Assessment of GPS Accuracy in Detecting Simulated Reservoir Subsidence

by

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17594

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CERTIFICATION OF APPROVAL

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Approved by,

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(Assoc. Prof Dr. Nasir Bin Matori)

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BANDAR SERI ISKANDAR, PERAK
SEPTEMBER 2016

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.

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Zuhaiza Binti Zakaria

ABSTRACT

Reservoir subsidence is one of the most common occurrences at the production zone. This is due to the large amount of hydrocarbon that was removed during the production of oil and gas that had caused the depletion and compaction of the reservoir. Hence, the purpose of this study is to verify the capability of the analytical approach by using GPS instrument to detect the probability subsidence that was calculated by the numerical model. Therefore on the basis of the numerical approach, a model that was called Geertsma model was developed to predict the possible subsidence that occurs in the platform. There are two types of GPS that were used in this project which are Static GPS and Real Time Kinematic (RTK) so that they can verify and detect the possible subsidence that was simulated by the model. The developed model (Geertsma model) show good agreement with these two types of GPS; however, sensible engineering judgement must be taken while conducting these approaches because the location of the study is not exactly at the production zone of the oil and gas. The overall results indicate that these two types of GPS can be able to verify and detect the possible subsidence that was simulated by the model, Geertsma model.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND OF STUDY

Subsidence commonly referred to the vertical downward movement within the ground (Anumba and Scot, 2001). Subsidence study of reservoir is a part of the most common geomechanics problem such as reservoir compaction besides it also lead to the land surface subsidence (Cheng and Pao, n.d.). The main aim of this project is to verify the capability of the instrument by using Global Positioning System (GPS) to detect the probability subsidence that was simulated by the model by using Geertsma model. The fuller understanding need to be developed before proceeding with the main aim for this project which are (1) the factors that lead to the reservoir depletion problems, (2) describe the relationship between reservoir compaction and surface subsidence, (3) significant impacts that will caused by the subsidence especially to the environmental concerns, (4) How the model and instrument work to predict the subsidence.

Reservoir depletion and its associated land surface subsidence interpretations are divided into several approaches which are studying rock mechanical properties of the reservoir like porosity of the reservoir rocks, pressure of the overburden, relationship between compaction and pressure gradient in the reservoir and its influence on the compaction rate and the surface subsidence (Hejmanowski, n.d.). The analyses of these factors of subsidence allow the relation of the subsidence elements such as the relationship between the reservoir compaction and surface subsidence, significant impact to the environments, besides the measures that will take to minimize the reservoir depletion.

Reservoir subsidence studies are further broadened especially in oil and gas industry. Some studies are done to evaluate the properties of the reservoir's rocks besides the effective methods to minimize the reservoir depletion. This is because in oil and gas exploration, the experts may encounter the possible subsidence that occurs in the platform caused by different factors. This kind of situation gives rise to the platform safety concerns in offshore production. Hence, by investigating the rock properties of the reservoir and the methods that were used will be able to minimize the reservoir depletion and its associated land surface subsidence.

1.2 PROBLEM STATEMENT

During the past years, as described by Cheng and Pao (n.d.) approximately half of the world's oil and gas reservoir had undergone the most common geomechanics problems which are reservoir compaction and its land surface subsidence that will lead to environmental concerns, leading to risk of flooding in land operations and platform safety concerns in offshore production. Hence, it will require the shut-down of production as one of the possesses risks of the platform subsidence from the significant subsidence. Both the interrupt production and also the maintenance will require a lot cost in operating the oil and gas production. Therefore, this research holds a key of analysing and understanding of the methods that will used to verify and detect the possible subsidence and this will lead to the mitigation of the geomechanics problems at the production of oil and gas.

1.3 OBJECTIVES

From this research, a project title entitled “ Assessment of GPS accuracy in detecting simulated reservoir subsidence” had been come out by using model (Geertsma) and instrument(GPS) approaches.

The study of this research will focus on:

1. Verify the capability of the instrument by using GPS to detect the subsidence that was simulated by the model (Geertsma)
2. Understanding how the numerical (Geertsma model) and analytical global positioning system (GPS) surveys work to predict the subsidence.

1.4 SCOPE OF STUDY

The scope of study for this project to verify the capability of the instrument by global positioning system (GPS) surveys to detect the subsidence that was simulated by the model (Geertsma). The time frame for this project will be from May 2016 until December 2016. The research will be conducted in two phases; (1) FYP 1 for the understanding on how the model works besides to relate the parameters in the model to simulate the subsidence; (2) FYP 2 for field work where the GPS equipment need to be setup so that the surveys for the subsidence can be carried out besides to verify the capability of the equipment to detect the subsidence that was simulated by the model. Hence, it was contributing to the feasibility of the project within the time frame.

CHAPTER 2: LITERATURE REVIEW

2.1 Conceptual Framework and Theories

Why predict the possible reservoir subsidence from occurring? This is because many important geotechnical issues that require a detailed understanding of the behaviour reservoir rocks besides the mechanical behaviour of the reservoir (Hettema et al. 2002). However, obtaining the enough samples of the reservoir rocks to fully characterize the reservoir subsidence is physically impossible. Therefore, estimates of reservoir depletion and its associated land surface subsidence must be either be extrapolated from the research through reading or derived from model.

According to Bruno and Boverg (1992) rock matrix and the partial of the fluid pressure in the rock pores support the weight of sediments above the producing reservoir during the withdrawal of oil and any other fluid. When fluids are extracted from an underground reservoir, pore pressure is reduced and that cause to the shrinkage or compaction to the reservoir. The shrinkage or compaction process occur due to the increase of the effective stress and cause the rock itself to shrink and lead to the compaction of the reservoir and in turn causes subsidence (Chen and Pao, n.d.)

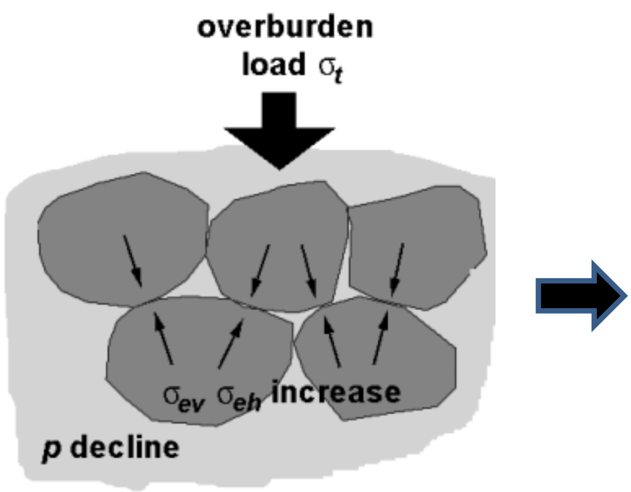


Figure 2.1: Shrinkage or Compaction process
(Source: *Teatini et al.,2006*)

