

CERTIFICATION OF APPROVAL

**Determination of Unknown Parameters for Pore Pressure Modelling
in High Pressure Reservoir**

by

Sumaiyah binti Md Anuar Al-Musadda

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Approved by,

(Dr. Likun Xia)

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

SUMAIYAH BINTI MD. ANUAR AL-MUSADDA

ABSTRACT

Numerous basins in the world involve areas with abnormal pore pressures Estimation and prediction of the pore pressure parameters in such areas are challenging tasks for safe and cost-effective drilling. This project is to calculate unknown Bowers' parameter for well logging/drilling. Well data such as sonic velocity log and density log will be applied to obtain the pressure. Graphical User Interface (GUI) is developed to analyse/observe the relationship between pore pressure and velocity. Throughout its progression, this project states that it is quite a challenge in finding a few unknown parameters in Bower's formula. However, via extensive reading and additional knowledge gained, that challenge will be overcome.

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ABBREVIATIONS AND NOMENCLATURES

GUI	Graphical User Interface
PETRONAS	Petroliam Nasional Berhad
TDV	True Vertical Depth
GR	Gamma Ray
RHOBC	Bulk Density
V _p	Velocity of p-wave
V _{shale}	Volume of Shale
PP	Pore Pressure
HSP	Hydrostatic Pressure
OBP	Overburden Pressure

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDIES

Accurate pore pressure prediction is vital to support harmless drilling operations. It is an essential input into well design, mainly in the selection of casing points. Pore pressure prediction also provides important data for reservoir planning and reserves estimation [1]. Pore pressure prediction involves quantifying pore pressure from rock property variations, in particular, changes in sonic velocity or resistivity [2] – [4]. Undeniably, goal of developing a pore pressure prediction approach is to accurately estimate pore pressure from seismic processing velocities. Some successful pore pressure prediction approaches, especially those using seismic data, here been employed in regions where overpressure is generated by disequilibrium compaction [5], [6]. Overpressures generated by undercompaction/compaction disequilibrium are associated with high sediment porosities and are thus more detectable [7]. However, over pressures generated by fluid expansion mechanisms are not associated with porosity and are thus more difficult to detect, and for pore pressures to be computed [5], [8].

1.2 PROBLEM STATEMENT

1.2.1 Problem Identification

Overpressured formations – pore pressure is higher than the hydrostatic pressure – will trap high amount of hydrocarbons. However, from exploration part, if the pore pressure exceeds an edge determined by the strength of a rock, the seal of reservoir may have been breached. Overpressure also will cause problems during drilling phase such as

kicks, blown-outs, borehole instability, stuck pipe, and lost circulation and lead to excessive time spent fighting formation fluid influxes and/or drilling fluid losses.

1.2.2 Significance of Project

Correct estimation of pore pressure is essential to avoid problem mentioned above. During drilling phase, pore pressure estimation provides an indicator prior to drilling by designing a suitable mud weight, and also drill casing program to be selected. Mud weight is drilling fluid property that balances and controls formation pressure and helps in borehole stabilization. Among other subsurface data, pore pressure prediction is vital to depth at which the hole needs to be cased in order for drilling to reach the desired total depth.

1.3 OBJECTIVE AND SCOPE OF THE PROJECT

1.3.1 Objectives

- To calculate unknown parameter of Bowers Method based on given set of data
- To verify the calculated parameter with another set of data from different well of the same location
- To develop GUI to analyse/observe the relationship between pore pressure and velocity

1.3.2 Scope of The Project

This project starts with literature review related empirical method to calculate effective stress. Next data gathering will be performed to get density log and sonic velocity log which are then will be used as the input for Bowers method. Unknown parameters for Bowers formula will be calculated. Finally, GUI is developed to demonstrate the validity of this method.

1.4 RELEVANCY OF PROJECT

Bowers formula consists of parameters that can be calculated based on a well logging data. The parameters will be determined after the data are obtained from PETRONAS.

1.5 FEASIBILITY OF PROJECT

The project will be conducted in two semesters. It includes three parts: evaluation, software development, model improvement. Sonic velocity and density will be traced. Using well log data obtained from PETRONAS, a GUI will be developed to perform the results. Above all, it is feasible to complete the project within the time frame.

CHAPTER 2

LITERATURE REVIEW

2.1 DEFINITION

Overburden pressure, also known as vertical stress, increases with depth as shown in Figure 1 [12], [15]. Overburden stress is the upper limit for pore pressure as criteria for defining overpressure is in term of percentage of overburden stress, i.e., pore pressure is more than 90% of overburden stress [9]. Pore pressure also known as formation pressure is defined as pressure acting on the fluids in the pore space of a formation [15]. For a given velocity at a given depth, pore pressure can vary depending upon how excessive the pressure has been generated [10]. Shale is the most preferred lithology for pore pressure interpretation because it is more responsive to overpressure than most rock types [9]. Shale compaction controlled by effective stress represents the portion of the total stress carried by the rock grains [9]. Figure 2 illustrates the effective stress concept with laboratory data for Cotton Valley shale [16]. Meanwhile, effective pressure is defined as a pressure acting on solid rock framework [15]. Reduction of effective stress will result in overpressure [15].

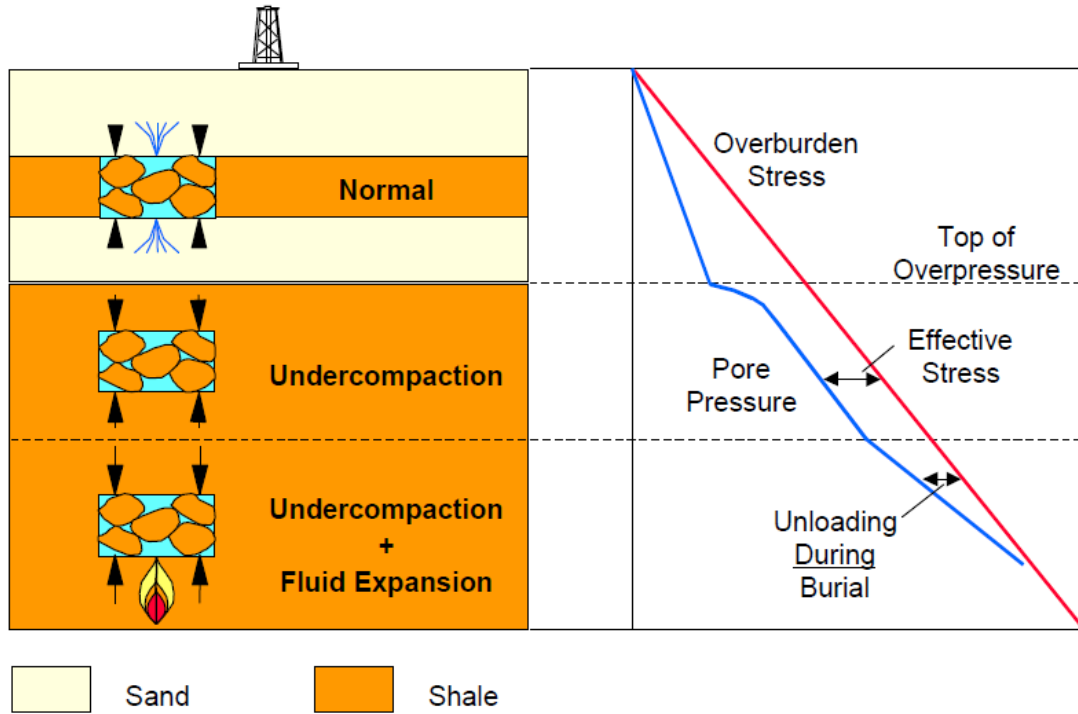


Figure 1: Effective stress response to different overpressure mechanism [12]

