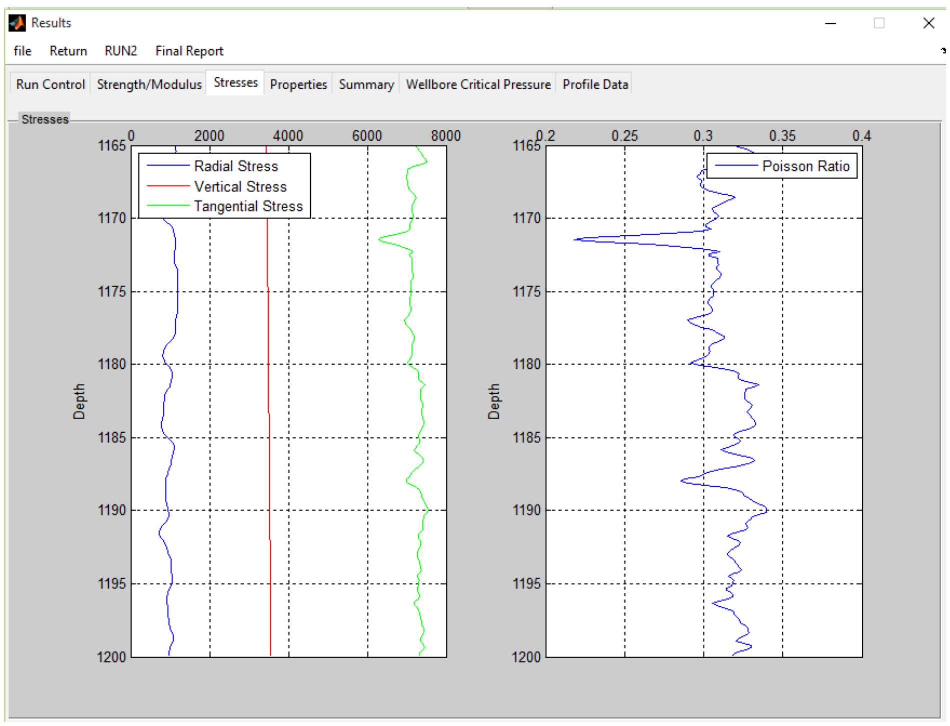


Fig 4.16 Poisson's Ratio and Stresses Diagrams - Greenberg-Castagna Equation

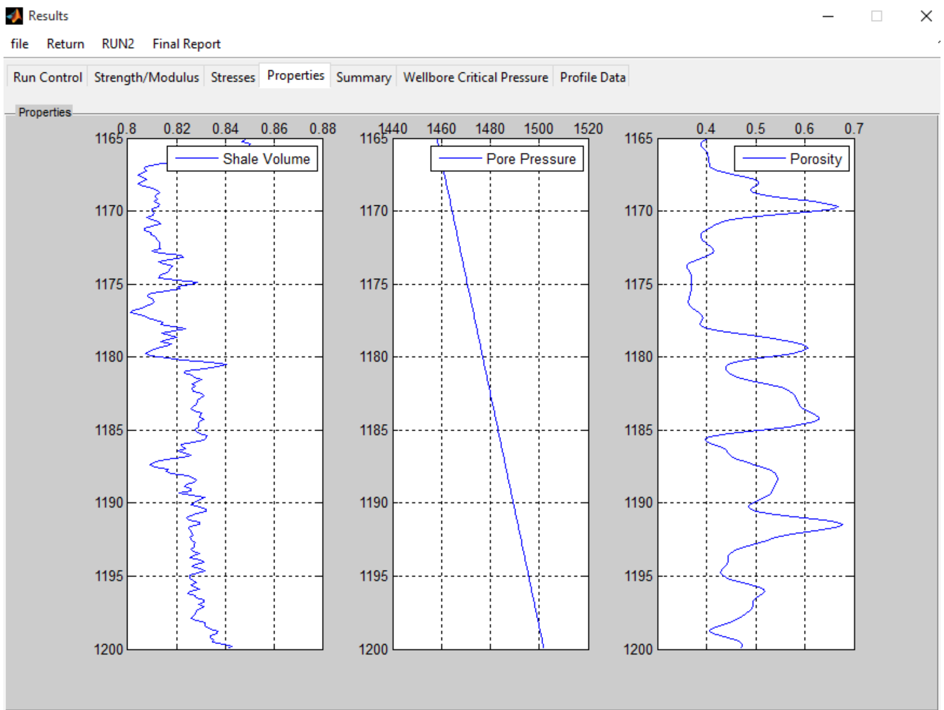


Fig 4.17 Shale Volume, Pore Pressure and Porosity Diagrams - Greenberg-Castagna Equation