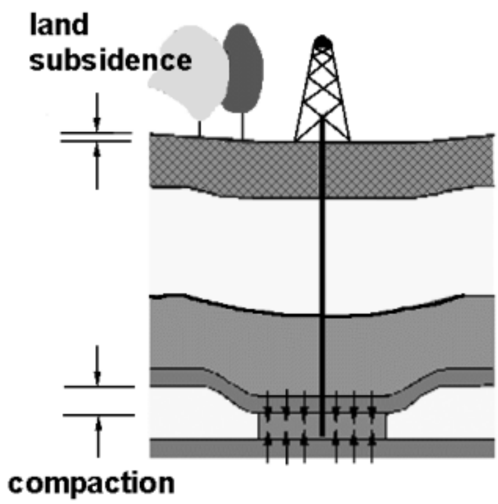


Figure 2.2: Reservoir Subsidence
(Source: *Teatini et al.,2006*)

The decreasing in pressure in the reservoir due to the extraction of oil at the production zone, the surface subsidence will be generated due to the changing of the stress field of the surrounding rock mass. Besides, the dimensions of the reservoir will change in the vertical plane that was caused from the lateral dimensions of a reservoir where the dimensions being large compared to its height (Ortiz et al. 2006). As mentioned by Geertsma (1973) the changing of the pore pressure in the reservoir was very important since the reservoir compaction was depends on this factor besides mobility, solubility, density, compressibility of the pore fluids, and boundary conditions like faults. The total compaction of the reservoir can be calculated where it can be obtained from:

$$C = \int_0^h C_m(z)\, \Delta p(z)\, dz$$

where:

$C_m(z)$ uniaxial compaction coefficient in (kPa^{-1})

h original reservoir thickness in (m)

$\Delta p(z)$ change in pore pressure of the reservoir in (kPa).

Equation 2.1: Compaction Equation
(Source: *Ortiz et al., 2006*)

Besides the properties and characteristics of the reservoir rocks that contribute to the reservoir subsidence, another factor that leads to this problem is the reservoir itself which are reservoir connectivity and aquifers which will be discussed further below:

2.1.1 Reservoir Connectivity

Reservoir connectivity initially defined as based on the geological boundaries like faults, shale layers and other geological barriers (Musani et al. 2013). Reservoir connectivity can affect the reservoir subsidence due to the discontinuous changes that can be found at the faults due to vary of the parameters like the amount of reservoir compaction. Uncertainty on the subsidence prediction can be happened if the interactions between the reservoirs blocks are not connecting with each other (Ketelaar, 2009).

2.1.2 Aquifers

As stated by Ketelaar (2009) aquifer is referring to the part of the reservoir that is filled with the water. The aquifer plays the significant part to determine the pressure distribution within the reservoir. This is because during the extraction of oil and gas, the pressure will drop if the aquifer present during the production. Since aquifer partly determines the pressure distribution hence reservoir compaction and its associated land surface subsidence can be predicted.

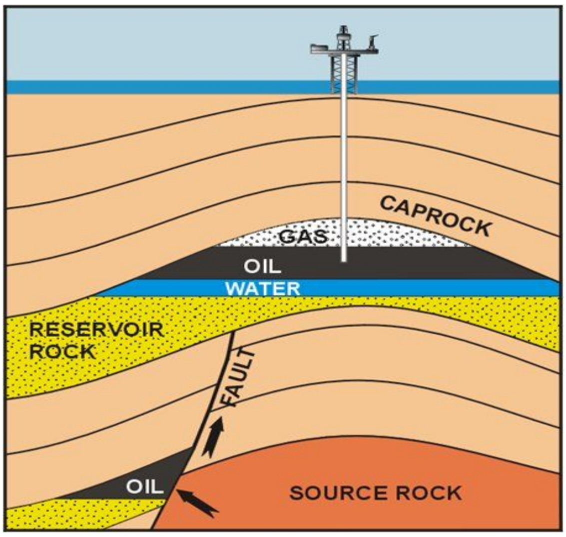


Figure 2.3: Reservoir Connectivity and Aquifers
(Source: *Hejmanowski, n.d.*)

2.2 Modelling of Reservoir Subsidence using the "*Nucleus Strain*" Approach

Subsidence occurrence can be predicted since the relationship between the reservoir compaction and its subsidence already exposed. *Nucleus of Strain* approach was applied by Geertsma to calculate the both vertical and horizontal displacement of the subsidence. As describe by Geertsma (1973) by assuming linear rock behaviour with both rock and reservoir being homogenous and having the same material properties, the reservoir subsidence can be determine by integrating the contribution of all the compression points over the reservoir by using a numerical solutions. Besides in this technique, local reduction in pore pressure had caused the volumetric strain at a point in reservoir where it was treated as a centre of compression in an elastic half-space that exert the displacement field at the surface (Ortiz et al. 2006).

The vertical displacement by using *Nucleus Strain* can be obtained from:

$$U_z(r,0) = -\frac{1}{\pi} c_m (1-\gamma) \frac{D}{(r^2+D^2)^{\frac{3}{2}}} \Delta p \, d_v$$

Equation 2.2: Vertical Displacement Equation
(Source: *Chen and Pao, n.d.*)

Where

C_m Compaction coefficient
d_v Finite volume
Δp Reservoir pressure reduction
ɤ Poisons value
D Depth of reservoir

Similarly, the horizontal displacement can be calculated by:

$$U_r(r,0) = +\frac{1}{\pi} c_m (1-\gamma) \frac{D}{(r^2+D^2)^{\frac{3}{2}}} \Delta p \, d_v$$

Equation 2.3: Horizontal Displacement Equation
(Source: *Chen and Pao, n.d.*)

Where

C_m Compaction coefficient
d_v Finite volume
Δp Reservoir pressure reduction
ɤ Poisons value
D Depth of reservoir

These vertical and horizontal formulas will be implemented into VBA developed in Excel to describe the subsidence prediction and will be used in this research to predict the subsidence.

2.3 Global Positioning Systems (GPS)

According to Jurovich et al. (2016) GPS is a very applicable for the navigation due to its highly accurate systems because it was using signals from the satellites to determine the location on the Earth's surface regardless of the weather conditions. GPS satellites high above the Earth were used to transmit signals containing the location and time of the satellites. GPS satellites that were transmits the signals to the any ground-based receiver will be used the navigation equations to calculate its location on the Earth's surface.

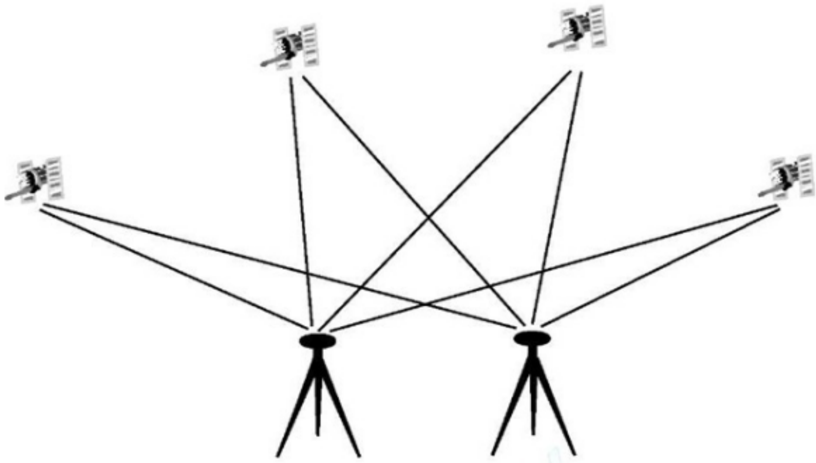


Figure 2.4: GPS relative positioning
(Source: *Zeiske, K., n.d.*)

Therefore, GPS was always used in surveying and mapping due to its accuracy. Besides, the first commercial adaptations of GPS is the surveying and mapping because it provides a latitude and longitude position directly without the need to measure angles and distance between points (Leal.J, 1989). As stated by McClusky and Tregoning (2013) the most appropriate techniques for measuring subsidence will depends on the spatial extent of the anticipated deformation and perhaps the more likely magnitude of the expected subsidence. GPS as one of the techniques that can provide highly accurate temporal estimates of the surface movement.

