MUD-WEIGHT PREDICTION FOR DEVIATED DRILLING

by

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CERTIFICATION OF APPROVAL

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September 2013

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.

(Muhamad Zakwan Bin Yusoff)

ABSTRACT

The success of drilling operations predominantly depends on the preparation of the mud weight design, which takes into consideration factors, such as narrowing of mud window, pressure loss as the well deviates, and availability of data from the field itself. This project aims to provide an in-house application to predict the mud weight design in deviated drilling. Specifically, the objectives of this project are 1) to develop an algorithm for predicting mud weight in deviated drilling; 2) to solve the governing equation for stresses around the wellbore for deviated drilling and 3) to build an integrated tool kit for different data that are available on the field. The project was divided into four main phase. The first phase consisted of background study and literature review related to wellbore instability, principle stress, mud window, and Mohr's Coulomb Criteria. The second phase identified the parameters and deriving the equation for stresses around deviated well. The third phase focused on building a model to calculate the stresses around the borehole and mud weight window. The fourth phase was testing and validation of the model and also improving the user interface. The project deliverable is a mud weight design tool for deviated drilling with capability to depict well trajectory.

ACKNOWLEDGMENTS

First and foremost, I would like take this opportunity to extend the utmost gratitude to those who have contributed either directly or indirectly for their continuous support and contribution in completing this Final Year Project. This 7 months experience has given me an opportunity to learn something new and embrace the challenge that has been given to me.

A heartfelt thank you goes to my supervisor Dr William Pao King Soon, for guiding me with endless patient and cooperation to help me complete the project. He has been a role model to me in terms of his experience and expertise. I would like to thank him for his continuous support and motivation and I sincerely appreciate all the guidance and knowledge that he has taught me so that I would be well prepared to face the real world in years to come. Henceforth, I am determined to strive for the best so that I could apply all that I have learnt throughout this journey.

Not to forget, I like to thank all my friends that have supported me directly or indirectly for their assistants in helping me to understand and learn visual basic for application skills which are needed in developing the program as a prototype of this project. Last but not least, thank you to my family for their support and encouragement which enable me to do my best for this project. I hope after this program, all the knowledge and experience I gained can be shared with everyone.

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CHAPTER 1: INTRODUCTION

1.1 Project background

Oil and gas operation has been progressing rapidly over the past few years as the technology advances coped with the current demand. Drilling operations in particular has become increasing difficult. Major oil and gas companies are starting to change the direction of oil production as they are trying to produce from reservoirs that are not easily accessible, for example, deviated drilling. In drilling operations, one of the major concerns is wellbore stability. Wellbore instability is one the major causes of non-productive time [10]. Millions of dollars are lost with every minute that are wasted due to wellbore instability during drilling operation. Muds or drilling fluids are used for many purposes in drilling operations. For example, it is used to cool the drill bits and to bring the drilled cuttings up to the surface. However, the most important functions is that it is designed specifically to create a hydrostatic pressure to prevent the wellbore from collapsing. Thus, mud weight design is a crucial part of maintaining wellbore stability.

1.2 Problem statement

The wellbore becomes more unstable as the wellbore deviates, which is caused by the narrowing of the mud window. Thus, it is crucial to determine the safe mud window for deviated drilling. Vertical drilling and deviated drilling is different in a way that the amount of pressure loss in the latter is a whole lot more than the former. The pressure loss is due to the frictional force introduced the wellbore due the deviated drilling. It is not a common misconception to assume that not all data are available in oil and gas operations. There are a lot of parameters that could help design a safe mud window. However, not all data are available for every field. Thus, the drilling engineers have to optimize the data that are available to them to predict the mud weight design.

There are a few problems that have been identified:

1. As wellbore deviation increases, the stability envelope narrows dramatically
2. The amount of pressure loss for deviated wells are a whole lot more than vertical wells
3. Some of the data are not always available on the field

1.3 Objectives

The objectives of the project are as follows:

1. Develop an algorithm for predicting mud weight in deviated drilling
2. Solve the governing equation for stresses around the wellbore for deviated drilling
3. Build an integrated tool kit for different data that are available on the field

1.4 Scope of study

1. Study on wellbore instability and the causes
2. Focusing on wellbore stresses for deviated drilling and identifying the parameters that governs it
3. Study on wellbore failure criterion
4. Study on mud weight window for deviated drilling
5. Learning to use Visual Basic for Application (VBA) to improve the current software.

1.5 Relevancy of the project

The project is related to the current demand of the oil and gas industry as more deviated wells are being drilled. It could help major oil and gas companies to increase their profit and prevent them from losing their investment due to non-productive time caused by wellbore instability. An in-house software predicting would provide drilling engineers an easier option to predict the mud weight design.

1.6 Feasibility of the project

The project is feasible to the time frame allocated for Final Year Project (FYP) which is 8 months. This project requires designing an in-house application using the VBA in Microsoft Excel, is readily available. Most of the time will be spent in designing the software. Thus, the project is feasible and can be completed within the given time frame.

CHAPTER 2: LITERATURE REVIEW

2.1 Wellbore instability

Wellbore instability is a condition where during drilling process, the pressure inside the wellbore is either too low or too high for the formation. It is crucial to prevent wellbore instability as it leads to complication for the well. Mohiuddin et al. (2005) mentioned that drilling is basically an interplay between the uncontrollable and controllable factor. Uncontrollable factors are factors that cannot be modified or control during drilling operation which are, the earth stresses, the pore pressure and also the rock strength. However, with the knowledge of these uncontrollable factors, a proper drilling program can be design to optimize the controllable factor. The controllable factors consist of mud weight, wellbore azimuth and inclination. Figure 1 shows the causes and effects of wellbore instability.

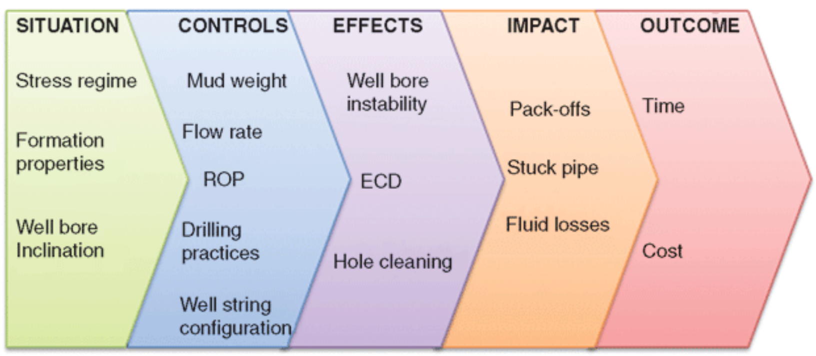


Figure 1: Wellbore instability (Veeningen, 2013)

According to Edwards et al. (2002), the instability is a result of stress concentration caused by the difference between the vertical and horizontal stress surrounding the wellbore. These differences disturb the formation original stress causing the wellbore to collapse. For deviated drilling, wellbore azimuth, inclination, and relative stress magnitude is a major factor that determines the stresses around the wellbore (Islam et al. 2010).

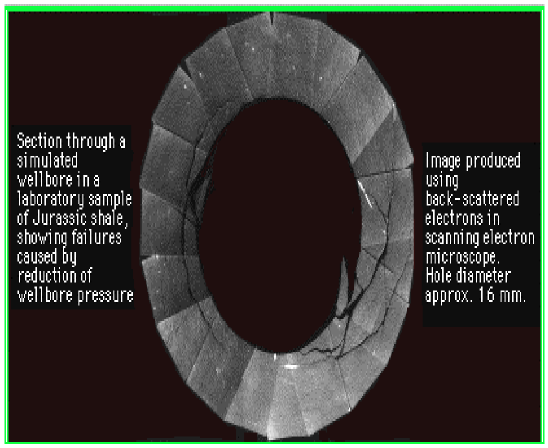


Figure 2: Wellbore instability caused by low mud weight (Hassan et al. 1999)

A proper mud weight is designed to prevent wellbore instability. Wellbore instability can cause a lot of complications that would affect the whole value of a project. Figure 2 shows an example of wellbore instability which is caused by low mud weight. Bassey et al. (2011) stated that a wellbore instability could lead to stuck pipe, reaming operation, poor cementation and lost circulation. In a worst case scenario, the wellbore has to be sidetrack in order to reach the original target location. Each one of the effect would cost a lot in order to mitigate the situation. Stuck pipe happens when the pressure created by the mud weight is not sufficient enough to maintain the pore pressure, causing the wellbore to collapse. Lost circulation on the other hand, is where the mud pressure exceeds the fracture pressure, which fractures the formation, causing the mud weight to enter the formation.

