Experimental Study of the Stability of Multilateral Well Junctions using Point Load Test

By

Afiq Aiman bin Hassan (10595)

Dissertation submitted in partial fulfillment of

the requirement for the

Bachelor of Engineering (Hons)

(Petroleum Engineering)

MAY 2011

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Experimental Study of the Stability of Multilateral Well Junctions using Point Load Test

by

Afiq Aiman bin Hassan

A project dissertation submitted to the

Geoscience & Petroleum Engineering Programme

Universiti Teknologi Petronas

in partial fulfillment of the requirement for the

BACHELOR OF ENGINEERING (Hons)

(PETROLEUM ENGINEERING)

Approved by,

Dr. Sonny Irawan
Senior Lecturer
Geoscience & Petroleum Engineering Department
Universiti Teknologi PETRONAS
Bandar Seri Iskandar, 31750 Tronoh
Perak Darul Ridzuan, MALAYSIA

28/9/2011

....

(Dr. Sonny Irawan)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2011

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 undertake or done by unspecified sources or persons.

....

AFIQ AIMAN BIN HASSAN

ABSTRACT

The strength of rock formation around multilateral (ML) well junctions is important. The objectives of this project were to determine the strength of cylindrical shape rock samples drilled with different geometrical configuration (inclination angle of lateral hole) and different orientation using Point Load Test (PLT). Vertical compressive forces were applied to several cylindrical shape rock samples that were placed between platen at the Point Load Tester. Maximum applied load were recorded and the index rock strength of each sample was recorded. Results proved that the highest strength of rock were shown from the sample drilled with the lowest inclination angle and sample drilled with horizontal parent hole.

ACKNOWLEDGEMENT

In the name of Allah, The Most Gracious, The Most Merciful. Praise to Allah S.W.T by whose grace and sanction I manage to complete Final Year Project within time.

First and foremost, I would like to extend my sincere gratitude to my supervisor Dr. Sonny Irawan for being a wonderful mentor in guiding, supporting and assisting me, also for his knowledge shared with me through the year, which are simply precious.

Not forgetting to other lecturers of UTP especially from the Petroleum Engineering department, thanks for useful thoughts and assistance that help me a lot in completing this project.

Last but not least, to my parents and colleagues, thanks for always stand in my back and keep supporting me until I manage to complete this project.

TABLE OF CONTENTS

ABSTRACT	**i**
ACKNOWLEDGEMENT	**ii**
TABLE OF CONTENTS	**iii**
LIST OF FIGURES	**v**
LIST OF TABLES	**vi**
NOMENCLATURE	**vii**
CHAPTER 1 - INTRODUCTION	**1**
1.1 BACKGROUND OF STUDY	1
1.2 PROBLEM STATEMENT	2
1.3 OBJECTIVES	3
1.4 SCOPE OF STUDY	3
1.5 THE RELEVANCY OF THE PROJECT	4
1.6 FEASIBILITY STUDY	5
CHAPTER 2 – THEORY & LITERATURE REVIEW	**6**
2.1 THEORY	6
2.1.1 Multilateral Well Junctions	6
2.1.1.1 Level 1	6
2.1.1.2 Level 2	7
2.1.2 Stress	7
2.1.2.1 Compressive Stress	7
2.1.3 Strength	8
2.1.2.3 Compressive Strength	8
2.1.4 In- Situ Stress	8
2.1.5 Vertical Stress	10
2.1.6 Point Load Test	10
2.2 LITERATURE REVIEW	11