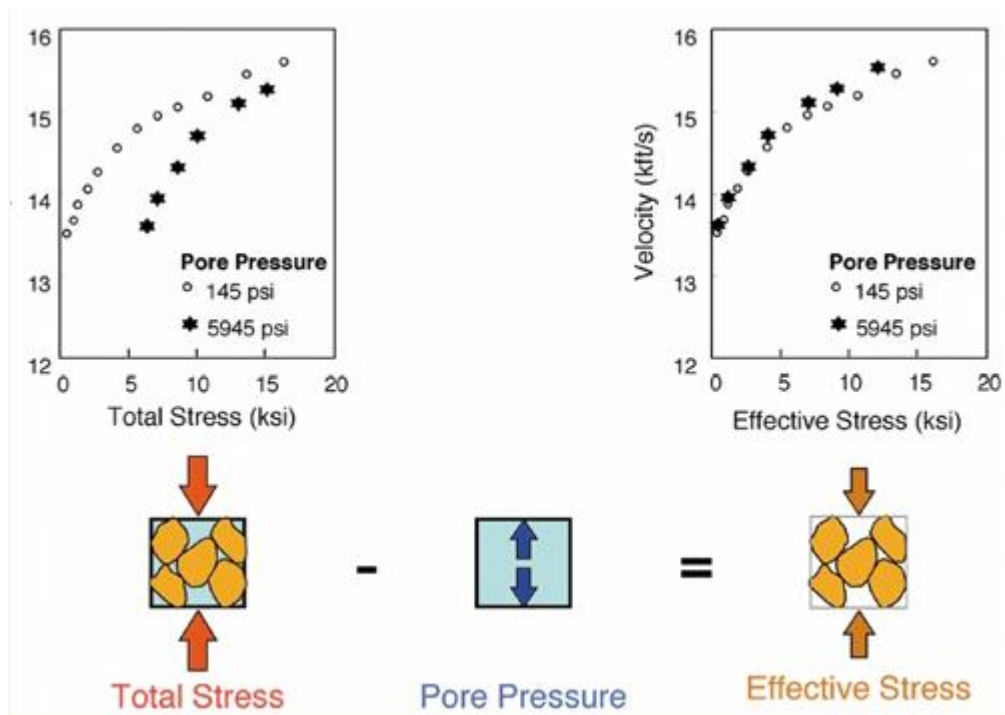


Figure 2: Laboratory example of the effective stress principle [16]

2.2 NORMAL TREND

During normal pressure, effective stress persistently increases with burial [9]. Density, resistivity and sonic velocity also proceed up their respective effective stress virgin curve [9]. Virgin curve is velocity-vs.-effective stress graph for non-decreasing effective stress states [10]. Normal trend is depth profile that a compaction dependent geophysical property would follow during burial under normal pressure condition [9]. Normal trend velocity-vs.-effective stress data follow virgin curve [10] as shown in Figure 3(a).

2.3 UNLOADING / ELASTIC REBOUND

Unloading is defined as reduction in effective stress as pore pressure increases rapidly under specific conditions [15]. This can clearly be seen in Figure 1. It is also an indicator of high pressure [9]. Signature of unloading is when velocity reversal in which the sonic velocity and resistivity data drop without a comparable change in bulk density [12]. Based on unloading curve, velocity will track faster velocity-vs.-effective stress relation. As the effective stress increases, velocity will follow unloading curve back to virgin curve [10]. Figure 3(a) illustrates data on virgin curve for the Gulf of Mexico sediments and Figure 3(b) shows unloading behavior with laboratory velocity-vs.-effective stress data for Cotton Valley shale [16]. The velocities measured at effective stresses below the maximum on-site stress state must be on an unloading curve. For easier comparison, the virgin curve for the Gulf of Mexico sediments is re-plotted in Figure 3(b) [10].

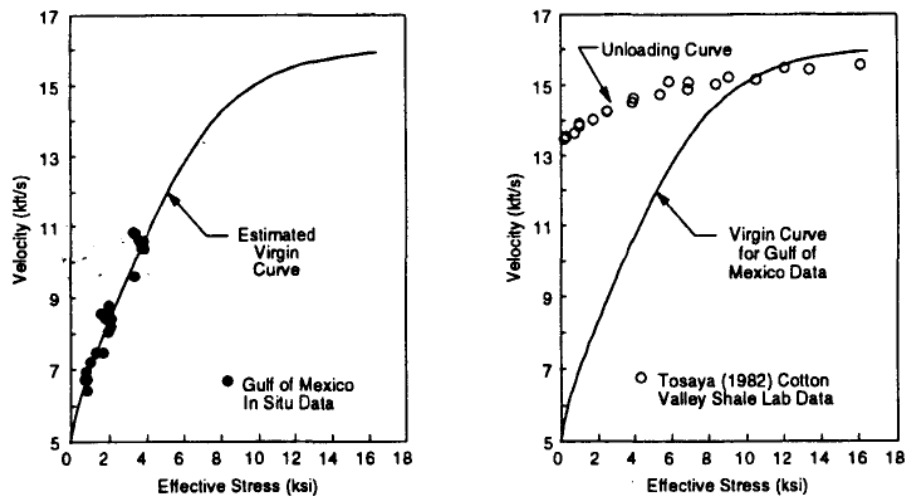


Figure 3: Shale compaction behavior: (a) virgin curve and (b) unloading curve [10]

There are two methods to determine whether or not high pressure method is required within velocity reversal [12]. By former method, cleanest shale from inside and outside reversal is picked. If reversal data lie on the same trend as points from lower pressure interval, Equivalent Depth method should work. More details on the method will be discussed in section 2.7.1. However, if reversal data tracks slower velocity trend, high pressure techniques will be used. The other way to determine is to compare sonic velocity, resistivity, and density log. If sonic velocity and resistivity log undergo reversal while density log does not, high pressure techniques will be carried out. If the three logs go through reversal, a point at the same depth in each reversal is picked and then it will be projected vertically upward until it crosses the log again. If all three crossed at similar depth, Equivalent Depth method will be used. If density log is intersected at deeper depth than the sonic velocity and resistivity log, high pressure technique will be executed.

2.4 VELOCITY REVERSAL

When pore pressure increases faster than overburden stress, effective stress will decrease as burial continues, which produce a velocity reversal [10]. Figure 4 demonstrates this with log data from an Indonesian well [10]. Velocity reversal effect on velocity-vs.-depth relationship is clearly shown in Figure 4(b). Velocity inside the reversal will track an unloading curve, while velocities outside the reversal will remain on a virgin curve [10]. Pore pressure, velocity, and stress data are displayed in Figure 4(a), 4(b), and 4(c), correspondingly. Figure 4(d) relates velocity-vs.-effective stress data from inside and outside the velocity reversal. It is observed that the start of the reversal coincides with the top of overpressure at approximate 6350 ft. According to Figure 4(d), it is concluded that the inside velocities reversal track a much faster trend [10].