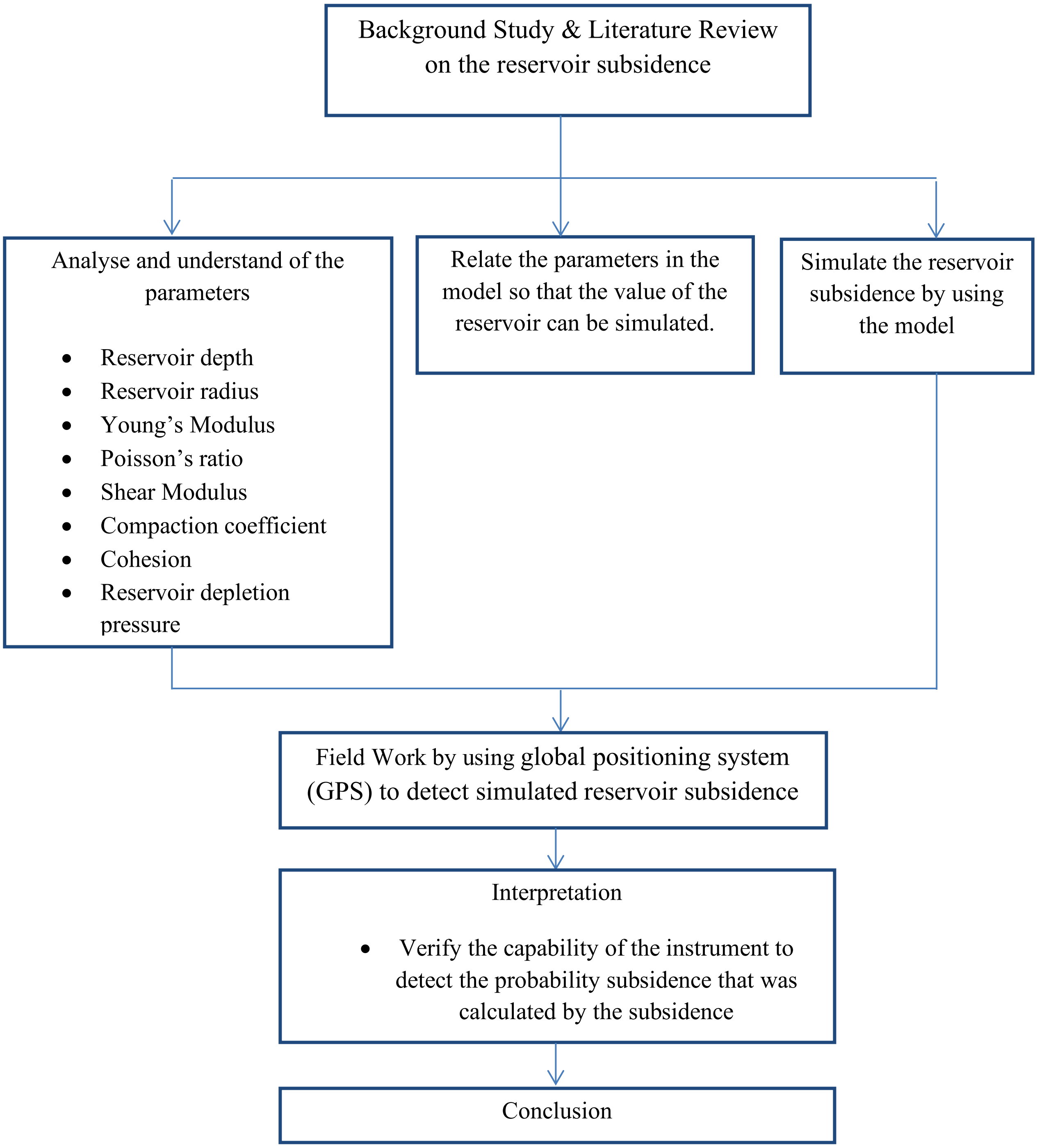
Therefore in this project, there are two methods of GPS measurements that were utilised in detecting the subsidence which are Static GPS and Real-Time Kinematics (RTK) GPS where the descriptions of these GPS are in a table as below:

Table 2.1: Methods of GPS measurements that are utilise (Pardee and Godbey,2016)

Types of GPS	Explanation
Static	The first method used in the field and continues to be the primary technique used today. Static surveys allows for the simultaneous data to be collected between stationary receivers for an extended period of time usually depending by the baseline length. The preferred approach compared to the other methods because it will establishing the most accurate positions for the survey points.
Real-Time Kinematics	Kinematics is a term applied to the GPS surveying methods where receivers are in continuous motion. This approach require at least one stationary reference receiver and another receiver that was called rover. RTK procedures do not require post-processing of the data to obtain a position solution. Without having to process the data, this will allow for the real-time surveying in the field and allows the surveyors check the quality of the measurement during the survey.