CHAPTER 3 - METHODOLOGY **15**

3.1 EXPERIMENT METHODOLOGY 15

3.2 POINT LOAD TEST METHODOLOGY 16

3.3 TOOLS AND EQUIPMENTS 17

3.4 GANTT CHART 18

CHAPTER 4- RESULTS AND DISCUSSION **19**

4.1 RESULTS 19

4.1.1 Rock Sample Identification using XRF 19

4.1.2 Results of Samples with Different Geometrical Configurations 21

4.1.3 Results of Samples with Different Orientation 23

4.2 DISCUSSIONS 25

CHAPTER 5- CONCLUSION **30**

5.1 CONCLUSION 31

5.2 RECOMMENDATION 31

REFERENCES **32**

APPENDIX 1 (Detail Methodology) **34**

LIST OF FIGURES

FIGURE	PAGE
Figure 1: Overview of Multilateral Wells	2
Figure 2: Classification of Multilateral Wells	2
Figure 3: M- L level 1	3
Figure 4: M- L level 2	3
Figure 5: Parent and lateral hole not supported by cemented casing	6
Figure 6: Parent hole is supported with casing but lateral hole is not	7
Figure 7: Compressive forces act on a material	8
Figure 8: 3-D stresses that act on underground rock formation	9
Figure 9: The position of principal stress from maximum to minimum	9
Figure 10: Young's Modulus vs Deviatoric Stress	11
Figure 11: Peak stress vs. Confining pressure in triaxial test	12
Figure 12: Geometrical Configurations of the tests	12
Figure 13: Geometries and stress conditions of the six experiments	13
Figure 14: Sketch of the breakout shapes observed after the experiments.	14
Figure 15: Side view of sample 1 in real scale	21
Figure 16: Side view of sample 2 in real scale	21
Figure 17: Side view of sample 3 in real scale	22
Figure 18: Top view of sample 5 in real scale	23
Figure 19: Top view of sample 6 in real scale	23
Figure 20: Side view of sample 4 & 5 in real scale	23
Figure 21: Top view of sample 6 in real scale	24
Figure 22: Top view of sample 7 in real scale	24
Figure 23: Side view of sample 6 and 7 in real scale	24
Figure 24: IS vs. Inclination Angle for Vertical Parent Hole	26
Figure 25: IS vs. Inclination Angle for Horizontal Parent Hole	26
Figure 26: Illustration of vertical compressive force reaction	28

LIST OF TABLES

Table	Page
Table 1: Gantt Chart	18
Table 2: Chemical Elements Composed in the Rock Sample	19
Table 3: Normal Percentage Range of Granite	19
Table 4: Normal Percentage Range of Sandstone	20
Table 5: Results for samples of vertical parent hole orientation	25
Table 6: Results for samples of horizontal parent hole orientation	25

NOMENCLATURE

Symbol	Definition	Unit
F	Force	N
A	Area	m^2
D	Diameter	m
IS	Rock Strength Index	MPa/mm^2
L	Length	m
P	Pressure	MPa

Symbol	Definition	Unit
σ	Stress	Pascal, Pa

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Multilateral wells offer not only improvement in accessibility and recovery but also reduction in drilling and development cost. Their effectiveness has been confirmed in many oil fields throughout the world. Despite their increasing economic appeal, the stability of the multilateral well junctions remains one of the most challenging problems in the industry. [1]

Drilling inclined wells through producing strata can greatly improve reservoir drainage and hydrocarbon recovery. The horizontal sections are accessed through multiple inclined wells drilled from a relatively small area in many or all, directions, something that allows better exploitation of offshore platforms and land rigs that are under economic and environmental restrictions. Drilling inclined and horizontal wells, though, is more difficult and more expensive, due to wellbore instabilities. A particular area of concern is the integrity of the rock near a multilateral (M- L) junction. The junction is the region where a second wellbore (lateral) takes off from the main wellbore (parent). [2]

Lateral junctions are a critical element of multilateral completions and can fail under formation stresses, temperature- induced forces and differential pressures during production. Junctions are divided into two broad groups, those that do not provide pressure integrity (Level 1, 2, 3 and 4) and those that do (Level 5 and 6). Multilateral success depends on junction durability, versatility and accessibility. [3]

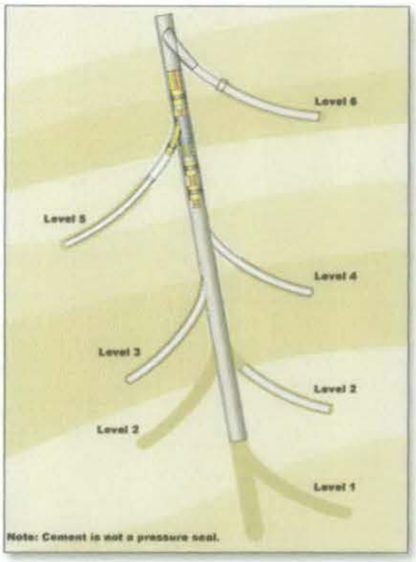


Figure 1: Overview of Multilateral Wells [24]