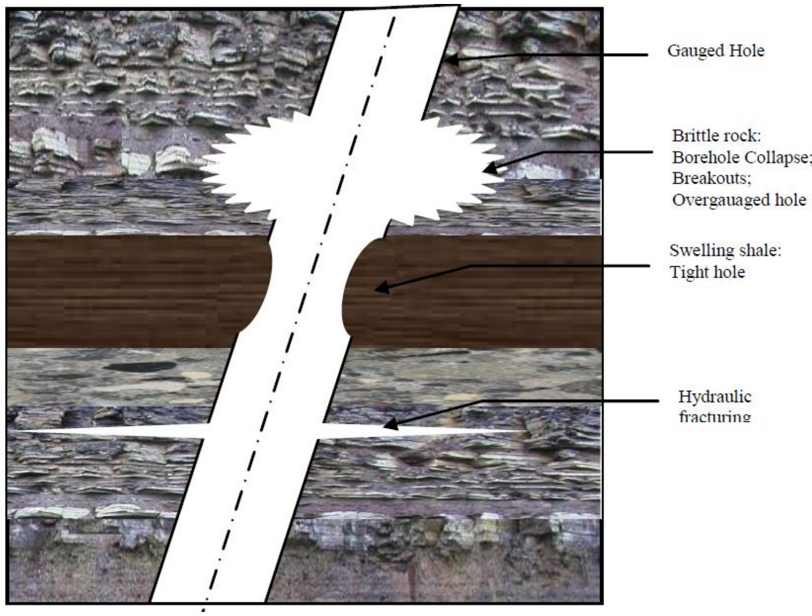


Figure 3: Typical borehole instability (Kang et al. 2009)

A good wellbore stability prediction and mud weight prediction are not only affected by the calculation of stresses around the wellbore, but also by selecting a proper mud weight criterion to determine the onset of failure. Islam et al. (2010) mentioned that typical wellbore instability, which is shown in Figure 3, can be prevented by using a failure criterion to design the mud weight. A wellbore will usually fail under a combination of stresses. A failure criterion is widely used in the oil and gas industry to determine the point where there wellbore will undergo shear failure. Since the project will only be focusing on the principle stresses around the wellbore, a linear elastic model will be used as the failure criteria.

Kang et al. (2011) listed a few factors that are the major parameters that affect wellbore stability:

- *Rock mechanical properties*

  It is important to know the rock mechanical properties as it affects the wellbore behavior. Some of the important properties are rock porosity, permeability, cohesive and tensile strength, internal friction angle, Young’s modulus, and Poisson’s ratio.

- *Principle stresses*

  The principle stresses are used to calculate the in-situ stress around the wellbore. The vertical can be easily obtained from density logs and the minimum horizontal stress can be measured from the Leak-Off Test (LOT). The magnitude and direction the stresses is important to maintain the wellbore stability

- *Wellbore trajectory*

  The stresses acting around the wellbore are a function of well inclination and azimuth. These parameters are used to calculate the in-situ stresses around the wellbore.

- *Pore pressure*

  It is important to predict an accurate pore pressure for the formation as it can affect the state of stresses around the wellbore.

- *Drilling fluid and pore fluid chemicals*

  A chemical potential difference can cause fluid flow in and out of the pores and causes pore pressure redistribution. The induced fluid flow can create significant pore pressure propagation especially for low permeability formation

- *Temperature*

  Thermal induced stress are caused by the difference in temperature between the mud and the formation, which would normally occur in deep wells.

- *Mud weight*

  Mud weights are used to provide support to the wellbore and prevent it from collapsing. Usually in drilling operations, the mud weights are increased in increment depending on the situation.

- *Time*

  Chemical and thermal effects can cause pore propagation in the formation. The process will take time to cause the changes which will then cause wellbore instability. This shows that wellbore stability is time dependent.

2.2 Principle stress

The original formation is subjected to a few principle stresses that are under equilibrium which is represented by the state of the rock as shown in Figure 4. The original state of the rock is subjected to three in-situ principle stresses which are, the overburden stress, the minimum horizontal stress, and the maximum horizontal stress (Kang et al. 2009). Overburden stress is also known as the vertical stress. Usually, the value for the vertical stress is obtained using the density log. Minimum is important in designing the safe range for mud weight. It can be measured using the LOT. LOT is a test where the well is shut in and fluid is pumped into the wellbore to gradually increase the pressure. At one point, the fluid will move into the formation either by using pore spaces in the formation or by fracturing the formation and creating a new path. That pressure is considered as the fracture pressure of the formation or the minimum horizontal stress. For safety purposes, the fracture pressure is assumed to be slightly below the leak off pressure.

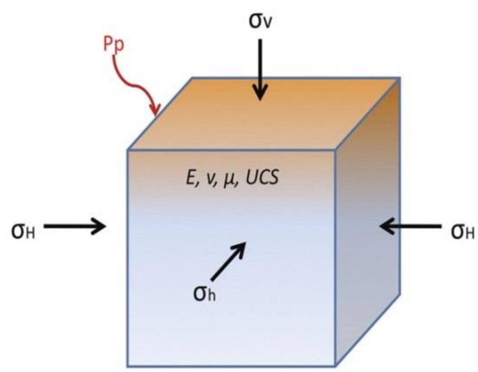


Figure 4 Principle stresses (Wikel, 2011)

Determination these data are important in designing the mud window especially for the minimum horizontal stress. Edwards et al. (2002) stated that the minimum horizontal stress is important in determining the upper limit of the mud weight window. Besides that, determination of the pore pressure is also important. For a normal pressured formation, the pore pressure gradient is assumed to be 0.465 psi/ft which is shown in Figure 5.

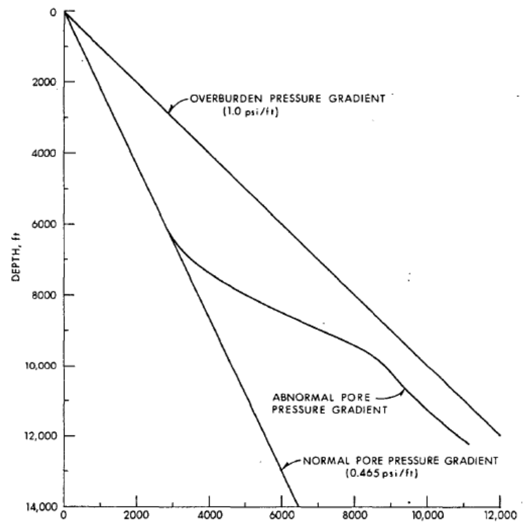


Figure 5: Formation Pressure Gradient (Bradley, 1974)

According to Bassey et al. (2011), during drilling operations, the principle stresses which are in equilibrium are redistributed which can lead to shear or tensile failure. The support that is originally offered by the drilled rock formations are displaced by the drilling fluid that creates a hydrostatic pressure that maintains the wellbore. The redistributed stresses after the drilling process around the borehole are known as the radial, tangential, and axial stress (Pasic et al. 2007). The radial stress acts from all directions perpendicular to the borehole wall, the tangential stress circles the borehole, and the axial stress acts parallel to the wellbore axis which is shown in Figure 6.

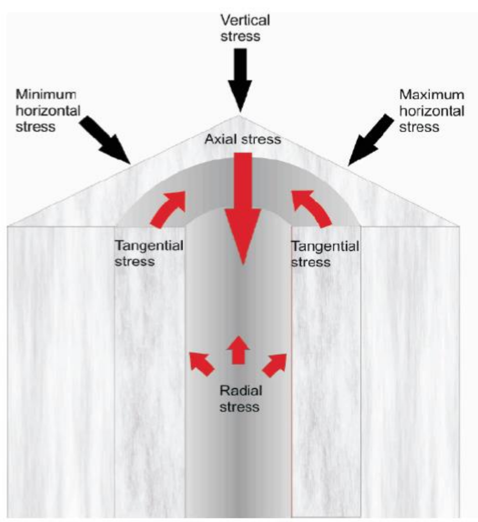


Figure 6: Wellbore stresses (Pasic et al. 2007)

Pasic et al. (2007) also mentioned that for deviated well, the local stresses induced by in-situ stress and hydraulic effect at the wellbore, can be expressed using the following equation:

$$\sigma_r = P_w \quad \ldots\ldots (2.1)$$

$$\sigma_t = (\sigma_x + \sigma_y) - 2(\sigma_x - \sigma_y) . \cos 2\theta - 4\tau_{xy} . \sin 2\theta - P_w \quad \ldots\ldots (2.2)$$

$$\sigma_a = \sigma_z - v[2 . (\sigma_x - \sigma_y).\cos 2\theta + 4\tau_{xy} . \sin 2\theta] \quad \ldots\ldots (2.3)$$

$$\tau_{\theta z} = 2(\tau_{yz} . \cos \theta - \tau_{xz} . \sin\theta) \quad \ldots\ldots (2.4)$$

$$\tau_{r\theta} = \tau_{zz} = 0 \quad \ldots\ldots (2.5)$$

2.3 Mud window

Guo et al. (2009) defined mud window as the range between the minimum and maximum allowable mud weight. The minimum mud weight is measured using the pore pressure that is obtained from density logs. The designed mud weight must exceed the minimum allowable mud weight to prevent influx which is also known as overbalance drilling. For safety purposes, a general safety factor of 200 psi is added to the minimum mud pressure (Islam et al. 2010). If the mud weight is less than the minimum mud weight, the wellbore will collapse because the pressure from the formation is higher than the hydrostatic pressure created by the drilling fluid. In a worst case scenario, it may also lead to kick. A kick is an unplanned influx of formation fluid into the wellbore (Cook et al. 2012). The mud pressure also must not exceed the minimum horizontal stress which is the fracture pressure. If the mud pressure exceeds, the minimum horizontal stress, it will cause the formation to fracture. The fracture will propagate around the area of the wellbore, causing drilling fluid loss circulation. Figure 7 shows the schematic relationship between mud weight and wellbore failure.