CHAPTER 3: METHODOLOGY

3.1 FLOW OF RESEARCH



3.2 Simulation of Reservoir Subsidence using Geertsma Model.

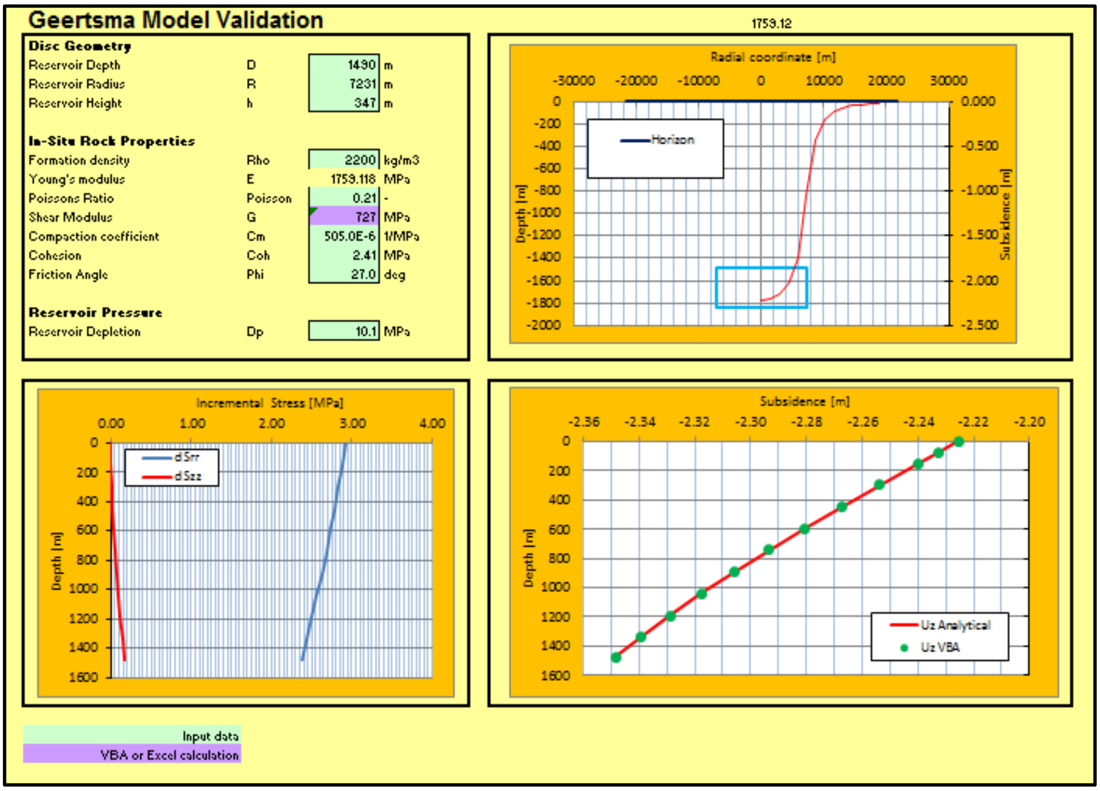


Figure 3.1: Geertsma Model Validation
(Source: *Chen and Pao, n.d.*)

Try and errors techniques will be carried out on each of the parameters in the model to analyse the parameters by determining which parameters that will give the values of the subsidence through simulating the model. The information then will be used to determine which parameters in the model that will fixed while the other parameters that need to be change to obtain the value of the subsidence. Since there are 11 parameters that need to be considered, there are 3 fixed parameters that will used the same values throughout the research which are:

1. Friction angle = 27.0°
2. Formation density = 2200 kg/m^3
3. Cohesion = 2.41 Mpa

While, there are 2 parameters that will change due to the changes of parameters since these parameters depend on the formula. These parameters are Young Modulus and Shear Modulus where the formula as below:

- Young Modulus = (1/Cm)*((1+Poisson)*(1-2*Poisson)/(1-Poisson))
- Shear Modulus = Young Modulus/(2*(1+Poisson))

Equation 3.1: Young Modulus and Shear Modulus Equation
(Source: *Chen and Pao, n.d.*)

Hence, there are 6 parameters that need to be simulated (Poisson's ratio, reservoir depth, pressure depletion, reservoir radius, compaction coefficient and reservoir height) in the model by varying one of the parameters while the other five parameters need to be fixed so that the subsidence can be predicted. For example, the reservoir depth as the first parameter for the values that need to be varies with the 10 trials while the other five parameters need to be fixed so that the range of the values changes of the reservoir subsidence can be observed. The values of these parameters are determined through some research on the range values that were normally applied to the parameters. The values that were applied on the parameters and the reservoir subsidence were shown in the tables below:

a) Reservoir depth

Parameters	Number of trials/Value used									
	1	2	3	4	5	6	7	8	9	10
Reservoir depth (m)	2000	1850	1650	1490	1350	1280	1250	1200	1170	1150
Reservoir radius (m)	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Reservoir height (m)	250	250	250	250	250	250	250	250	250	250
Formation density (kg/m^3)	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200
Young's Modulus (MPa)	2611.5	2611.5	2611.5	2611.5	2611.5	2611.5	2611.5	2611.5	2611.5	2611.5
Poisson's ratio	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Shear Modulus (MPa)	920	920	920	920	920	920	920	920	920	920
Compaction Coefficient (1/MPa)	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015
Cohesion (MPa)	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41
Friction Angle (deg)	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0
Pressure depletion (Mpa)	8	8	8	8	8	8	8	8	8	8
Simulated Reservoir Subsidence (m)	**0.05**	**0.058**	**0.068**	**0.079**	**0.09**	**0.095**	**0.098**	**0.11**	**0.16**	**0.19**

Table 3.1: Simulated subsidence value as reservoir depth varies

b) Reservoir radius

Parameters	Number of trials/Value used									
	1	2	3	4	5	6	7	8	9	10
Reservoir depth (m)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Reservoir radius (m)	1200	1350	1450	1550	1600	1750	1800	1880	1920	1950
Reservoir height (m)	250	250	250	250	250	250	250	250	250	250
Formation density (kg/m^3)	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200
Young's Modulus (MPa)	2611.5	3461.5	2751.3	2724.3	2875.3	2571.4	2067.5	1973.0	1871.4	1844.9
Poisson's ratio	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Shear Modulus (MPa)	920	1282	1058	1081	1169	1071	884	858	821	839
Compaction Coefficient (1/MPa)	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015
Cohesion (MPa)	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41
Friction Angle (deg)	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0
Pressure depletion (Mpa)	8	8	8	8	8	8	8	8	8	8
Simulated Reservoir Subsidence (m)	**0.05**	**0.06**	**0.068**	**0.072**	**0.078**	**0.086**	**0.09**	**0.095**	**0.098**	**0.10**

Table 3.2: Simulated subsidence value as reservoir radius varies

c) Reservoir height

Parameters	Number of trials/Value used									
	1	2	3	4	5	6	7	8	9	10
Reservoir depth (m)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Reservoir radius (m)	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Reservoir height (m)	250	270	290	320	350	370	390	430	450	480
Formation density (kg/m^3)	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200
Young's Modulus (MPa)	2611.5	3461.5	2751.3	2724.3	2875.3	2571.4	2067.5	1973.0	1871.4	1844.9
Poisson's ratio	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Shear Modulus (MPa)	920	1282	1058	1081	1169	1071	884	858	821	839
Compaction Coefficient (1/MPa)	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015
Cohesion (MPa)	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41
Friction Angle (deg)	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0
Pressure depletion (Mpa)	8	8	8	8	8	8	8	8	8	8
Simulated Reservoir Subsidence (m)	**0.05**	**0.054**	**0.06**	**0.065**	**0.07**	**0.075**	**0.08**	**0.086**	**0.09**	**0.95**

Table 3.3: Simulated subsidence value as reservoir height varies

d) Poisson's ratio

Parameters	Number of trials/Value used									
	1	2	3	4	5	6	7	8	9	10
Reservoir depth (m)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Reservoir radius (m)	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Reservoir height (m)	250	250	250	250	250	250	250	250	250	250
Formation density (kg/m^3)	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200
Young's Modulus (MPa)	2611.5	4153.8	4952.4	5448.6	5750.6	6000.0	6202.4	6313.7	6448.5	6518.5
Poisson's ratio	0.42	0.35	0.30	0.26	0.23	0.20	0.17	0.15	0.12	0.10
Shear Modulus (MPa)	920	1538	1905	2162	2338	2500	2651	2745	2879	2963
Compaction Coefficient (1/MPa)	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015
Cohesion (MPa)	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41
Friction Angle (deg)	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0
Pressure depletion (Mpa)	8	8	8	8	8	8	8	8	8	8
Simulated Reservoir Subsidence (m)	**0.05**	**0.057**	**0.06**	**0.064**	**0.068**	**0.07**	**0.071**	**0.072**	**0.077**	**0.78**