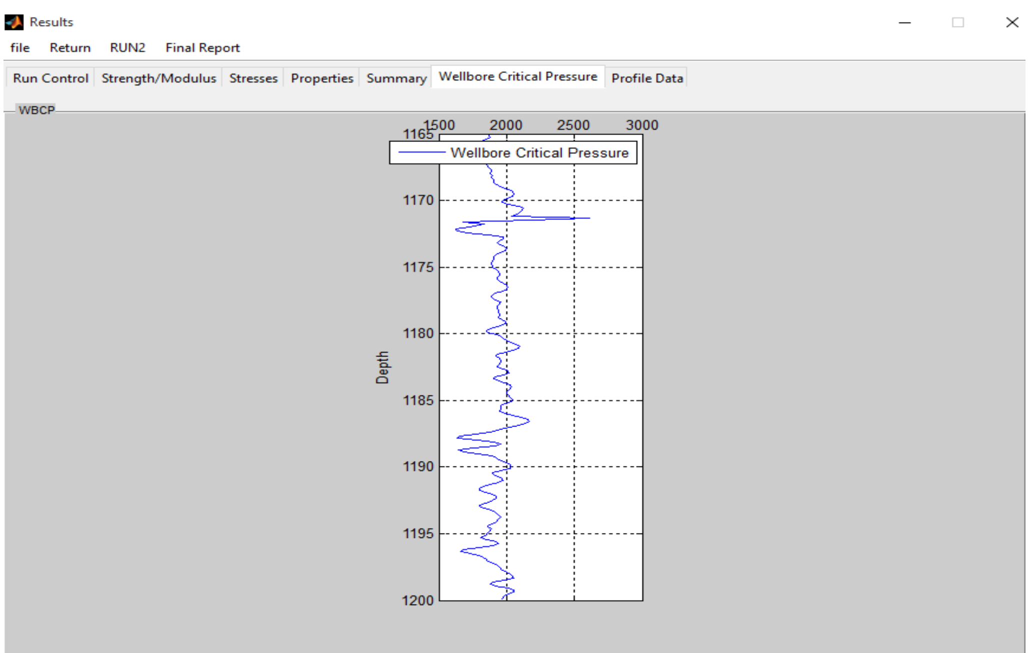


Fig 4.18 Wellbore Critical Pressure Diagram - Greenberg-Castagna Equation

From Fig 4.19 it is also observed that if avoiding perforating the depth between 1171.5 to 1173.0 m, and the depth from 1187.5 to 1189.0 m, and 1196.5 to 1197.0 the well can produce effectively without sanding problems if the pressure was kept greater than the critical pressure.