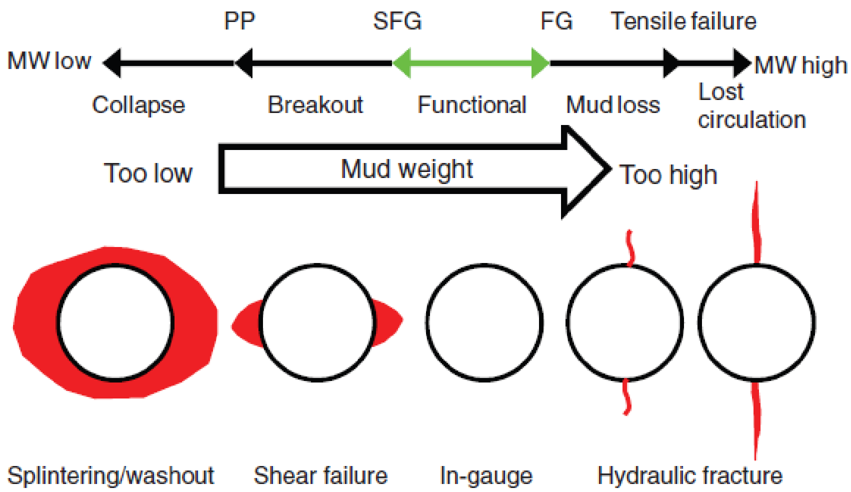


Figure 7: Schematic relationship between mud weight and wellbore failure (Zhang et al. 2008)

In the case of deviated wells, the mud window is largely affected by the wellbore azimuth and inclination. Mohiuddin et al. (2005) showed that the mud density depends on the azimuth and inclination of the deviated well. Deviated drilling will cause the stability envelope to narrow dramatically. So, as the inclination increases, the risk of wellbore instability increases as shown in Figure 8. He also mentioned that in general, deviated wells can safely be drilled with mud weight range of 76 – 78 PCF with minimum wall failure.

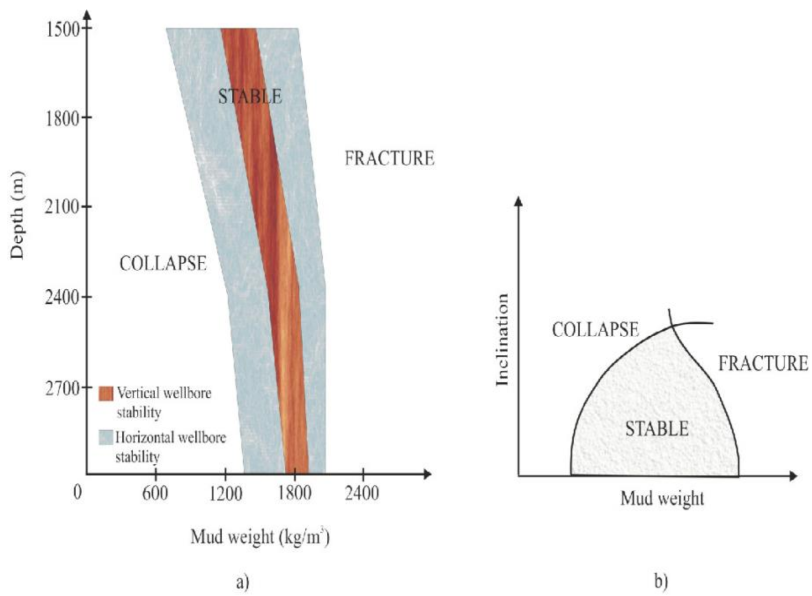


Figure 8: Effect of the well depth (a) and the hole inclination (b) on wellbore stability (Pasic et al. 2007)

2.4 Mohr's Coulomb Criteria

There are a lot of failure criteria that are used to identify the shear or tensile failure of the reservoir. Islam et al. (2010) stated that a failure criterion tells under what combination of stresses the wellbore will fail. A borehole will fail either by exceeding the tensile strength of the rock or the pore pressure exceeds the pressure inside the wellbore causing wellbore breakouts. Accordingly, the term borehole failure criterion represents the boundary conditions in which the wellbore failure occurs. If shear failure occurs, the rock will break off from the virgin formation and fall into the borehole.

The Mohr's Coulomb shear failure model, which is shown in Figure 9, is one of the most widely used models for calculating borehole collapse. The model does not consider the effect of the intermediate stress or the maximum horizontal stress (Islam et al. 2010) & (Pasic et al. 2007). The shear failure criteria can be expressed as the following:

$$\tau = \sigma_n \tan(\phi) + c \quad \text{(2.6)}$$

Charlez (1999) mentioned that in the Mohr diagram, the rock strength is represented by the straight line (The Mohr Coulomb line), with two material constants (cohesion c and friction angle ϕ), while the mechanical state around the wellbore is represented by the circle. The size of the circle depends on the horizontal stress (assuming $\sigma_H = \sigma_h$), pore pressure, and the mud pressure. The mud pressure and horizontal stress can affect the diameter of the circle. When the stress increases, the circle becomes bigger. Whilst as the mud pressure increases, the circle becomes smaller. Pore pressure on the other hand, does not change the diameter of the circle. However, if the pore pressure decreases, the circle will move to the right, and if the pore pressure increases, the circle will move to the left. So, the higher the pore pressure, the higher the risk of instability.

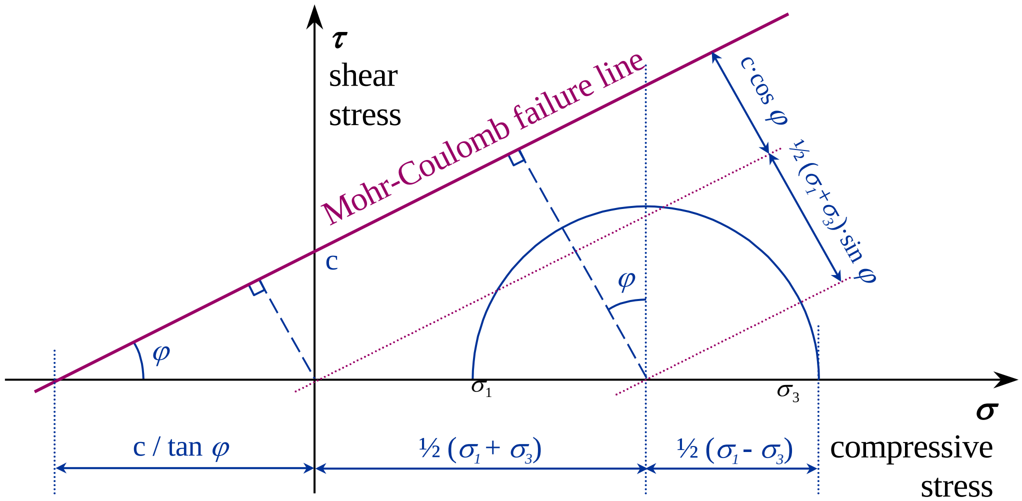


Figure 9: The Mohr-Coulomb failure criteria (Van den Bogert, 2011)

Christensen et al. (2004) stated that the advantages of using the Mohr's Coulomb Criteria are:

1. It is commonly used in the geotechnical society
2. The parameters that are required can be easily defined
3. It can be implemented in a numerical code

CHAPTER 3: METHODOLOGY

3.1 Project Methodology

Figure 10 below shows all the important phase for the whole project. The activities are divided into four phases which are the background study and literature review, stress equation derivation, model integration, and lastly validation of application.