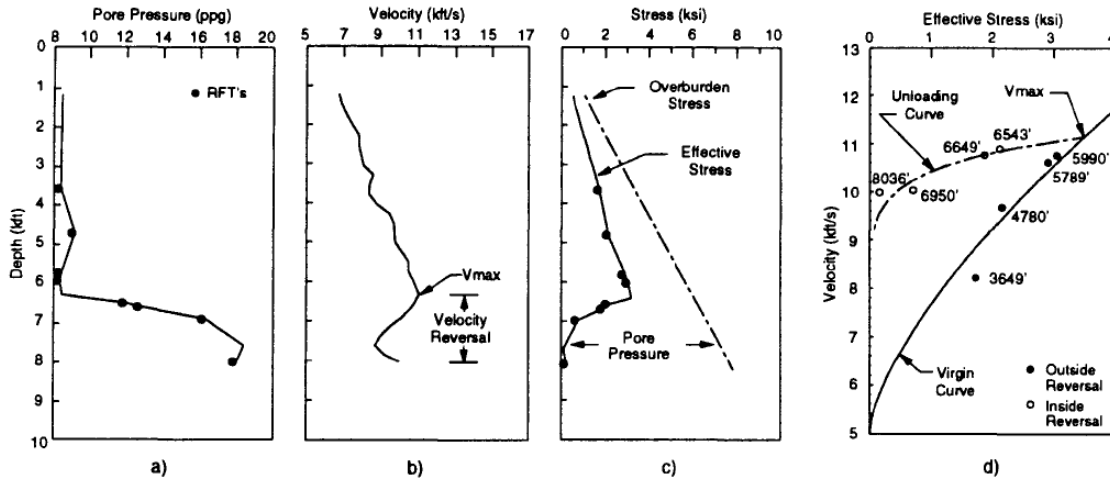


Figure 4: Fluid expansion overpressure offshore in Indonesia [10]

2.5 CAUSES OF OVERPRESSURE

2.5.1 Undercompaction / Compaction Disequilibrium

Undercompaction is a well understood overpressure mechanism used to explain and quantify overpressure [17]. It occurs when there is transition from sand-prone to shale-prone environment and trapped pore fluid being squeezed by the weight of more recently deposited sediments [9], [12]. This process has been demonstrated in Figure 1. Undercompaction generates the greatest overpressure at shallower depth, where formations are soft [10]. However, undercompaction cannot cause effective stress to decrease, hence may never drive pore pressure towards overburden curve and cannot cause stress reduction [9]. In other word, the velocity-vs.-effective stress graph still follows virgin curve.

2.5.2 Fluid Expansion

It occurs when excess pressure results in rock medium constraining pore liquid as the volume fluid tries to increase [10]. Fluid expansion mechanisms include heating, hydrocarbon maturation, expulsion / expansion of intergranular water during clay diagenesis, changing from other zones, dip-up transfer of reservoir pressure [9], [10], [12]. Pore pressure increases faster than overburden stress [12]. Therefore, unlike

undercompaction, fluid expansion can force effective stress to reduce as the burial continues resulting in velocity reversal [10], [12]. Clear understanding how fluid expansion can react on effective stress is illustrated in Figure 1. It is more likely to be important source of overpressure at deeper depth, in harder rock [10]. Velocity outside reversal can be track on virgin curve while velocity inside reversal can be track on unloading curve [10].

2.5.3 Tectonic Loading

Tectonic loading can cause vertical stress to decrease, but the compaction is not only controlled by vertical effective stress alone [9]. Therefore, the result to high pressure will be similar as undercompaction [15].

2.5.4 Lateral Transfer

Sediments that have fluid injected into in from more highly-pressured zone [15].

Determination of cause of overpressure can be achieved by measuring pore pressure. There are two methods to measure pore pressure. The first method is to plot velocity-vs.-effective stress data from inside and outside reversal. If overpressure is caused by fluid expansion, reversal data will track faster trend. Another method is by comparing measured pore pressure with those computed with the Equivalent Depth method. Equivalent Depth method underestimates caused by fluid expansion [10]. Figure 5 illustrates high pressure well log example [9]. Sonic and resistivity logs undergo reversals not seen by the density log. Pore pressures are underestimated when undercompaction is assumed the cause of overpressure (Equivalent Depth Solution). Figure 6 shows when Equivalent depth method work and Figure 7 illustrate when Equivalent Depth method failed.

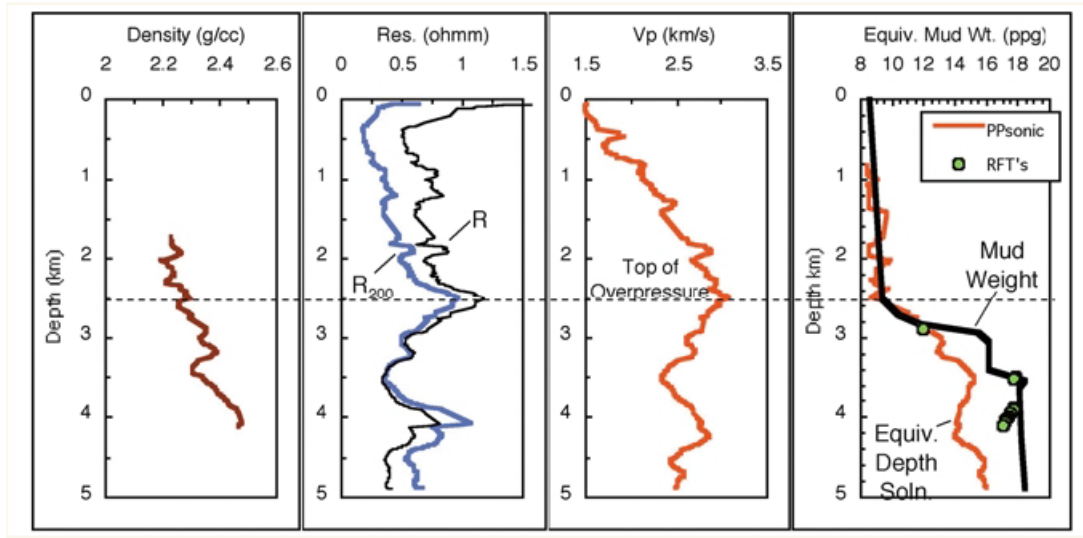


Figure 5: High pressure well log example [9]