Table 3.4: Simulated subsidence value as poisson's ratio varies

e) Compaction coefficient

Parameters	Number of trials/Value used									
	1	2	3	4	5	6	7	8	9	10
Reservoir depth (m)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Reservoir radius (m)	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Reservoir height (m)	250	250	250	250	250	250	250	250	250	250
Formation density (kg/m^3)	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200
Young's Modulus (MPa)	2611.5	2176.2	1450.8	1305.7	1224.1	1119.2	870.5	816.1	768.1	739.1
Poisson's ratio	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Shear Modulus (MPa)	920	766	511	460	431	394	307	287	270	260
Compaction Coefficient (1/MPa)	0.00015	0.00018	0.00027	0.0003	0.00032	0.00035	0.00045	0.00048	0.00051	0.00053
Cohesion (MPa)	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41
Friction Angle (deg)	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0
Pressure depletion (Mpa)	8	8	8	8	8	8	8	8	8	8
Simulated Reservoir Subsidence (m)	**0.05**	**0.06**	**0.09**	**0.10**	**0.11**	**0.12**	**0.15**	**0.16**	**0.17**	**0.18**

Table 3.5: Simulated subsidence value as compaction coefficient varies

f) Reservoir depletion

Parameters	Number of trials/Value used									
	1	2	3	4	5	6	7	8	9	10
Reservoir depth (m)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Reservoir radius (m)	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Reservoir height (m)	250	250	250	250	250	250	250	250	250	250
Formation density (kg/m^3)	2200	2200	2200	2200	2200	2200	2200	2200	2200	2200
Young's Modulus (MPa)	2611.5	2611.5	2611.5	2611.5	2611.5	2611.5	2611.5	2611.5	2611.5	2611.5
Poisson's ratio	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Shear Modulus (MPa)	920	920	920	920	920	920	920	920	920	920
Compaction Coefficient (1/MPa)	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015
Cohesion (MPa)	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41
Friction Angle (deg)	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0
Pressure depletion (Mpa)	8	8.2	10.8	11.3	11.5	11.8	12.0	12.5	13.2	13.4
Simulated Reservoir Subsidence (m)	**0.05**	**0.051**	**0.068**	**0.07**	**0.072**	**0.074**	**0.075**	**0.08**	**0.082**	**0.85**

Table 3.6: Simulated subsidence value as reservoir depletion varies

The 6 of the manipulated subsidence values from all values had been decided to be used in this project in order to be verified with the GPS equipment. This is because, the values of the subsidence are mostly close with each other besides it will also save time so that this project can be completed within the time frame. Hence, the 6 values with the lowest, highest and the average by calculating the average subsidence values from each of the parameters that had been manipulated. The subsidence values that had been taken into the considerations are: 0.05m, 0.07m, 0.11m, 0.17m, 0.20m.

3.3 **Field Work**

It has been observed from the simulation where the simulated subsidence range from 0.05m to 0.20m. Therefore through this fieldwork, GPS equipment was set up which are Static and Real Time Kinematics (RTK) so that these equipment can detect the simulated subsidence as mentioned above. Besides, the comparison and analyse of the accuracy between these two types of GPS in verifying the capability of the GPS can also be conducted.

Before starting the field work processes, the most important task that need to be done is to check the instruments that will be used in this project; Base and Rover GPS, measuring rod, tripods, surveying nail and survey marker disc. Next, locate and determine the location/point to place the GPS. Ensure that the location has a clear line of sight to the sky in all directions. Then, place the surveying nail and survey marker disc because this point will be used to place the tripod in its place when lowering the tripod during the processes.

Figure 3.2: Equipment that will be used (Rover & Base GPS)

Figure 3.3: Surveying Nail and Survey Marker Disc

3.3.1 Static GPS

In this study, Static GPS is one of the equipment that was used to detect for the probability subsidence. A rover receiver will be used to receive the satellite signals so that it can detect the latitude, longitude and also the elevation height. During this process, measurement of the height is a very important element to determine the accuracy of the GPS to detect for subsidence.

For this study, the starting height of the tripod is set up to the vertical height which is 132.3 cm then the tripod was lowered vertically based on the selected subsidence that was simulated by the model using measuring rod. The GPS have to be turned off during lowering the tripod height and then after lowering the tripod to a certain height the GPS was turned on back to receive the signals from the satellites. Besides, time is also significant during this process because each data/signals will be collected every 30 minutes after lowering the tripod so that the GPS can be more stable and the accurate result can be obtained. In addition to this, the data/signals that were collected will be process in the software (Topcon Tools Office Software) to get the result of elevation height.

Figure 3.4: Base GPS mounted on tripod

Figure 3.5: Vertical measurement by using measuring rod

3.3.2 Real-Time Kinematic (RTK) GPS

The procedures for RTK are basically the same with the Static GPS but for the RTK, there are two tripods that need to be set up with Base GPS and also Rover GPS that will be mounted on each of the tripods. Place the tripod with the Base GPS at the location where the Static GPS study was conducted and the other tripod at the other location with some distance. Ensure that the distance between these two tripods must be at least 2 metres and approximately with the same height.

The starting height of the tripod with Rover GPS is set up to the vertical height which is 130.0 cm and was lowered vertically based on the selected simulated reservoir subsidence. The difference between RTK and Static is that during lowering the height of the tripod, the signals were recorded when the receiver is still on and this will allow for the real-time surveying during the processes .The author needs to save the data/signals in the controller and process the data in the software.

Figure 3.6: Base GPS mounted on tripod

Figure 3.7: GPS Controller

3.3.3 Topcon Tools Office Software

Figure 3.8: Topcon Tools Office Software

Topcon Tools Office Software was used to process the data that was collected during the fieldwork. This software is very crucial and significant in this study because it will execute the elevation height from the receiver. The elevation height will be used to determine the capability of the GPS equipment to detect the probability reservoir subsidence by comparing the elevation height of the starting height of the tripod with the elevation height after the tripod was lowered to a certain height. Besides, the author can also compare the accuracy of these two types of GPS to determine on which these two types of GPS that can produce more accurate results in verifying the probability subsidence based on the elevation height data that will processed in this software.

3.4 GANTT CHART

i. Final Year Project I

No	Activities		1	2	3	4	5	6	7	8	9	10	11	12	13	14
			9/5 - 20/5/2016		23/5 - 3/6/2016		6/6 - 17/6/2016		20/6 - 1/7/2016		3/7 - 15/7/2016		18/7 - 29/7/2016		1/8 - 12/8/2016	
1	Selection of project topic	Planning	■	■												
2	Decide on report structure		■	■												
3	Preliminary Research work	Research		■	■	■										
4	Study about parameters			■	■	■										
5	Submission of Extended proposal	FYP					■									
6	Proposal defend Preparation							■	■							
7	Proposal defend									■	■					
8	Submission of Interim Draft Report											■	■			
9	Submission of Interim Final Report													■	■	■

ii. Final Year Project II

No	Activities		1	2	3	4	5	6	7	8	9	10	11	12	13	14
			14/9 – 23/9/2016		26/9 - 7/10/2016		10/10 - 21/10/2016		24/10- 4/11/2016		7/11 - 18/11/2016		21/11 - 2/12/2016		5/12 - 16/12/2016	
1	Check for the instruments that will be used	FYP	■													
2	Start on the field work			■	■	■	■	■	■	■	■	■				
3	Data Analysis											■	■			
4	Submission Final Report													■		
5	PRE-SEDEX														■	
6	Viva															■