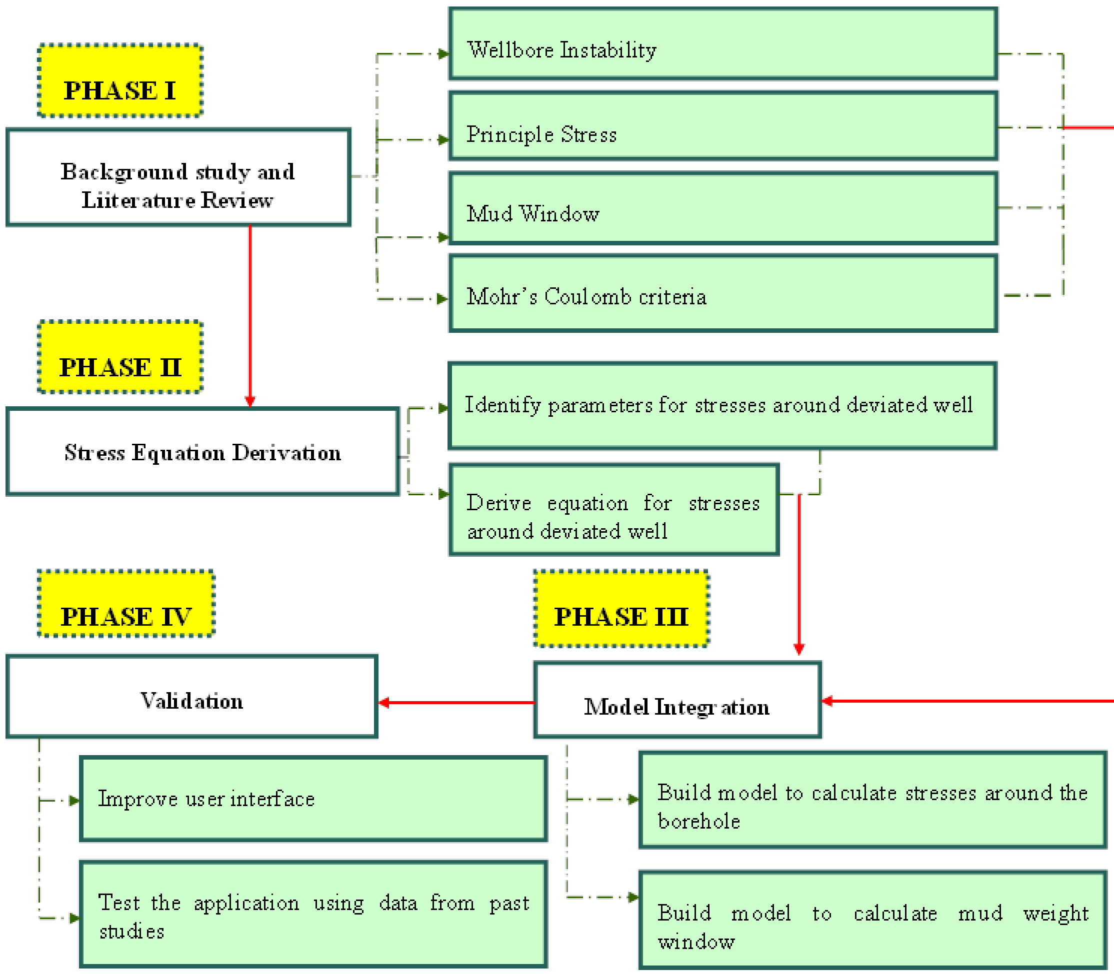


Figure 10: Methodology

Phase 1

Initial research is conducted which consist of background study and literature review related to wellbore instability, principle stress, mud window, and Mohr's Coulomb Criteria which are the main ideas behind the project. The objectives, scope of study and significant of study are identified to create the boundary of this project. Literature review is conducted to further identify the relationship between the effects of wellbore inclination towards the mud weight window. In addition, the author needs to have an adequate skills and knowledge to use Visual Basic for Application in Microsoft Excel as a main tool to complete this project

Phase 2

It is known that as the wellbore deviates during drilling operations, the stability envelope will narrow dramatically. The stability envelope is also known as the mud weight window. The mud designed for drilling must stay inside the safe mud window in order to prevent the wellbore from experiencing tensile or shear failure. The failure around the wellbore is caused by the stresses that are redistributed due to the formation that is displaced during drilling operation which is essentially the in-situ stresses. However, there are also other parameters that govern the stresses in wellbore stability. So, in order to prevent wellbore instability, the first step is identifying the parameters that have an effect on the stresses around the deviated well. Islam et al. (2010) mentioned that for deviated drilling, wellbore azimuth, inclination, and relative stress magnitude is a major factor that determines the stresses around the wellbore. In addition to that, the pore pressure is also an important parameter, because it represents the limit at which the wellbore can withstand the pressure before fracturing.

Based on these parameters, the equation to calculate the effective stresses that acts around the borehole will be derived. After calculating the effective stresses around the borehole, the next step is to define the failure condition of the rock at that point. . A borehole will fail either by exceeding the tensile strength of the rock or the pore pressure exceeds the pressure inside the wellbore causing wellbore breakouts. The failure of the formation will be determined using the Mohr's failure criterion. Charlez (1999) mentioned that in the Mohr diagram, the rock strength is represented by the straight line

(The Mohr Coulomb line), with two material constants (cohesion c and friction angle ϕ), while the mechanical state around the wellbore is represented by the circle. The straight line is represented by the following equation:

$$\tau = \sigma_n \tan(\phi) + c \quad \text{..........} (3.1)$$

Phase 3

After the equation has been identified, it will be developed into a model by integrating the equation into the application along with the failure condition. The model will be developed to allow the user to input the necessary data and calculate the stresses around the deviated well. The model for the mud weight window will also be integrated into application. After the stresses are calculated, the mud weight model will provide a safe mud weight window for the deviated well.

Phase 4

At this stage, all the calculations process required is already implemented into the application. The program can be used to calculate the stress distribution around borehole and also estimate the range of mud weight required. Graphical User Interface (GUI) acts as a medium of interaction for the user where they can key-in the required parameters and be presented with the desired result. The improvement of the interface is a continuous process.

The application will be tested in terms of its function and accuracy to produce a result by comparing it to the results that have already been produced. This will help validate the effectiveness of the application. The set of previous data will be obtained from studies that have been conducted.

3.2 Calculation of well trajectory

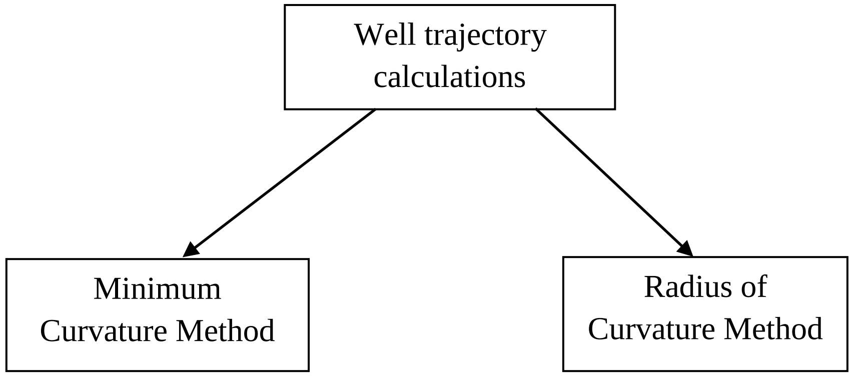


Figure 11: Well trajectory calculations

Data Input	Data Output
Measured Depth	TVD
Wellbore Inclination	Northing
Wellbore Azimuth	Easting
Vertical Stress Gradient	Vertical Section
Minimum Horizontal Stress Gradient	Dog-leg severity
Maximum Horizontal Stress Gradient	Mud Weight Window
Pore Pressure Gradient	

Table 1: Data input and output

There are 2 well trajectory calculation methods as shown in Figure 13 that were taken in consideration to fulfill the purpose of the project which are the Minimum Curvature Method and Radius of Curvature Method. These methods will assist in showing the well trajectory of the wellbore based on the survey data that are uploaded into the program. Table 1shows the required data that has to be uploaded into the software and also the output that will be provided based on the calculation that is done.

Minimum curvature method

This method minimizes the total curvature within the constraints of the wellbore to produce a smooth circular arc. Ratio factor is calculated to smooth the vectors on the wellbore curve where the surveys at the two stations define vectors which are tangent to the wellbore at the survey points.

First calculate the dog-leg angle in degrees (DL)

$$\cos DL = \cos(I_2 - I_1) - \sin I_1 \times \sin I_2 \times (1 - \cos(A_2 - A_1)) \quad \text{.......................(3.2)}$$

Then calculate the ratio factor (RF)

$$RF = \frac{2\times180}{DL\times\pi} \times \tan\frac{DL}{2} \quad \text{...(3.3)}$$

$$\Delta TVD = \frac{\Delta MD}{2}(\cos I_1 + \cos I_2) \times RF \quad \text{...(3.4)}$$

$$\Delta N = \frac{\Delta MD}{2} \times (\sin I_1 \cos A_1 + \sin I_2 \cos A_2) \times RF \quad \text{......................................(3.5)}$$

$$\Delta E = \frac{\Delta MD}{2} \times (\sin I_1 \sin A_1 + \sin I_2 \sin A_2) \times RF \quad \text{......................................(3.6)}$$

Where

ΔMD = increment of course length

I_1 I_2 = inclination andgles at station 1 and 2 respectively

A_1, A_2 = azimuth angles at stations 1 and 2 respectively

Radius of curvature method

This method uses the top and bottom angles to generate a space curve having a spherical arc shape that connects two stations. Each course length is assumed to be circular arc in both vertical and horizontal planes.