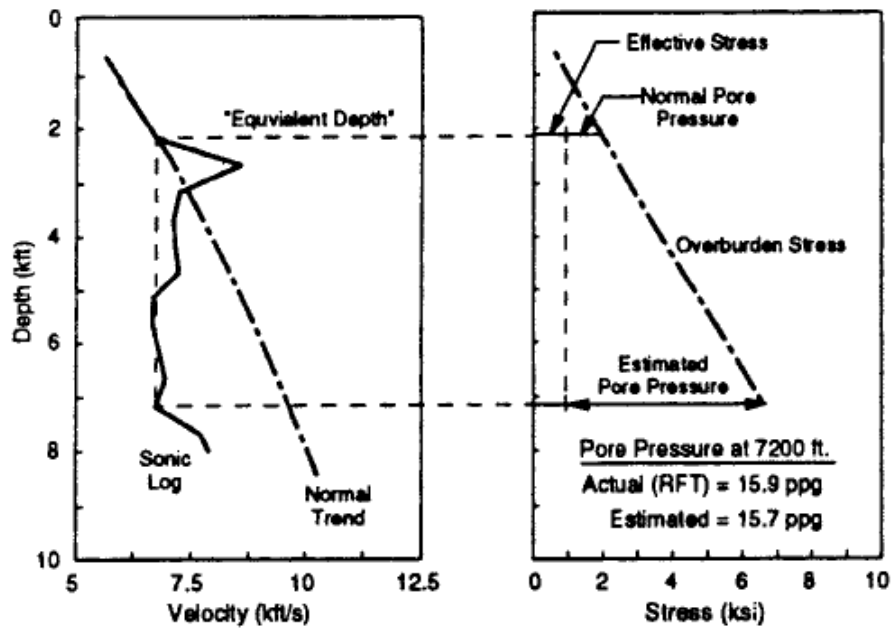


Figure 6: A case where equivalent depth method works – Gulf of Mexico [10]

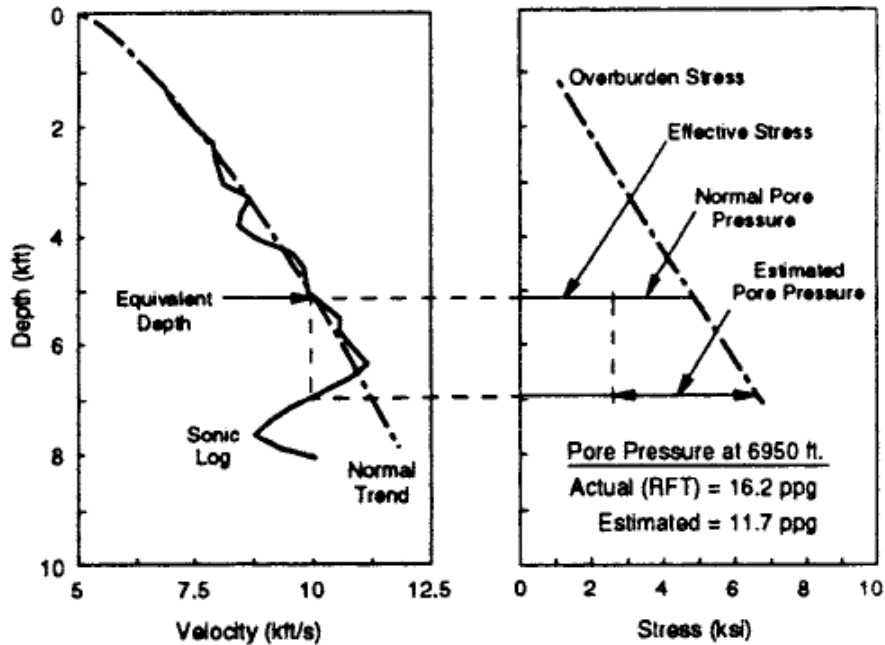


Figure 7: A case where equivalent depth method fails-offshore Indonesia [10]

2.6 DETECTION OF OVERPRESSURE

Detecting overpressure means determining where unusual overpressure mechanism may be encountered [9]. Well logs are used to construct trend and detect overpressure after drilling meanwhile to detect overpressure before drilling, reflection seismic method is used [15]. Overpressure detection from borehole data will detect changes in overpressure from sonic, resistivity, porosity and density logs [15]. Overpressure detection from seismic data on the other hand will only take velocity that are dense, accurate and close to formation of interest out of many types of seismic velocity [15].

2.7 METHODS FOR CALCULATING PORE PRESSURE

2.7.1 Equivalent Depth Method

Equivalent Depth method compares the effective stress in an overpressure zone to that in a normal pressure interval with the same velocity, assuming that overpressure data is on the same velocity, see Figure 6 [18]. If fluid expansion has driven the data into unloading curve, as in Figure 4, the effective stress will be overestimated while the pore

pressure will be underestimated [19]. Equivalent Depth method may fail whenever unloading has occurred [12].

2.7.2 Hottman and Johnson Method

Hottman and Johnson method empirically correlates departure from the velocity normal trend line to an equivalent pore pressure gradient [20]. They simply reflect whatever the dominant cause of overpressure mechanism. This correlation will overestimate the pore pressure at wells where undercompaction truly is the dominant cause of overpressure [10].

2.7.3 Eaton Method

Eaton method implies that both normally pressured and overpressured formations follow a virgin curve relation [21]. This method also must often be adjusted from one location to another to handle local variations [15]. However, Eaton Method underestimates fluid expansion caused of overpressure [10].

2.7.4 Bowers Method

Bowers method employs virgin and unloading curve relations to take into consideration for both undercompaction and fluid expansion cause of overpressure [10]. Bowers states that rock properties change or overpressure could result in velocity reversal data to diverge from main compaction trend, which is virgin curve, and overpressure results from undercompaction of fluid expansion [14]. Vertical effective stress of fluid expansion formation can be determine by unloading equation and vertical effective stress in other formation can be calculated by virgin curve equation [14]. Virgin curve for shale can be determined with Equation (1) where V is velocity and σ is effective stress [10].

$$V = 5000 + A\sigma^B \quad (1)$$

Formula (2) is the calculation for unloading curve [10]. The value of σ_{\max} can be obtained from Formula (3) where σ_{\max} and V_{\max} is the effective stress and the velocity at

onset of unloading respectively [10]. V_{max} is usually set equal to velocity at start of velocity reversal [10].

$$V = 5000 + A \left[\sigma_{max} \left(\frac{\sigma}{\sigma_{max}} \right)^{\frac{1}{U}} \right]^B \quad (2)$$

$$\sigma_{max} = \left(\frac{V_{max} - 5000}{A} \right)^{\frac{1}{B}} \quad (3)$$

Should U equals to unity, indicates that no parameter deformation (unloading curve reduce to virgin curve), meanwhile if U equals to ∞ , deformation is irreversible [10]. Though, the value of U is normally between 3 to 8 [10]. Unloading data from multiple well lie on multiple unloading curve [10]. Equation (4) should solve for U value, parameter σ_{vc} – stress which current velocity intersect virgin curve – can be calculated using Equation (5) [10].

$$\frac{\sigma}{\sigma_{max}} = \left(\frac{\sigma_{vc}}{\sigma_{max}} \right)^U \quad (4)$$

$$\sigma_{vc} = \left(\frac{V - 5000}{A} \right)^{\frac{1}{B}} \quad (5)$$

2.8 CALCULATING PORE PRESSURE

Depth interval area of pressure loading and unloading needs to be confirmed to calculate pressure profile. It will be used when calculating overburden stress later on [14]. Effective stress computed using Equation (1) to (5) will then be employed to calculate pore pressure with Terzaghi's principle. Terzaghi stated that pore pressure (P_p) is the difference between overburden pressure (P_{OB}) and effective stress (σ), as shown on Equation (6) [22].