3.5 KEY MILESTONE

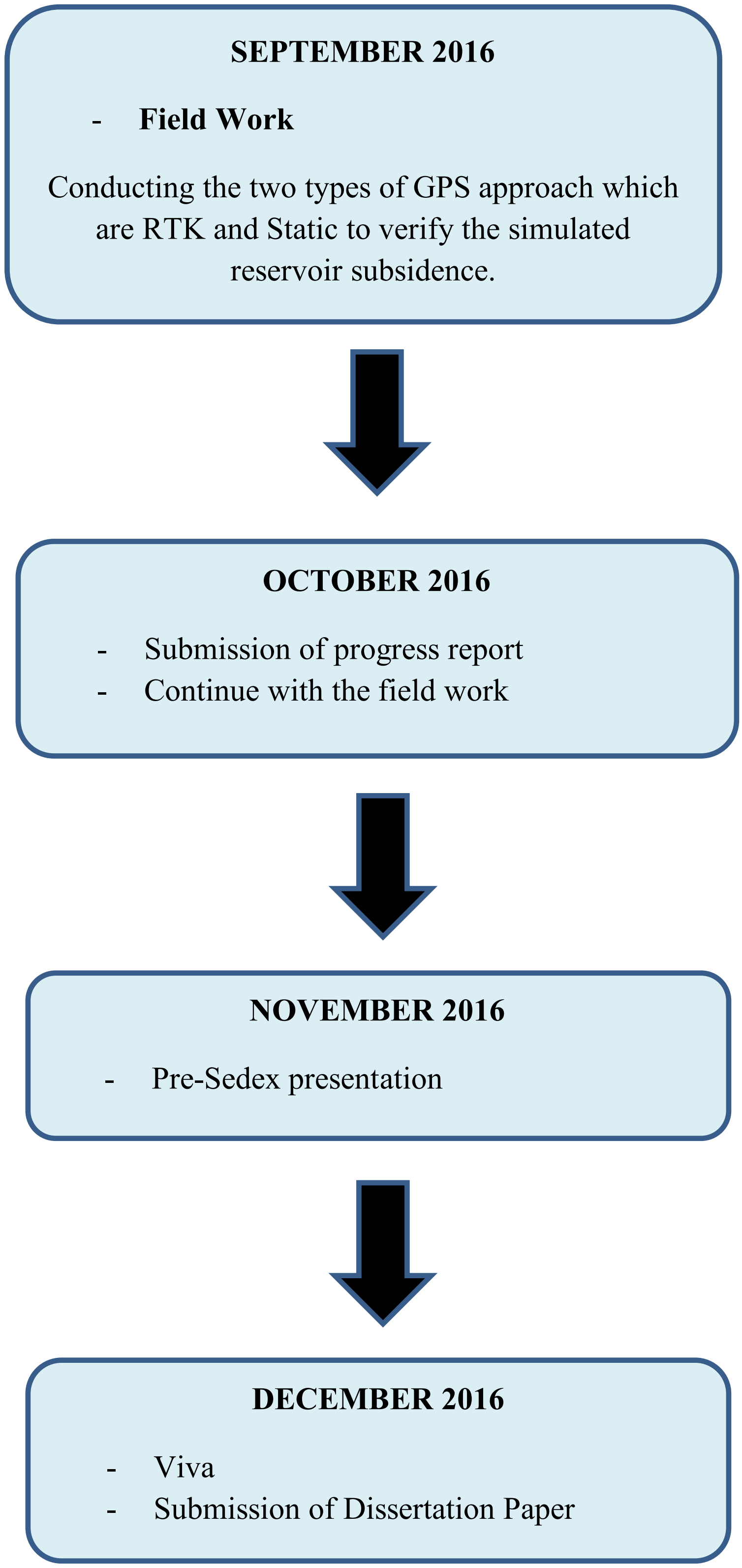


Figure 3.10: Key milestone for FYP II

CHAPTER 4: RESULTS AND DISCUSSION

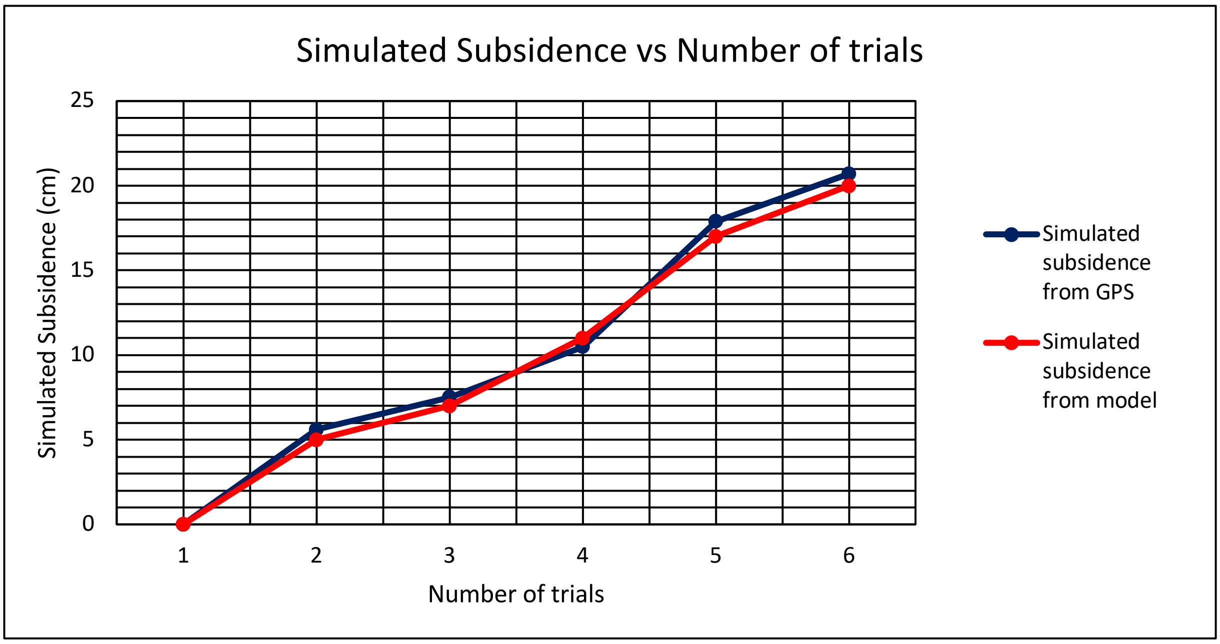
The processed data that were executed from the software are crucial and significant in order to verify and determine the accuracy of the GPS in order detect the reservoir subsidence that was simulated by the model. Besides, Static and RTK can also be compared based on their accuracy in determining the reservoir subsidence.