Increment of true vertical depth (ΔTVD):

$$\Delta TVD = \frac{360\times\Delta MD(\sin I_2-\sin I_1)}{2\pi(I_2-I_1)} \quad (3.7)$$

Increment of northing co-ordinate (ΔN)

$$\Delta N = \frac{(360)^2\Delta MD(\cos I_1-\cos I_2)(\sin A_2-\sin A_1)}{4\pi(A_2-A_1)(I_2-I_1)} \quad (3.8)$$

Increment of easting co-ordinate (ΔE)

$$\Delta E = \frac{(360)^2\Delta MD(\cos I_1-\cos I_2)(\cos A_1-\cos A_2)}{4\pi(A_2-A_1)(I_2-I_1)} \quad (3.9)$$

Where

ΔMD = increment of course length

I_1 I_2 = inclination andgles at station 1 and 2 respectively

A_1, A_2 = azimuth angles at stations 1 and 2 respectively

3.3 Prototype Flow Chart

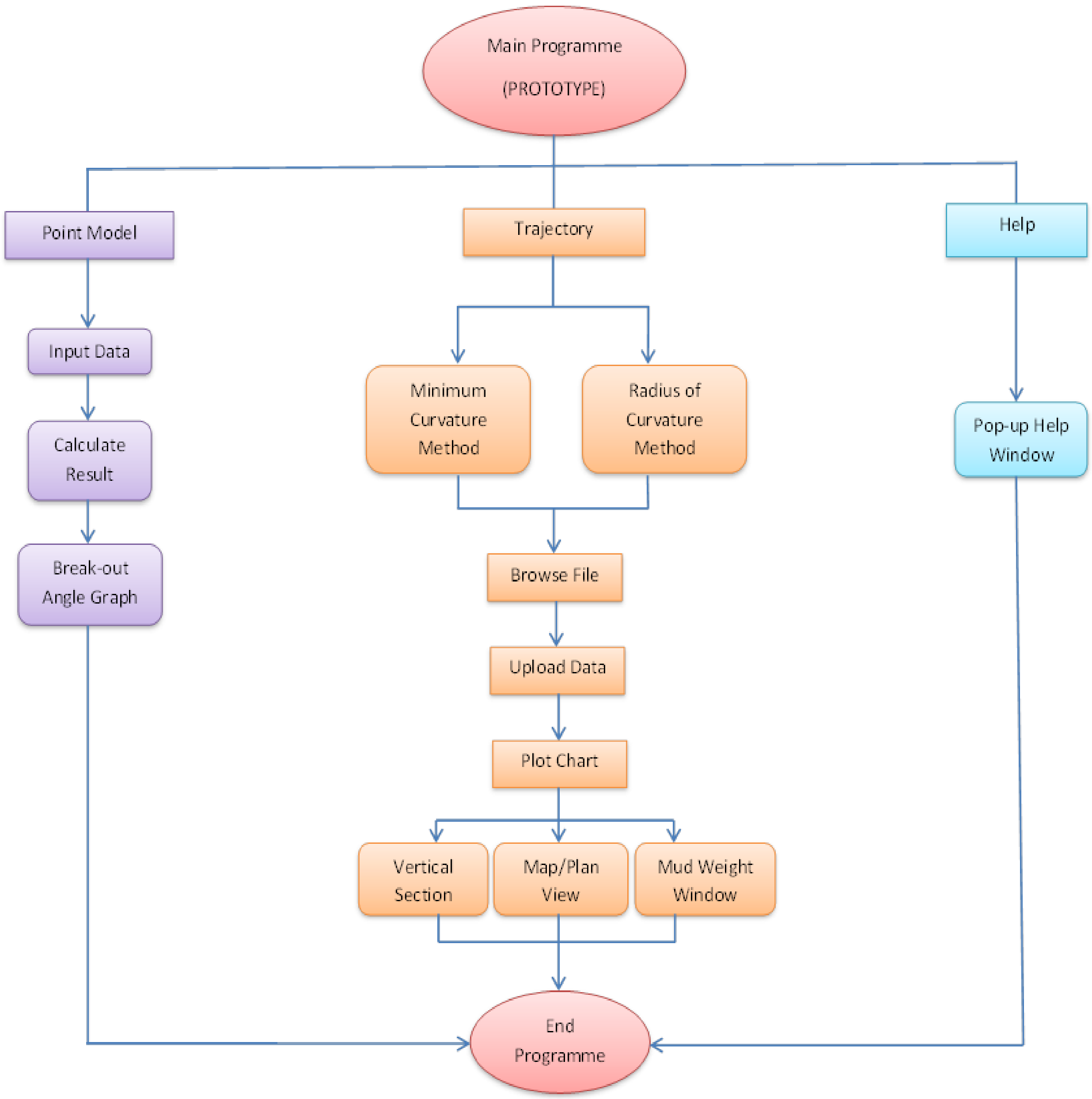


Figure 12: Prototype flow chart

3.4 Gantt chart

Table 2: Gantt chart and Key Milestones for FYP 1 and FYP 2

● Key milestone

	FYP I														**FYP II**													
Activities / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of Project Topic																												
Preliminary Research Work Regarding Borehole Stability and Principle Stresses																												
Literature Review																												
Working On Governing Equation For Stress Distribution Around Deviated Wells And Identifying Key Parameters										●																		
Research On Stress Distribution Around Deviated Well Calculation Tool Using Microsoft Excel											●																	
Build model to calculate the stress and mud window													●	●														
Build model for well trajectory calculations																			●									
Improving the Existing User Interface for Stress Distribution Using VBA																									●			
Testing and validation																											●	●

3.5 Tools required

Microsoft Excel is a spreadsheet application that features calculation, graphing tools, pivot tables, and a macro programming language called Visual Basic for Applications. The macro function allows the application to be configured using the VBA programming language. It provides an easier way to perform a mundane, repetitive task, or to perform some task that the standard Excel User Interface does not seem to address. This program will be the only tool required to complete this project in order to build the application.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Stress Analysis

Four important values as shown in Table 3 are required for effective stresses calculation, which are total vertical stress, total maximum horizontal stress, total minimum horizontal stress, and total pore pressure. These values are obtained by multiplying the stress gradient with true vertical depth. From that, the effective vertical stress, maximum effective horizontal stress, and minimum effective horizontal stress are obtained by subtracting pore pressure from each respective value. The following stress values were taken from a SIEP Report by Shell International Exploration and Production team to be used as a guideline in researching and validating the effect of wellbore inclination to the mud weight margin.

Stress Gradient \ TVD	0	3688 m	3840 m	4054 m	4237 m	4389 m	5029 m
Vertical (kPa/m)	0	13.67	14.00	14.42	14.83	15.09	16.02
Maximum horizontal (kPa/m)	0	13.52	13.84	14.27	14.70	14.95	15.92
Minimum horizontal (kPa/m)	0	13.36	13.67	14.12	14.57	14.80	15.83
Pore pressure (max) (kPa/m)	0	12.00	12.95	13.59	13.59	13.64	13.42
Pore pressure (min)	0	11.89	12.26	12.42	12.46	12.57	13.42

Table 3: In-situ stress gradients along the well trajectory

Since the trajectory of the well were not given, a set of survey data, as shown in Table 4, were prepared to depict well trajectory, which are measured depth, inclination angle, azimuth, and target bearing. These values can be used to show the vertical section and the map/plan view of the well trajectory. Vertical section profile is defined in a plane bounded by the direction straight from the surface location to the target. This direction is described as the vertical section azimuth or target direction. The total horizontal displacement of the well projected onto this plane is called vertical section. The map/plan view on the other hand, represents the actual well path in the horizontal plane by using the easting and nothing coordinates.