$$P_p = P_o - \sigma \quad (6)$$

2.9 CALCULATING OVERBURDEN PRESSURE

Determination of the overburden pressure can be obtained by summing the pressure contributions for each density as shown in Equation (7) where P_{OB} is overburden pressure at depth h , for i different rock densities, each with thickness h_i [24].

$$P_{OB} = \sum_i(\rho_i g h_i) \quad (7)$$

2.10 CALCULATING HYDROSTATIC PRESSURE

Hydrostatic pressure, P_H at any depth h is equal to the weight of a column of water from sea level with water density ρ_h . Hydrostatic pressure can be determined by Equation (8) where z is equal to zero at sea level [25].

$$P_H(h) = \int_0^h g \rho_w dz \quad (8)$$

CHAPTER 3

METHODOLOGY

3.1 RESEARCH METHODOLOGY

In order to achieve the main objective of this project, the goals the three said objectives need to be accomplished. With data obtained from PETRONAS, effective stress will be determined using Bowers method. Parameters A, B and U in Bower's formula are calculated beforehand. Once effective stress for all the points had been found, a relationship velocity-vs.-effective stress will be plotted. Should the velocity-vs.-effective stress graph is as per theoretical, the parameter will then be verified using different set of data from different well of the same location.

3.2 FLOW CHART

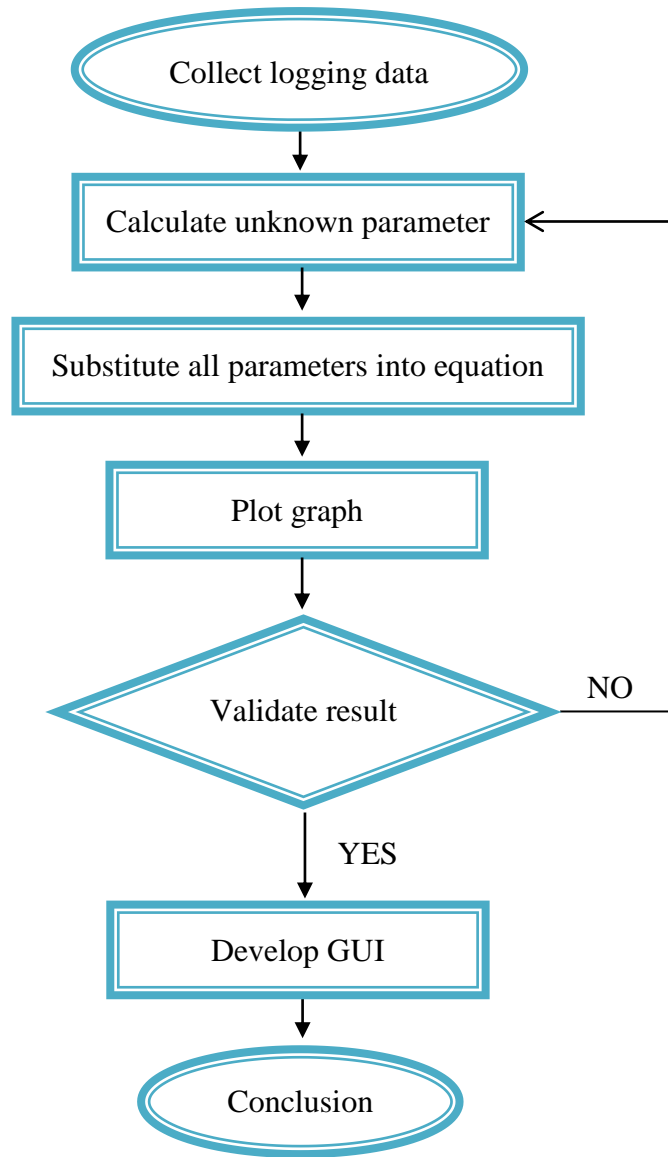


Figure 8: Project Flowchart

3.3 PROJECT DURATION

3.3.1 FYP 1

Table 1: Gantt Chart for FYP 1

	1	2	3	4	5	6	7		8	9	10	11	12	13	14	
Selection of Project Topic	█							MID-SEMESTER BREAK								
Preliminary Research Work		█														
Submission of Extended Proposal						█										
Data Gathering							█									
Proposal Defense										█						
Data Analysis												█				
Submission of Interim Draft Report															█	
Submission of Interim Report																█

3.3.2 FYP 2

Table 2: Gantt Chart for FYP 2

	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15	
Project Work Continues	█							MID-SEMESTER BREAK									
Submission of Progress Report									█								
Project Work Continues									█								
Pre-EDX													█				
Submission of Draft Report														█			
Submission of Dissertation															█		
Submission of Technical Paper															█		
Oral Presentation																█	
Submission of Project Dissertation																	█

3.4 TOOL REQUIRED

Software required for plotting graph purposes are as per below:-

- MATLAB
- Microsoft Excel

CHAPTER 4

RESULT AND DISCUSSION

4.1 DATA GATHERING

Data is taken from South China Sea area at water depth 32 m. Well log data for calibration obtained from PETRONAS is as per shown in Figure 9. There are 120 points taken at different depth. For each true vertical depth (TVD), the available data are gamma ray (GR), bulk density (RHOBC), observed pressure, velocity of the p-wave (V_p) and effective stress.

Full data provided is as in Appendix 1.

			Observed		
			Pressure	Vp	Effective
TVDmss	GR	RHOBC	Mpa	m/sec	Stress
3036.8380	62.0124	2.4020	30.2742	4020.0591	25.6139
3038.5003	64.8385	2.4231	30.4650	4019.9857	24.8966
3040.1627	69.1480	2.4366	30.6989	4042.6874	23.2796
3041.8250	80.8764	2.5073	30.9761	4043.0633	21.0105
3043.4876	90.4902	2.5370	31.1982	4149.8028	19.9993
3045.1476	72.6202	2.5067	31.4200	4262.4224	22.4260

Figure 9: Calibration Data obtained from PETRONAS

4.2 DATA PROCESSING

From data provided, overburden, hydrostatic and pore pressure can be plotted. Before that, some calculation has to be made such as to find thickness, average bulk density, and volume of shale before overburden stress and hydrostatic pressure can be calculated. All of these calculation is being made using MATLAB.