4.1 Static GPS

The result of the elevation heights that were determined by the Static GPS and the difference between the simulated height from GPS and model were tabulated in a table and graph below:

Tripod Height (cm)	Computed Elevation height (m)	Simulated subsidence from GPS (cm)	Simulated subsidence from model (cm)	Difference between simulated height from GPS and model (cm)
132.3	33.477	0	0	0
127.3	33.421	5.6	5.0	0.6
125.3	33.402	7.5	7.0	0.5
121.3	33.372	10.5	11.0	0.5
115.3	33.298	17.9	17.0	0.9
112.3	33.270	20.7	20.0	0.7

Table 4.1: Results of Static GPS



Graph 4.1: Comparison of simulated subsidence between GPS and model

From the results that were shown in the table above, it was shown that the computed elevation height decreased as the tripod was lowered which are up to 20 cm. However, there are some variances by obtaining the difference between the computed elevation height and the simulated subsidence which are the elevation height is field work data that were acquired through the GPS equipment while the subsidence are the ones that were simulated by the model.

From the graph, the results were shows that there are not much difference between the simulated height from the GPS and model. The highest difference that can be recorded is 0.9 and it was shows that Static method is one of the approaches that can generate the most accurate results from this experiment and it was very appropriate methods to verify and detect the simulated subsidence from the model though there are some variations in the results that did not let the result of the simulated subsidence from GPS to be exact with the one from the model.

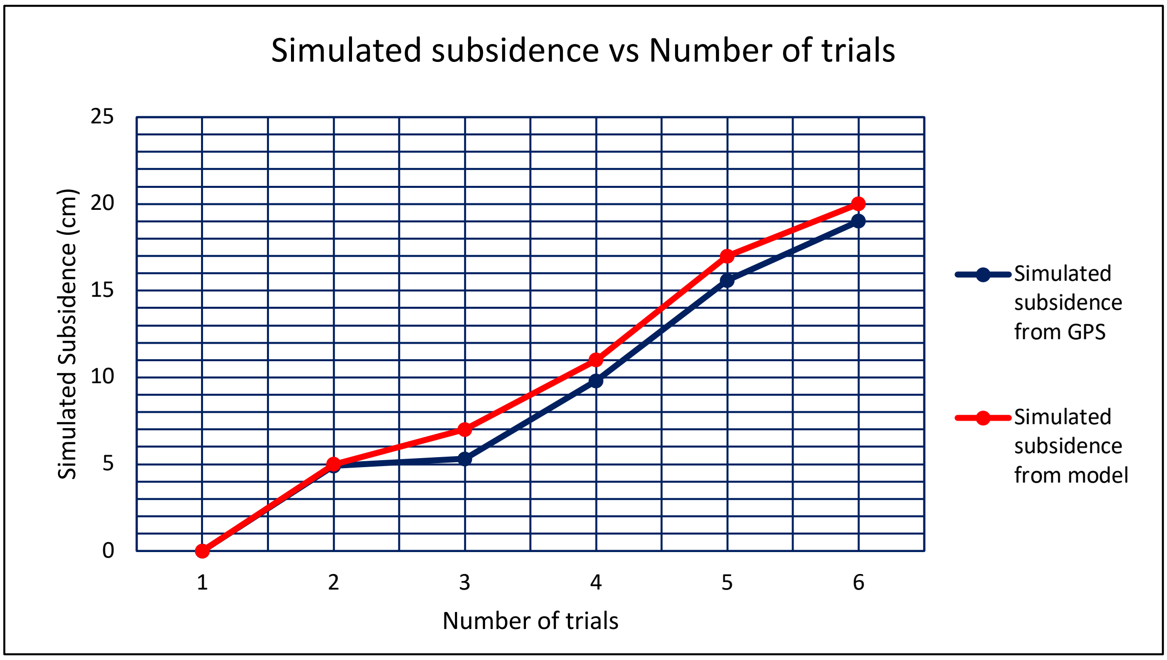
The variations of the results may be developed from the parallax error during the measurement of the height which is the eyes is not squarely aligned with the scale of the measuring rod when taking the reading of the lowering tripod during the processes.

4.2 Real Time Kinematics (RTK) GPS

The result of the elevation heights that were determined by the RTK GPS and the difference between the elevation height and probability subsidence were tabulated in a table and graph below:

Tripod Height (cm)	Computed Elevation height (m)	Simulated subsidence from GPS (cm)	Simulated subsidence from model (cm)	Difference between simulated height from GPS and model (cm)
130.0	26.418	0	0	0
125.0	26.369	4.9	5.0	0.1
123.0	26.365	5.3	7.0	1.7
119.0	26.320	9.8	11.0	1.2
113.0	26.262	15.6	17.0	1.4
110.0	26.228	19.0	20.0	1.0

Table 4.2: Results of RTK GPS



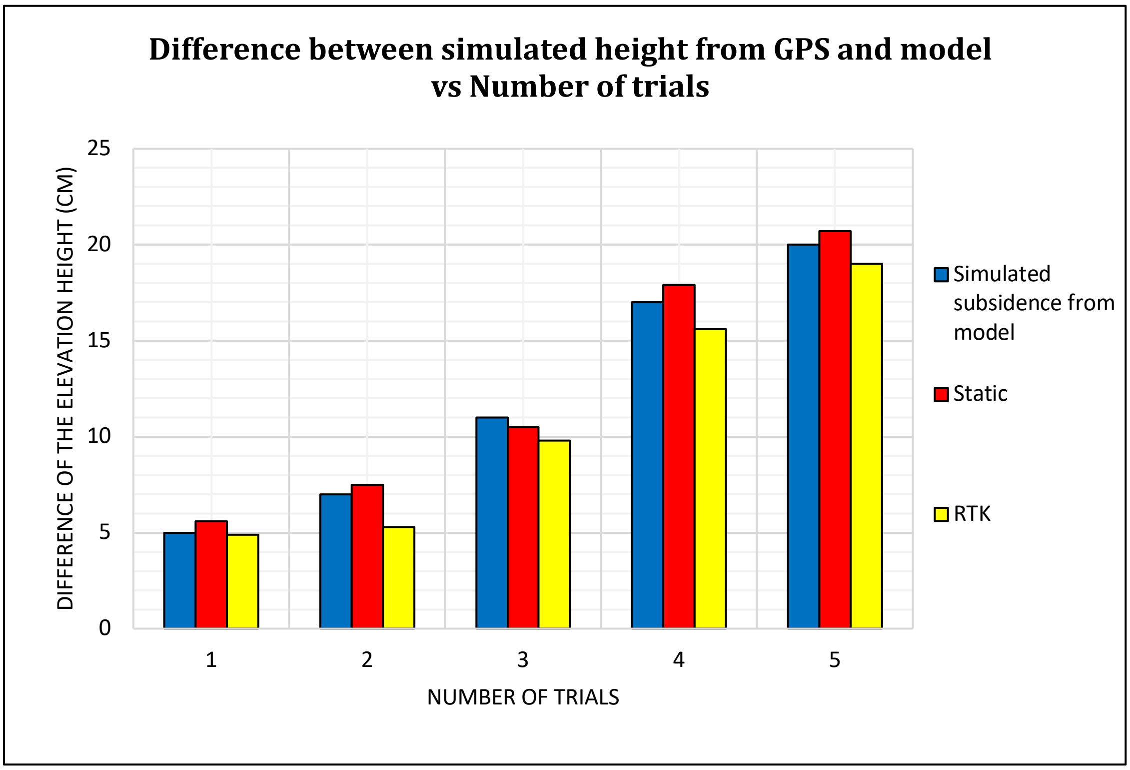
Graph 4.2: Comparison of simulated subsidence between GPS and model

From the results that were shown in the table and graph above, it was shown that the computed elevation height decreased as the tripod was lowered which are up to 20 cm. The results shows that there are much difference between the simulated subsidence from GPS and the model where the highest difference that can be recorded is 1.7 cm. As compared to the static approach, RTK methods execute the big difference between the GPS and the model and this will lead to inaccuracy of the results. The higher difference that were generated may due to the some faults that were caused during the processes. One of the errors that could be done during lowering the tripod is the parallax error which the eyes are not perpendicular to the scale of the measuring rod.