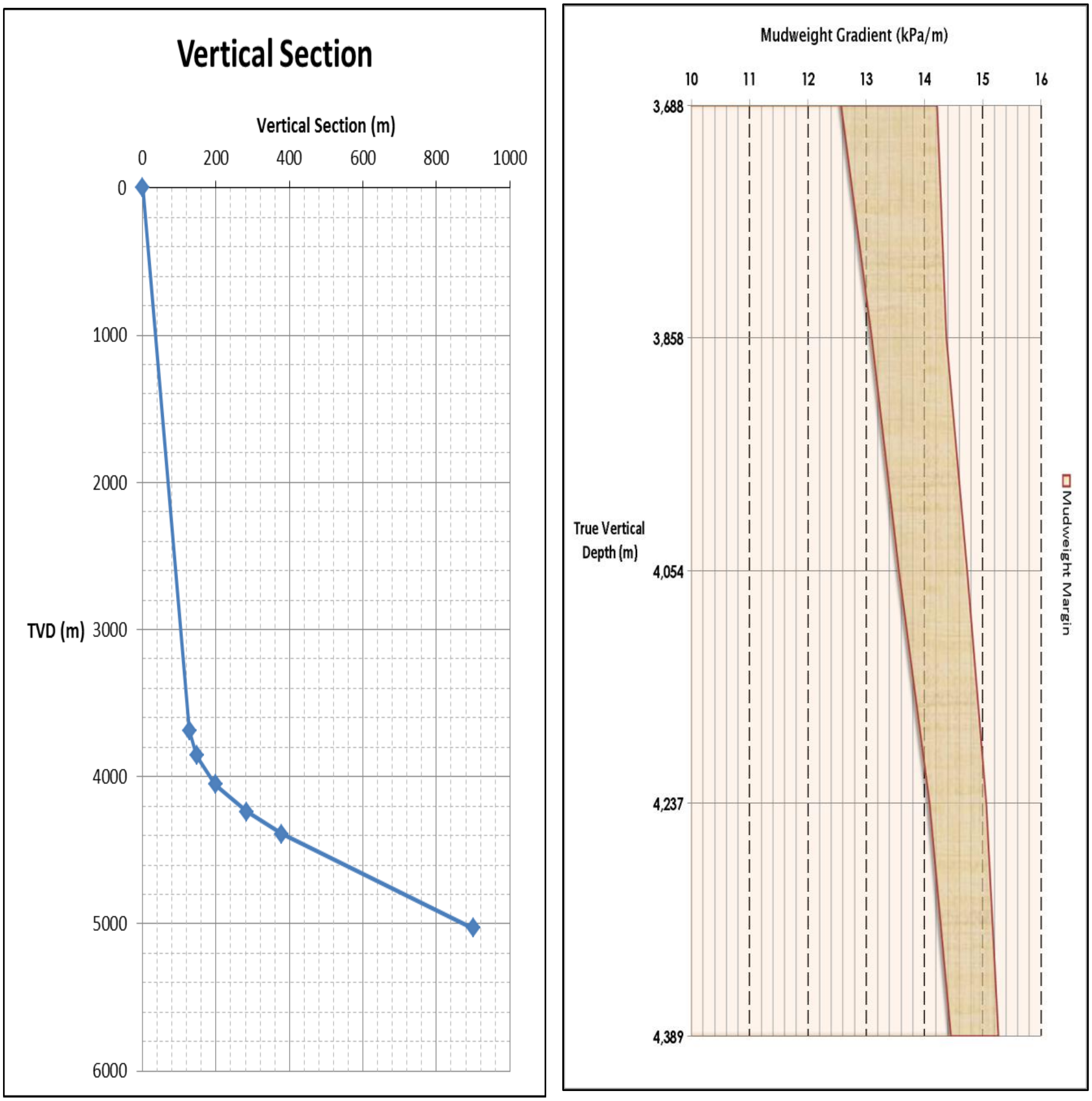
Target Bearing, Degrees	Measured Depth, m	Inclination Angle, Degrees	Azimuth, Degrees
45	0	0	0
45	3692.69	5	15
45	3684.05	10	25
45	4067.88	20	40
45	4270.05	30	50
45	4450.03	35	58
45	5286.86	45	60

Table 4: Well trajectory data

4.2 Development of mud weight window

Mud weight window is the estimated range between the minimum and maximum allowable mud weight along the well trajectory. It can give a general idea of a safe range to prepare mud weight along the well path. For deviated drilling, inclination and azimuth will cause the narrowing of the mud window. Mohiuddin et al. (2005) showed that the mud density depends on the azimuth and inclination of the deviated well. Deviated drilling will cause the stability envelope to narrow dramatically. So, as the inclination increases, the risk of wellbore instability increases. As shown in Figure 13, the mud window narrows as the inclination of the well increases along the well trajectory which proves the effect of inclination and azimuth to the mud window. The mud window is represented by the area within the elastic-brittle mud weight, which is the lower limit of the range, and the elastic upper limit, which is the upper limit of the range.

Potential fracturing may occur if the mud weight is raised too high which may lead to significant loss of drilling fluid. The mud weight that induces tensile failure is usually not equal to the minimum in-situ stress, because the in-situ principle stresses were redistributed around the wellbore when it is drilled. This implies that the mud weight required to initiate a fracture from the borehole wall is different (often higher) than the mud weight required to propagate the fracture beyond the zone of stress redistribution. The minimum in-situ stress is therefore preferred to as Loss-Circulation mud weight. Any additional stress barrier around the wellbore is considered as safety margin to accommodate swab-surge pressure oscillations. Fractures that stay within the near wellbore region can only store a limited volume of drilling fluid and usually do not pose a problem from operational point of view. Hence, the elastic mud weight margin approach is more beneficial as it adds a safety factor in predicting the mud weight.



(a) (b)

Figure 13: a) Vertical section profile b) Mud weight window

Figure 13 (a) shows the well trajectory based on the survey data that were prepared. The vertical section profile is plotted along with the mud weight window, Figure 13 (b), predicted along the wellbore trajectory. As the depth increases, the Elastic-Brittle limit and the Elastic Upper limit increases. The mud weight window also narrows as the wellbore inclination increases.

4.3 Result Validation

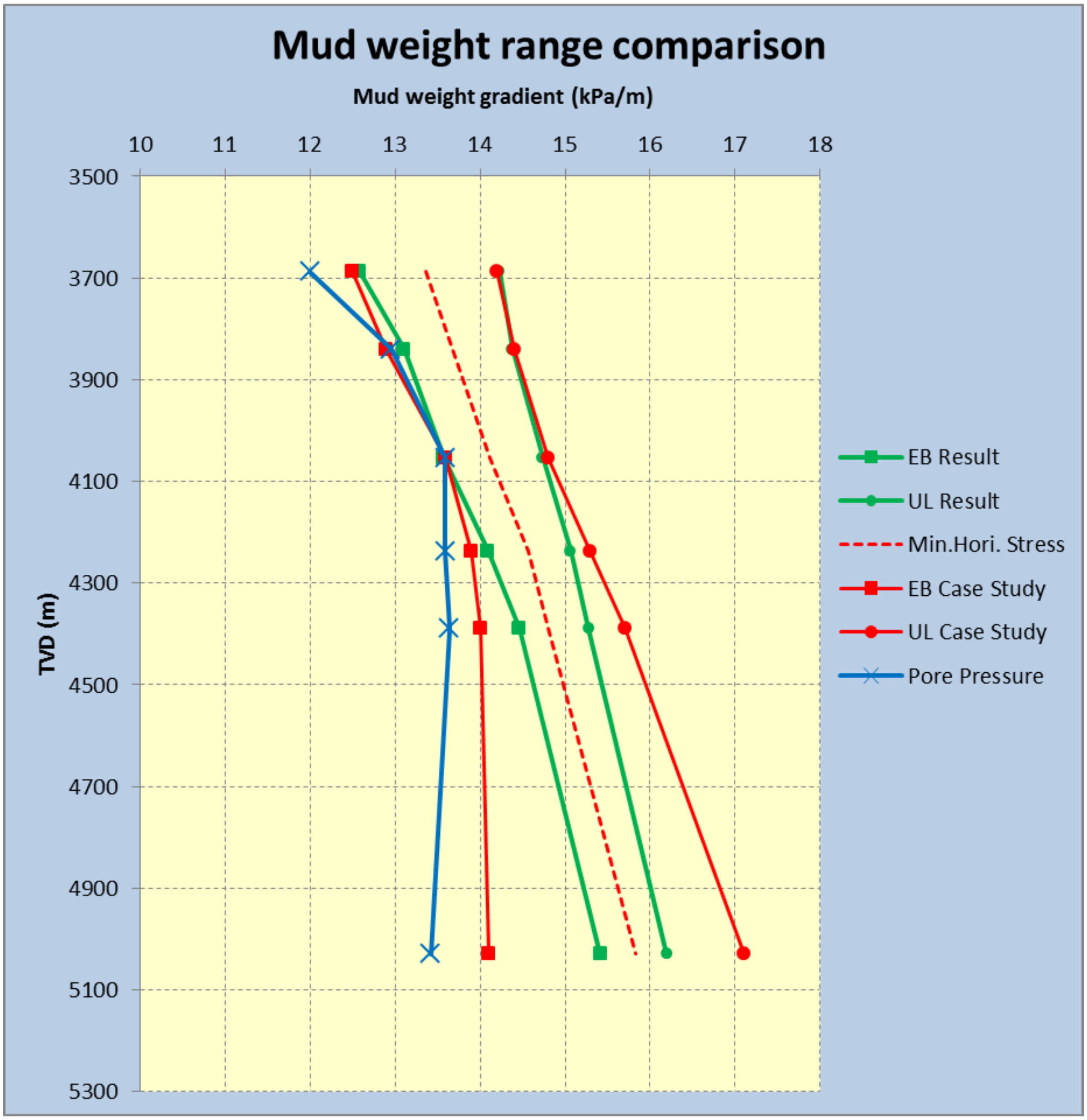


Figure 14: Mud weight range comparison

The values of mud weight calculated in this project are compared with the result achieved from the Shell SIEP Report for the data that were provided in Table 3. After comparison, the calculated mud weights range, which are represented by the EB and UL result, are close to the known mud weights in the case study used (shown in Figure 14). However, there is difference in mud weight range for every depth that was calculated. The differences in mud weight calculated are because the well trajectory data were assumed, since the exact coordinates of easting and northing for the well are not available. Also, several parameters at certain point, for example the well inclination and azimuth need to be assumed due to limitation in field data.