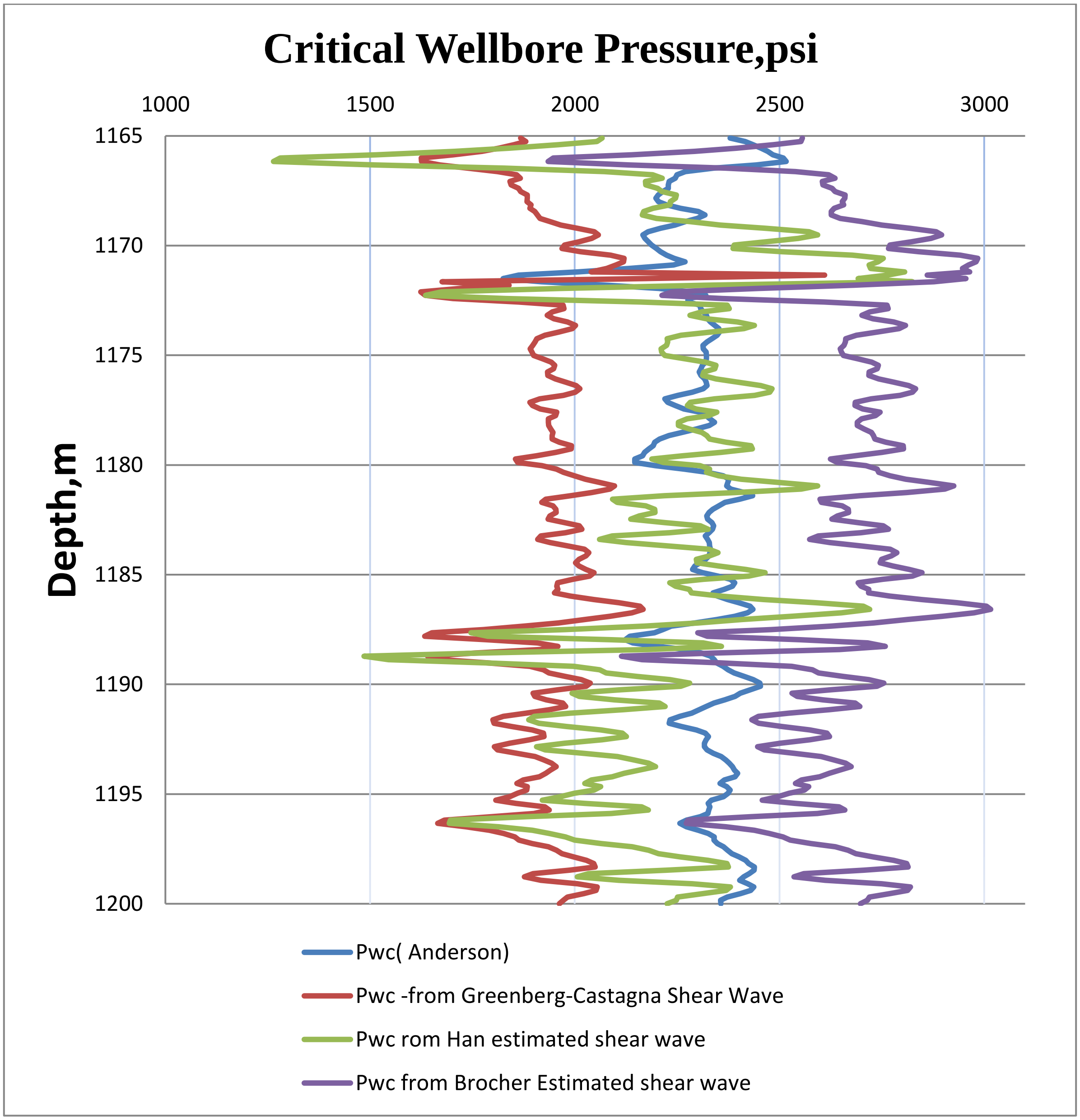


Fig 4.19 Comparison between Wellbore Critical Pressure

Chapter5

Conclusions and Recommendations

5.1 Conclusions

Based in work presented through this study the following conclusions can be pointed:

A new local Sand Production Prediction program (SPPS) has been designated using MATLAB programming language, the program deals with the input logging data in many different ways.

Rock mechanical properties (Shear modulus and Young's modulus and Bulk modulus) are calculated in the absence of shear wave for unconsolidated sandstone based on Anderson's equation which calculate Poisson's ratio as a function of the shale index. Shear wave was calculated using Han, Brocher and Greenberg - Castagna Equations and the rock mechanical properties were calculated using the estimated hear waves

The critical wellbore pressure calculated using Henry equation is highly affected by the shear wave values or the elastic properties of the rock; and variation was found between the different correlations.

Avoiding the friable formations during perforation can increase the critical production rate.

The suitable wellbore pressure to run the well is 1950 psi according to Greenberg-Castagna prediction method, 2300 psi Han Equation, 2800 psi Brocher method, and 2300 psi according to Anderson Estimation Method.

5.2 Recommendations

Through this presented work some limitation about the program need to be addressed;

1. Further development can be made using other shear wave correlations
2. Before starting the calculations, an accurate correlation for shear wave need to be selected and validation for the case is required.

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