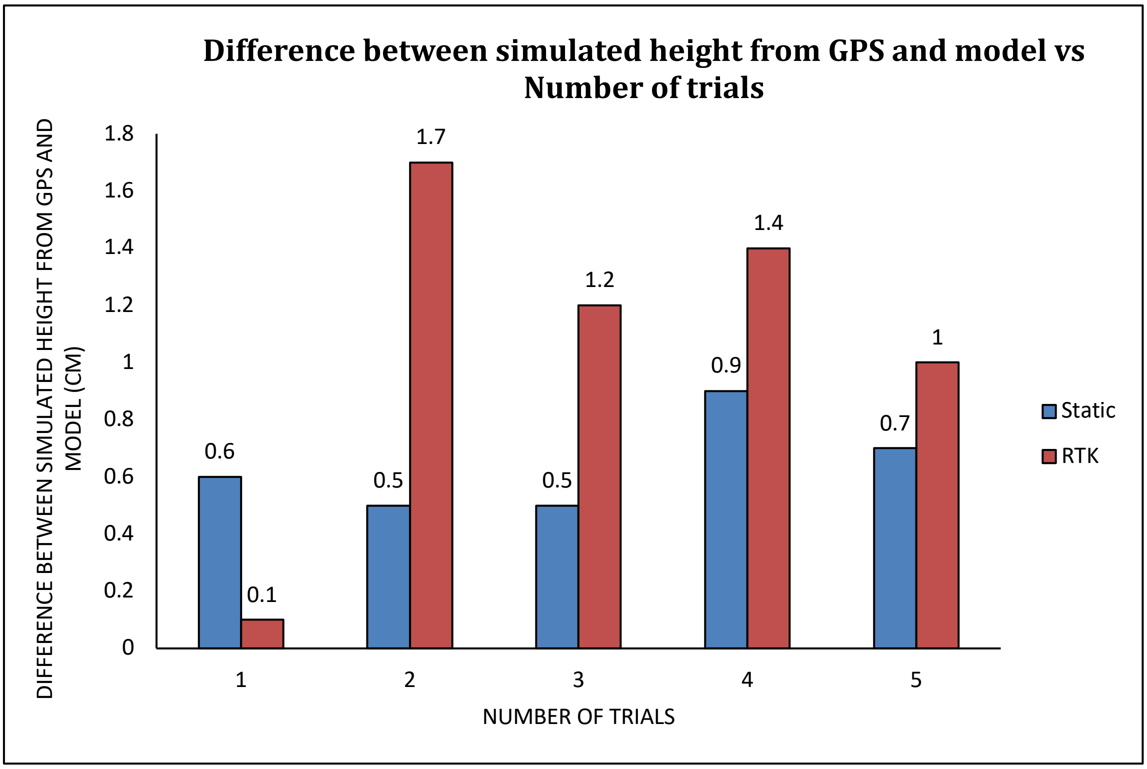
Besides, the other experimental faults that could done is the systematic error where the GPS require time to reach equilibrium, and taking a measurement before the instrument is stable that will be produce to the lower accuracy results. This is because during the process, the author has to lower the height of the tripod when the receiver is still on and it will lead to the unstable GPS to produce data/signals. These two factors can be the biggest contributors that lead to the higher errors that were generated by the GPS.

4.3 Comparison between the Static and RTK

The comparison between the Static and RTK are executed in the graphs as below:



Graph 4.3: Difference of the elevation height from the GPS and model



Graph 4.4: Difference between the stimulated height from the GPS and model

From the results, it can be shown that RTK execute the higher differences as compared to the Static. Through this field work, the Static can give more accuracy in determining and verifying the stimulated reservoir subsidence by using GPS equipment. This is because during the field work processes for static, the receiver is more stable as compared to RTK due to the time that was taken during the processes which is 30 minutes for the data/signals to be recorded by GPS. For the RTK, the GPS recorded the signals/data once the tripod was lowered to a certain height, hence the time to receive the data was very short and the GPS may not in the stable state during receiving the signals. Therefore, the accuracy of RTK is lower as compared to Static in determining the subsidence.

The accuracy between these methods can be conveyed in the percentage of the differences of the simulated height. The percentages of the differences were tabulated in the table as below:

Methods of GPS	**Percentages of the difference simulated height between GPS and model (%)**				
Static	12.0	7.1	4.5	5.3	3.5
Real-Time Kinematics	2.0	24.3	10.9	8.2	5.0

Table 4.3: Percentages of the difference simulated height between GPS and model

The percentages of the difference simulated height between GPS and model shows that the RTK method show the higher percentages values as compared to the Static. From this percentages values, it was shows that RTK method can also be one of the approach to verify and detect the stimulated subsidence but the results that were recorded will be not as accurate as the Static. This is because during the RTK approach, the receiver are in the continuous motion and it will lead to the inaccuracy of the data that will be recorded during the processes.

Besides, the difference between the simulated height from the GPS and model of the Static GPS shows that there are also some difference as the height of the tripod goes lowered. This was due from the experimental error which is the parallax error where the eyes are not equally aligned to the scale of the measuring rod and this type of error can affected the accuracy of the GPS to verify and determine the reservoir subsidence that was simulated by the model.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

Based on this study, *Nucleus Strain* approach was used for subsidence modelling since this approach has been developed into Geertsma model which is the tool that will be applied to predict the subsidence A variety of tools and techniques can be used in reservoir subsidence to minimize the risks from the subsidence. However, only a few methods are selected for this project which is Geertsma model and global positioning system (GPS) surveys due to the accuracy of the GPS to detect the subsidence. There are two types of GPS methods to be conducted in this study which are Static and RTK.

The results that were obtained from the field work can determined on the approach that will be used to verify and detect the subsidence that was simulated by the model. Based on calculated percentages values of the difference simulated height between GPS and model, it was shows that the Static method execute the lower percentage values as compared to the RTK method where the highest percentage values that was calculated is 7.1% as compared to the RTK which is 24.3%. While the overall percentage values of the difference simulated height between Static and RTK shows that Static give the lower percentage values as compared to the RTK.

Therefore from this comparison, it was indicate that both of these methods can be used to verify and detect the simulated subsidence but Static approach is more preferred in this study due to the accuracy of the results that were obtained during the processes. Besides, Static methods is very applicable in this study because the experimental errors that need to be handle is not so much as compared to the RTK during the field work processes.

The recommendation of this study is to conduct different approaches and techniques to verify the capability of the instrument to detect the probability subsidence that was calculated by the model since there are a lot of approaches that were studied by different researchers to mitigate the risks of the subsidence. This would give a comprehensive comparison and confirmation on the existing results.

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