The variation in field data and method had produced variation in the results. However, the results obtained in this project are still within the range of mud weight estimated by Shell's research team. This shows that the techniques used for this project are correct and is applicable for industry scale. To study the effectiveness of the recommended mud weights further, the mud weight can be applied to the available database of oil wells.

4.4 Prototype

The software was built to predict the safe mud weight margin for deviated drilling. The software prototype was developed using Visual Basic for Application (VBA) in Microsoft Excel and the model is built inside Microsoft Excel spreadsheet. The model is connected using VBA by designing a Graphical User Interface (GUI). The GUI will allow the user to interact with the software and input the required data to predict the mud weight margin. Figure 15 shows the latest version of the software. In the main window, the user will be able to choose the option whether to use Point Model, calculation for single point of interest, or to calculate the mud window for a specified well trajectory.

Figure 15: Wellbore Stabilizer main window

In the first page of the well trajectory interface, the user will be asked to select the method they would prefer to use whether Minimum Curvature Method or Radius of Curvature Method. Once the users have selected their preferred method, they will be directed to a new window of that method. For example, if the user chooses the Radius of Curvature Method, the following window will appear (shown in Figure 16). In this window, there are 3 tabs which are vertical section, map/plan view, and mud window. Vertical section is the horizontal distance (departure) of a well path projected to a vertical plane of specific azimuth. The specific azimuth typically is equal to the final target azimuth. Map/plan view is the representation of the trajectory from the initial point to the target from above. The mud window tab will compare the vertical section of the trajectory with the predicted mud weight window. To continue with the prediction, the user has to browse and upload their data files through the upload button.

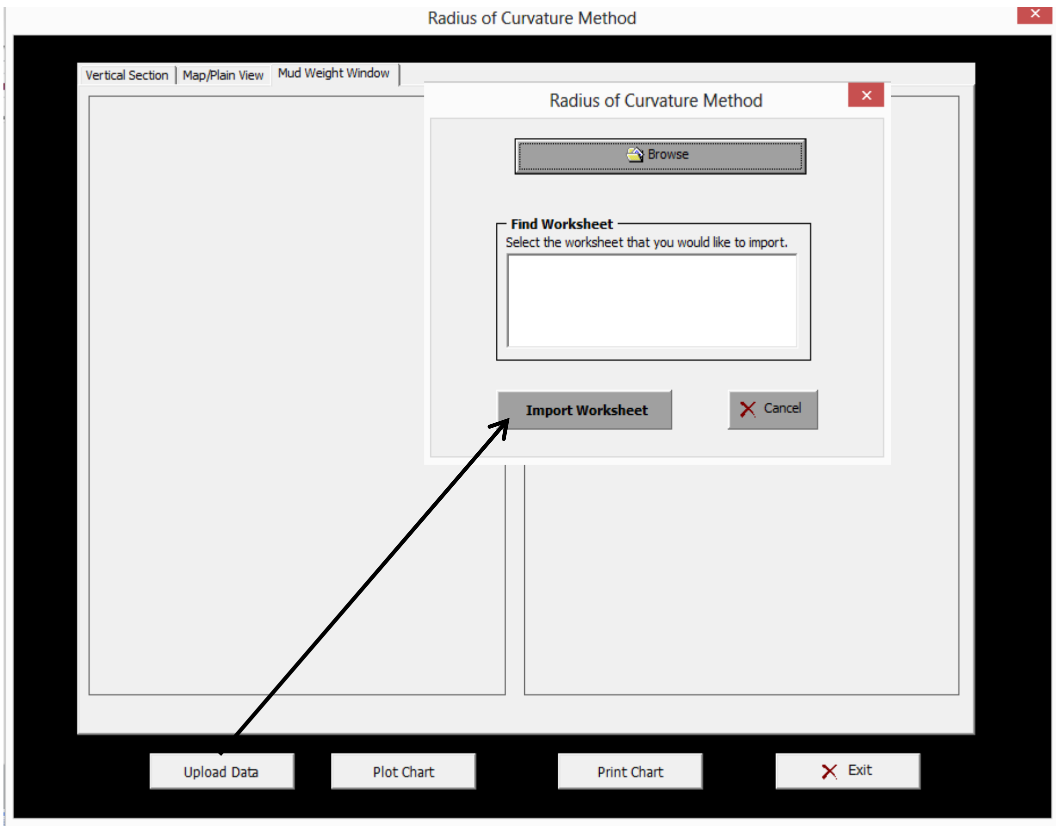


Figure 16: Radius of Curvature window

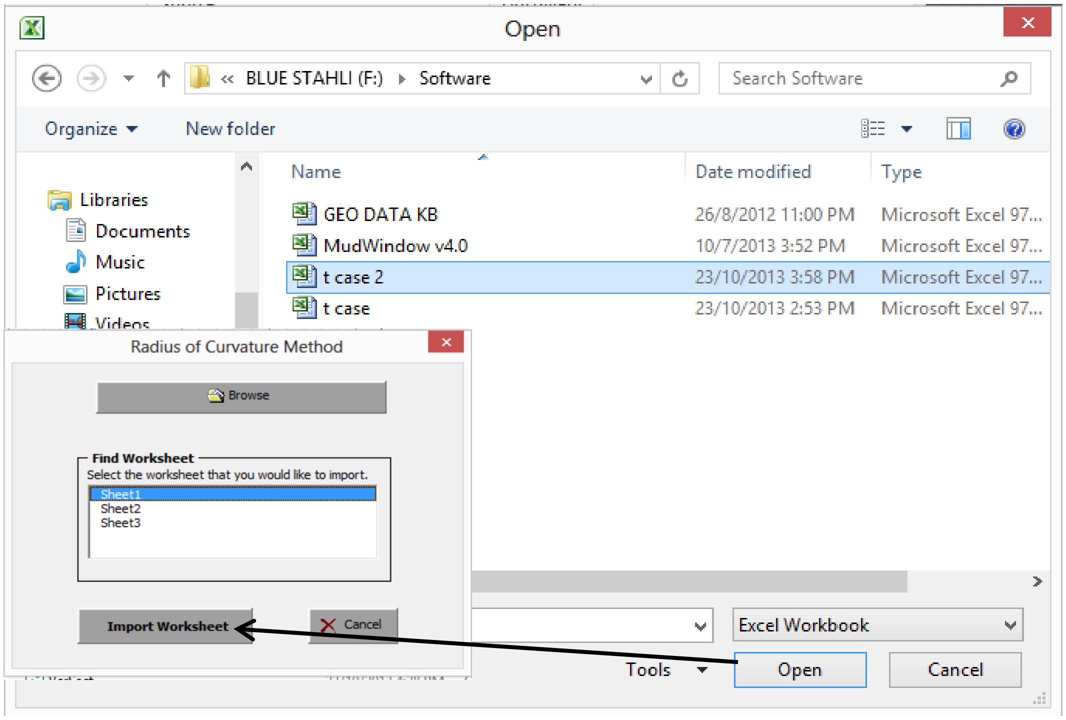


Figure 17: Window Browser

A new window will open when the user clicks the upload button which is shown in Figure 17. Before uploading the data files, the user have to browse for the intended file using the browser window. When the file has been opened, the user will have to select the sheet where the data is located and finally import the worksheet into the spreadsheet of the software. It will display a message if there are data missing from the files that is required for the calculation. Once the data has been successfully uploaded, the user will be redirected to the Radius of Curvature Method window and the user can click on the Plot Chart button where the software will calculate the trajectory and predict a safe mud weight margin. The plotted chart will be shown in their respective tabs.