Thickness is the difference between two depths, and can be calculated using codes as per shown in Figure 10.

```
Depth1=[Depth;0];
a=size(Depth1);
i=1:a-1;
Thickness=abs(Depth1(i)-Depth1(i+1));
[r1,c1]=size(Thickness);
Thickness(r1)=[];
```

Figure 10: MATLAB Codes to Find Thickness

Average bulk density is a 119 by 1 matrix resulting from summation and division of two rock densities (RHOBC). Codes to calculate average bulk density is shown in Figure 11.

```
RHOBC1=[RHOBC;0];
b=size(RHOBC1);
i=1:b-1;
Average_RHOBC=(RHOBC1(i)+RHOBC1(i+1))/2;
[r2,c2]=size(Average_RHOBC);
Average_RHOBC(r2)=[];
```

Figure 11: MATLAB Codes to Find Average RHOBC

Shale volume is calculated based on gamma ray data. The formula to calculate volume of shale is as per Equation (9) [24]. Based on the formula, MATLAB codes to find volume of shale is generated as per shown in Figure 12.

$$V_{shale} = \frac{GR - GR_{min}}{GR_{max} - GR_{min}} \quad (9)$$

```
GR1=[GR;0];
c=size(GR1);
GR_max=max(GR);
GR_min=min(GR);
i=1:c-1;
Vshale=abs((GR1(i)-GR_min)/(GR_max-GR_min));
[r3,c3]=size(Vshale);
Vshale(r3)=[];
```

Figure 12: MATLAB Codes to Find Shale Volume

Based on the calculated thickness and average bulk density, overburden stress and hydrostatic pressure can be calculated. Calculation of overburden stress is as per shown below based on Equation (7):-

1. First point of overburden stress is calculated by multiply first value of depth by 1.027, where 1.027 is density of seawater [23].

2. Second point and forward is calculated by summing previous value of overburden stress with multiplication of their corresponding thickness and their corresponding average RHOBC.

$$P_{OB} = \sum_i(\rho_i g h_i) \quad (7)$$

MATLAB is used to perform these calculations and MATLAB codes is as per Figure 13.

```
[r4 c4]=size(Thickness);
Overburden=zeros(r4,c4);
Overburden(1)=Depth(1)*1.027;
for i = 2 : r4
    Overburden(i,1)=(Thickness(i)*Average_RHOBC(i))+Overburden(i-1);
end
Overburden;
```

Figure 13: MATLAB Codes to Find Overburden Stress

Hydrostatic pressure is calculated with slightly different way. For the first point of hydrostatic pressure, the value can be calculated by multiplying the first depth data by density of seawater. Second point and forward can be calculated by summing previous value of hydrostatic pressure with multiplication of corresponding thickness by density of seawater. A MATLAB code for hydrostatic pressure is as shown in Figure 14.

```
[r5 c5]=size(Thickness);
Hydrostatic=zeros(r5,c5);
Hydrostatic(1)=Depth(1)*1.027;
for i = 2 : r5
    Hydrostatic(i,1) = (Thickness(i)*1.027)+Hydrostatic(i-1);
end
Hydrostatic;
```

Figure 14: MATLAB Codes to Find Hydrostatic Pressure

The more essential element to determine whether or not that particular reservoir is in normal pressure, overpressure, or hard overpressure is pore pressure. To determine that, pore pressure is plotted together with overburden pressure and hydrostatic pressure. Pore pressure is the difference between overburden pressure and effective stress. MATLAB codes to calculate pore pressure is as per shown in Figure 15.

```

OB1=[Overburden;0];
d=size(OB1);
e=size(Effective_Stress);
i=1:d;
j=1:e;
Pore_Pressure=(OB1(i)- Effective_Stress(j));
[r6,c6]=size(Pore_Pressure);
Pore_Pressure(r6)=[];

```

Figure 15: MATLAB Codes to Find Pore Pressure

Since overburden stress, hydrostatic pressure and pore pressure was found, the relationship between these pressures can be plotted. Codes to plot them and plotted graph are shown in Figure 16 and Figure 17 separately.

```

figure(1)
[r7 c7] = size(Overburden);
[r8 c8] = size(Hydrostatic);
[r9 c9] = size(Pore_Pressure);
OB2=[Overburden;Overburden(r7)];
plot (OB2,Depth, '-.b')
hold on
HS2=[Hydrostatic; Hydrostatic(r8)];
plot (HS2,Depth, 'Color', [0,0.5,0])
PP2=[Pore_Pressure; Pore_Pressure(r9)];
plot (PP2,Depth, ':r')
hold off
xlabel ('Pressure (Mpa)')
ylabel ('Depth (m)')
legend ('Overburden Stress', 'Hydrostatic Pressure', 'Pore Pressure')
grid on
set(gca, 'YDir', 'reverse')

```

Figure 16: MATLAB Codes to Plot Overburden Stress, Hydrostatic Pressure and Pore Pressure

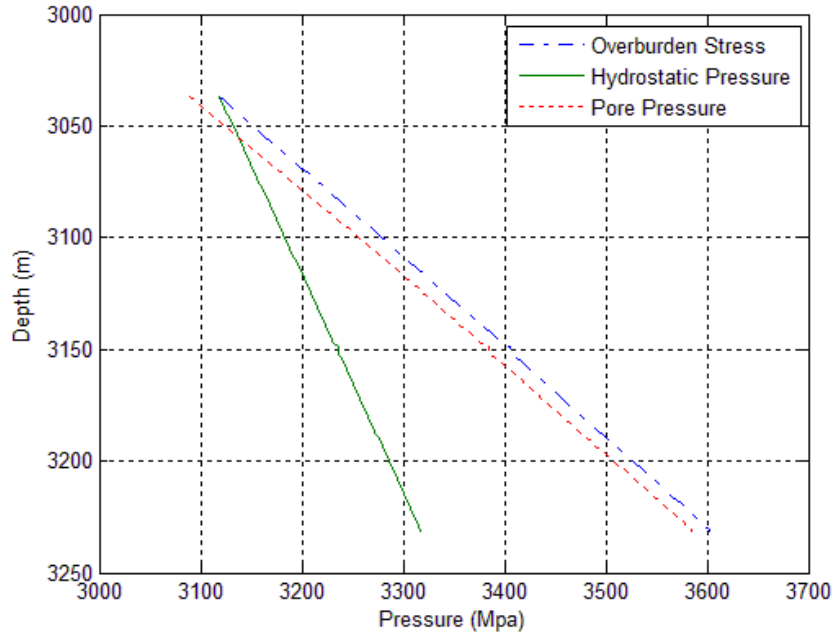


Figure 17: Overburden Stress, Hydrostatic Pressure and Pore Pressure Relationship

Based on shale volume calculated earlier, velocity and effective stress to be used in order to find value of unknown parameters – A and B – can be determined. Velocity and effective stress are chosen according to maximum shale volume. In this case, maximum shale volume is found at depth 3098.0595 m. Velocity and effective stress at that particular depth are 3980.8597 m/s and 22.5628 Mpa respectively.