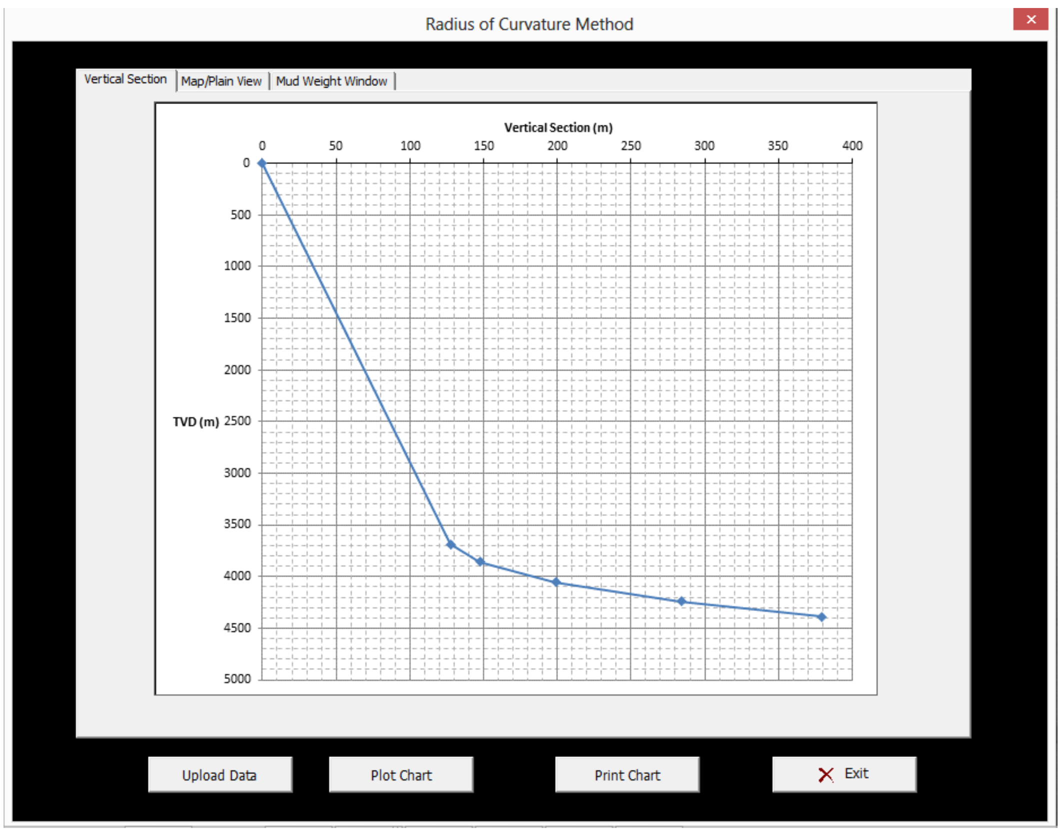


Figure 18: Vertical Section

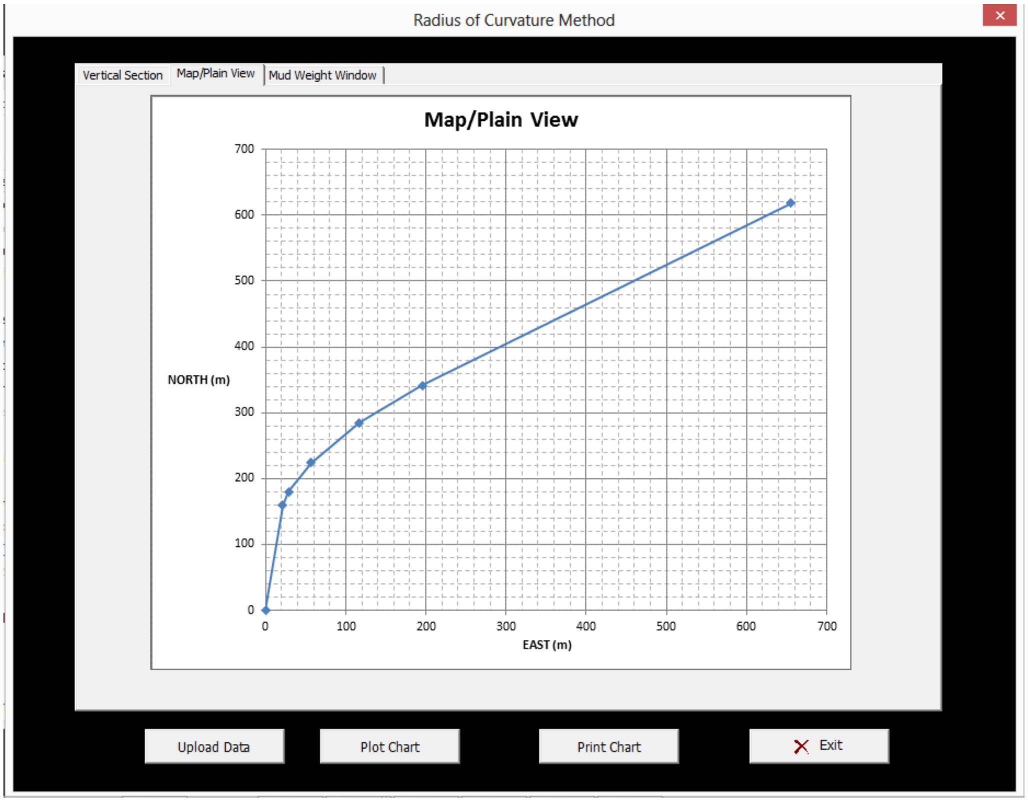


Figure 19: Map/Plan View

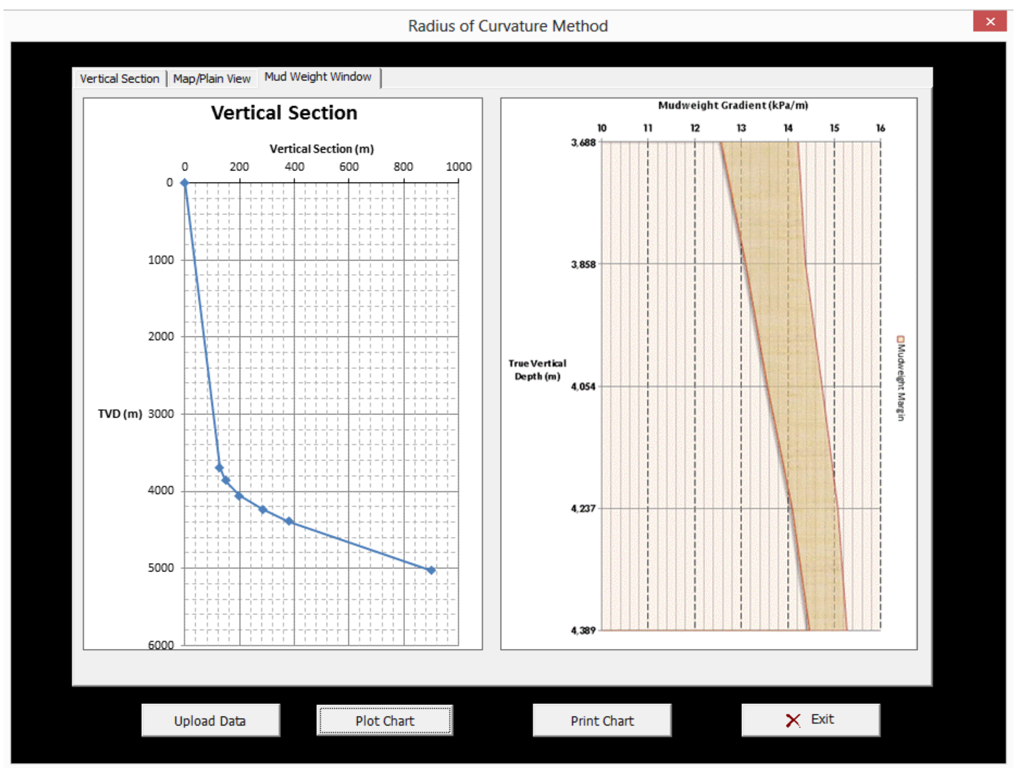


Figure 20: Mud Weight Window

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Lesson Learnt

Developing a program is whole new challenge that is beneficial to every person involved in the oil and gas industry. Learning the process of developing the program using VBA in Excel has given the author an opportunity to learn and apply the knowledge in order to build the program itself. The whole experience has enable the author to think and see the problem from a broader point of view which, in this project, requires the author to take into consideration the user point of view while at the same time developing the program.

5.2 Recommendation

Borehole stability research required a lot of field data that are not always available to the students. Results achieved can be improved and detailed calculation can be done if sufficient data are available. This program can help ease the future work in predicting the mud weight design for drilling deviated wells which can give the engineers a general idea of the required mud weight design for the particular wells. There a lot of potential that can still be improved in this software. There are a few recommendations that can be implemented to help improve the software to make it more efficient for future contribution to the industry, which are the following:

1. Use a set of available drilling and field data from any oil and gas company such as PETRONAS or Shell. This will allow the application to compare the results from actual field and the one that will be calculated using the software. In turn, it can provide a validation for the application itself and provide a stepping stone to fine tune the software.
2. The current software will take a few minutes to give the result because it needs to calculate each point that is uploaded by the user. From the author’s observation, the speed of the calculation depends on the capability of the computers that is being used. It is suggested that further development to improve the speed of the calculation process.

5.3 Concluding Remarks

Drilling mud design is a crucial part in ensuring a safe and optimized drilling operation. The mud is designed inside a safe range called the mud window. For deviated drilling, as the wellbore deviates, the stability envelope will narrow dramatically which will increase the possibility of wellbore instability if the mud is not designed properly. Hence, the purpose of this project is to provide an alternative to predict the mud weight design in deviated drilling by using the identified algorithm and equation of stress. At the same time, it will provide a mean to show the well trajectory of the drilled well.

A working prototype was successfully built in predicting the mud weight window for deviated drilling along the well trajectory. Based on the results that were obtained, it shows that the mud weight window is influenced by the inclination of the wellbore trajectory. This software can help improve the efficiency of reducing uncertainty in drilling operations by utilizing computer technology.

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