Using that value of velocity and effective stress as reference, Equation (10) and (11) can be solved. MATLAB codes to solve for B and A are shown in Figure 18 and Figure 19 respectively.

$$V_1 - 5000 = A\sigma_1^B \quad - (1)$$

$$V_2 - 5000 = A\sigma_2^B \quad - (2)$$

$$(1) - (2)$$

$$A\sigma_1^B - A\sigma_2^B = V_1 - V_2$$

$$A(\sigma_1^B - \sigma_2^B) = V_1 - V_2$$

$$A = \frac{V_1 - V_2}{\sigma_1^B - \sigma_2^B} \quad (10)$$

$$\log\left(\frac{V_1 - 5000}{A}\right) = B \log \sigma_1 \quad - (1)$$

$$\log\left(\frac{V_2 - 5000}{A}\right) = B \log \sigma_2 \quad - (2)$$

$$\log(V_1 - 5000) - \log A = B \log \sigma_1 \quad - (1)$$

$$\log(V_2 - 5000) - \log A = B \log \sigma_2 \quad - (2)$$

$$(1) - (2)$$

$$\log(V_1 - 5000) - \log(V_2 - 5000) = B \log(\sigma_1 - \sigma_2)$$

$$B = \frac{\log(V_1 - 5000) - \log(V_2 - 5000)}{\log(\sigma_1 - \sigma_2)} \quad (11)$$

```
[rr cc]= max(Vshale);
f=size(Effective_Stress);
g=size(Velocity);
i=1:f; %ES
j=1:g; %V
BU1=Velocity(cc)-5000;
BU2=log10 (BU1);
BU3=Velocity(j)-5000;
BU4=log10 (BU3);
BU=BU2-BU4;
BD1=Effective_Stress(cc);
BD2=Effective_Stress(i);
BD3=BD1-BD2;
BD=log10(abs(BD3));
B1=BU./BD;
[r10,c10]=size(B1);
B2=sum(B1);
[B3,B4]=size(B1);
Average_B=B2/B3
```

Figure 18: MATLAB Code to Find B Value

```

AU1=Velocity(cc);
AU2=Velocity(j);
AU=AU1-AU2;
AD1=Effective_Stress(cc)^Average_B;
AD2=Effective_Stress(i).^Average_B;
AD=AD1-AD2;
A1=(AU./AD);
A1(cc)=[];
[r11,c11]=size(A1);
A2=sum(A1);
[A3,A4]=size(A1);
Average_A1=A2/A3;
Average_A=abs(Average_A1)

```

Figure 19: MATLAB Code to Find A Value

Based on calculation done, it is found that A is equal to 4412.492 meanwhile B is equal to 0.2172. Hence, Virgin Curve for Equation (1) can be plotted. Figure 20 and Figure 21 shows the plotted graph and MATLAB codes to generate the graph accordingly.

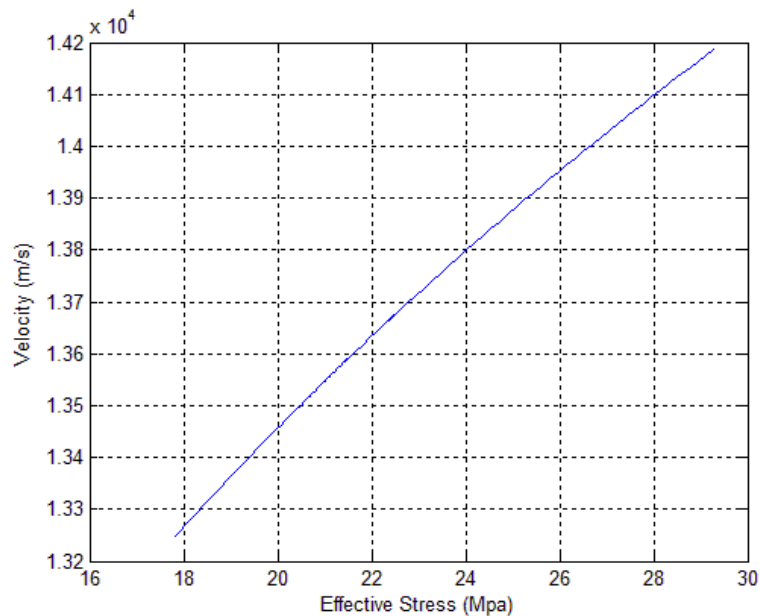


Figure 20: Virgin Curve Plotted by MATLAB

```

figure(2)
V_virgin=5000+(Average_A*(Effective_Stress.^Average_B));
plot(Effective_Stress,V_virgin)
xlabel('Effective Stress (Mpa)')
ylabel('Velocity (m/s)')
grid on

```

Figure 21: MATLAB Codes to Plot Virgin Curve

For unloading curve, parameter that needs to calculate is U. Solving for U in unloading equation will result as per Equation (12).

$$\begin{aligned}
 V &= 5000 + A \left[\sigma_{max} \left(\frac{\sigma}{\sigma_{max}} \right)^{\frac{1}{U}} \right]^B \\
 V - 5000 &= A \left[\sigma_{max} \left(\frac{\sigma}{\sigma_{max}} \right)^{\frac{1}{U}} \right]^B \\
 \log(V - 5000) &= B \log \left\{ A \left[\sigma_{max} \left(\frac{\sigma}{\sigma_{max}} \right)^{\frac{1}{U}} \right] \right\} \\
 \log(V - 5000) &= B \log A + B \log \left[\sigma_{max} \left(\frac{\sigma}{\sigma_{max}} \right)^{\frac{1}{U}} \right] \\
 \log(V - 5000) - B \log A &= B \log(\sigma_{max}) + B \log \left(\frac{\sigma}{\sigma_{max}} \right)^{\frac{1}{U}} \\
 \log(V - 5000) - B \log A - B \log(\sigma_{max}) &= \frac{1}{U} B \log \left(\frac{\sigma}{\sigma_{max}} \right) \\
 U &= \frac{B \log \left(\frac{\sigma}{\sigma_{max}} \right)}{\log(V - 5000) - B \log A - B \log(\sigma_{max})} \quad (12)
 \end{aligned}$$

Based on Equation 12, MATLAB codes are wrote to compute U value. The codes are shown in Figure 22.

```

U1=Effective_Stress(i)/max_ES;
U2=log10 (U1);
U3=vc_ES/max_ES;
U4=log10 (U3);
U=U2./U4;
[r12,c12]=size(U);
U5=sum(U);
[U6,U7]=size(U);
Average_U=U5/U6

```

Figure 22: MATLAB Codes to Find U

U is found to be 4.597. Based on the value, Unloading Curve can be plotted. Figure 23 shows MATLAB codes to plot the curve while Figure 24 shows the Unloading Curve.

```

V_unloading1=1/Average_U;
V_unloading2=Effective_Stress(i)/max_ES;
V_unloading3=max_ES*V_unloading2;
V_unloading4=(V_unloading3).^(V_unloading1);
V_unloading5=V_unloading4.^Average_B;
V_unloading6=Average_A*V_unloading5;
V_unloading=5000+V_unloading6;
figure(3)
plot(Effective_Stress,V_unloading,'r')
xlabel('Effective Stress (Mpa)')
ylabel('Velocity (m/s)')
grid on

```

Figure 23: MATLAB Codes to Plot Unloading Curve

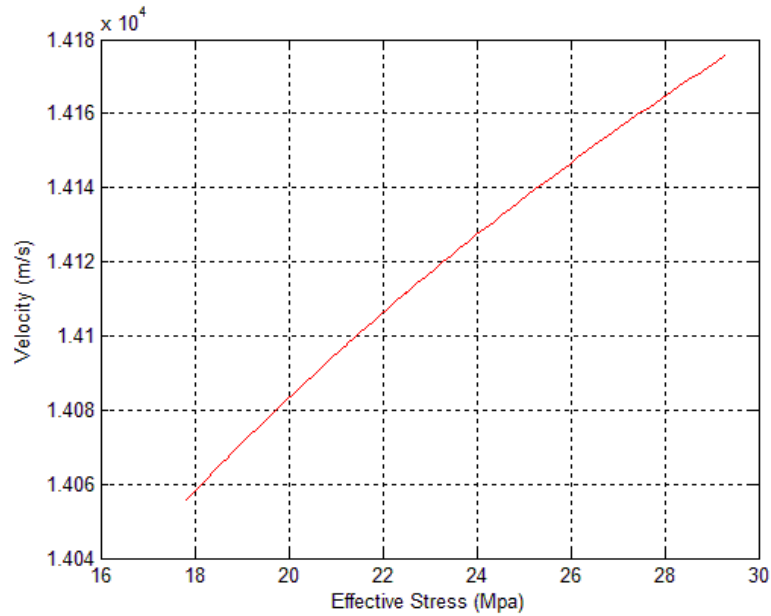


Figure 24: Unloading Curve Plotted by MATLAB

Full MATLAB codes to calculate all the calculation and to plot all the data is as in Appendix 2.

Based on the results obtained so far, GUI will then be created using GUIDE tool in MATLAB. Design for GUI is as per shown in Figure 25.

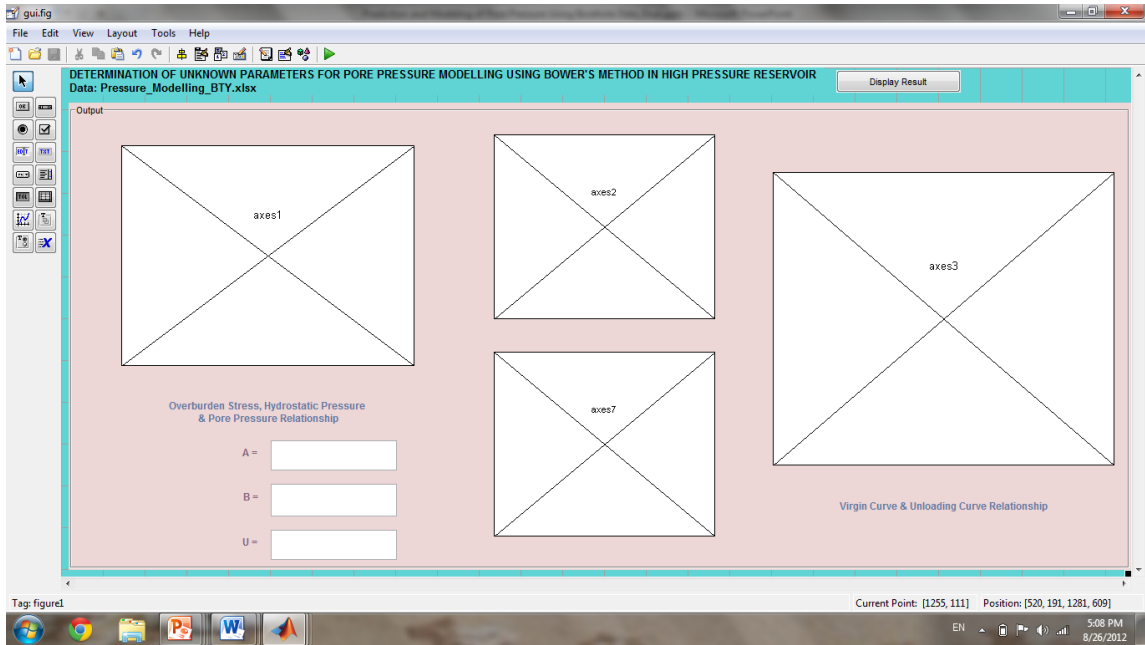


Figure 25: GUI Basic Design

Based on this design, MATLAB codes were generated by GUIDE. With all data was already loaded from Microsoft Excel to MATLAB, when the Push Button ‘Display Results’ is clicked, all these graphs and value of A, B and U will appear in their designated box accordingly as per shown in Figure 26.

Full MATLAB codes to create the Graphical User interface is as in Appendix 3.

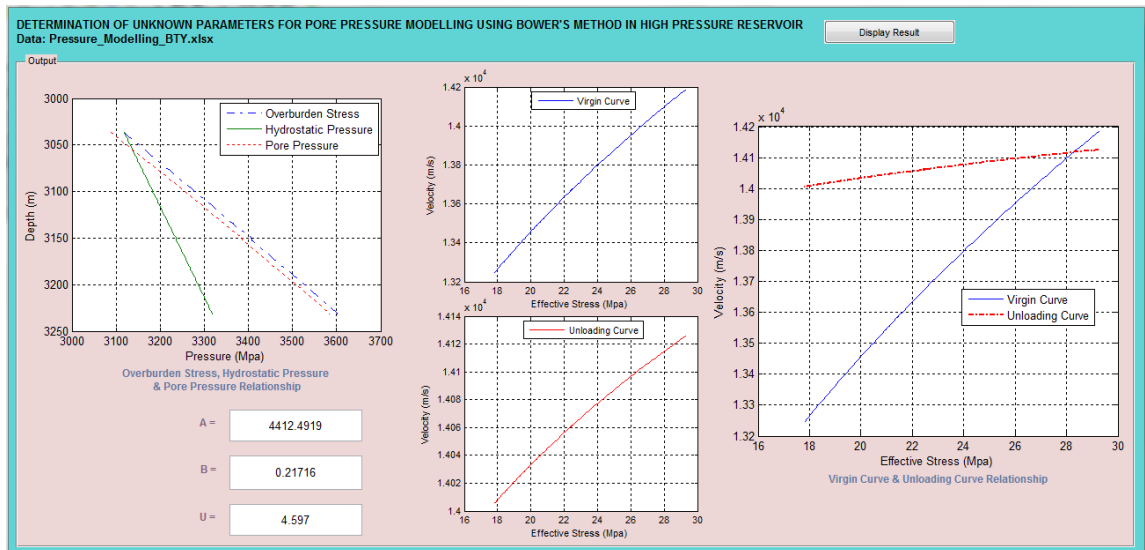


Figure 26: Resulting GUI

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

In conclusion, this project will be able to calculate certain parameter in order to model the pore pressure using Bowers Method for well logging / drilling. In addition to that, Graphical User Interface is developed to analyse and observe the relationship between hydrostatic pressure, overburden stress and pore pressure. GUI also should be able to show virgin and unloading curve of Bowers Method to indicate that whether or not overpressure in the reservoir is caused by undercompaction alone or fluid expansion is taking place as well. Should the unloading curve shows corresponding result, it indicate that there are fluid expansion activities in the reservoir. Otherwise, only undercompaction /compaction disequilibrium is the only cause of overpressure.

5.2 RECOMMENDATIONS

The understanding of petroleum geoscience is very important to carry out this project. Deep interest in the area is required for Electrical & Electronic Engineering students to study about field that are extraneous to the students. A lot of related journal have to be read in order to gain necessary knowledge regarding basic background of this project. It is recommended that the study is done early and extensively to ensure this project can be done successfully. Other than that, familiarity of MATLAB is highly required as all the calculation and plotting graph is conducted purely using MATLAB.

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APPENDIX A

Well Logging Data

APPENDIX B

MATLAB Codes

APPENDIX C

MATLAB GUI

Codes