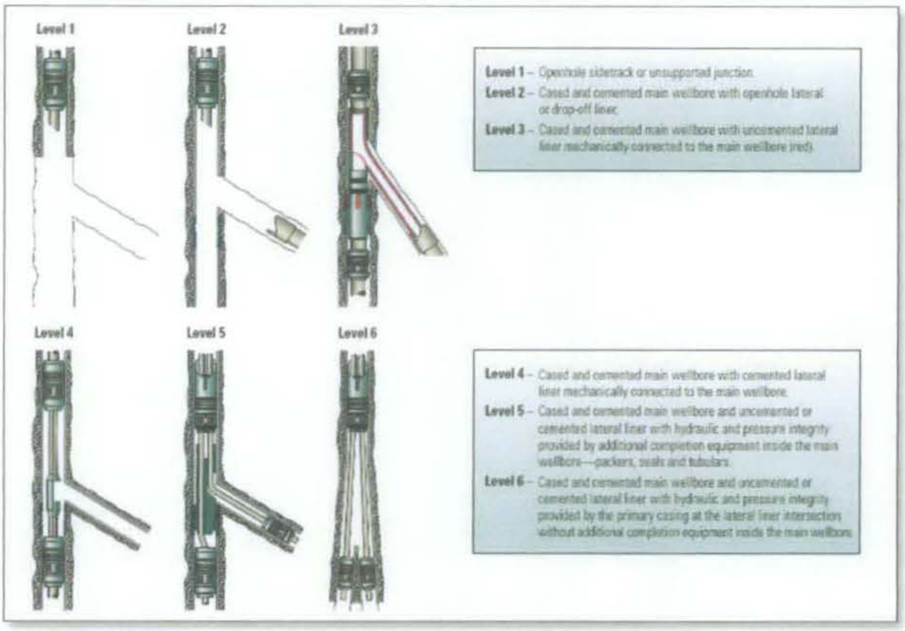


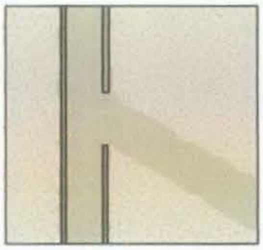
Figure 2: Classification of Multilateral Wells [2]

1.2 PROBLEM STATEMENT

The main problem of drilling multilateral wells is the wellbore instabilities. The integrity of rock near an M- L junction is a particular area of concern. The integrity of the rock around the area of two intersecting tubes becomes very important in terms of stability in M- L level 1 and 2 since the rock at the junction is independent and not supported mechanically with cemented casing. The rock formation must have enough strength to maintain the stability of multilateral well junctions. A good geometrical configurations and orientation of multilateral wells can maintain the strength of the rock formation around the M-L junctions.

1

Figure 3: Multilateral Junction Level 1[3]



2

Figure 4: Multilateral Junction Level 2[3]

1.3 OBJECTIVES

1. To determine the strength of cylindrical shape rock samples drilled with different geometrical configurations.
2. To determine the strength of cylindrical shape rock samples drilled with different orientation.

1.4 SCOPE OF STUDY

The scope of study revolved around the stability the rock formation around the multilateral junction. In this project, several cylindrical shape rock samples were drilled with two holes that intersected at a certain point in the cylindrical shape rock sample. The two holes simulated a parent hole and a lateral hole that are drilled in a rock formation. The rock formation underground is represented by the cylindrical shape rock sample.

This project was focusing on running several series of experiment using point load test to determine the strength of the cylindrical shape rock samples that were drilled in different geometrical configurations (different inclination of lateral angle) and different orientation.

For the first objective which is to determine the strength of cylindrical shape rock samples drilled with various geometrical configurations using point load test, several cylindrical shape rock samples were drilled at the centre with vertical parent hole until a certain point of specific depth. Then lateral hole were drilled with different inclination angle with respect to the parent hole for each core sample. The different inclination angle for each cylindrical shape core sample represents various geometrical configurations. Then each cylindrical shape rock sample was tested using point load tester to determine the strength of each sample.

For the second objective which is to determine the strength of cylindrical shape rock samples that are drilled with parent hole and lateral hole in different orientations using point load test, several cylindrical shape rock samples were also drilled with parent hole and lateral hole, but this time the parent hole were drilled horizontally at a certain specific depth compared to the previous objective which the parent hole was drilled vertically. Then, the lateral hole was drilled with different inclination angles with respect to the parent hole.

For additional information about the type of rock that is used for this project, the sample of the rock in crushed form underwent X- Ray Fluorescence test to determine the chemical elements that the rock composed and the chemical elements are studied to identify the type of rock sample used in this project.

1.5 THE RELEVANCY OF THE PROJECT

The integrity of the rock formation around the junction between the parent hole and lateral hole is the main concern that has been studied for several years until today. Unfortunately, some of the studies for the stability of multilaterals have been limited because the complex geometry and stress state involved.[1] After completing this experimental study hopefully the results will be useful to help the drilling engineers to decide in which formation, in which azimuth and which deviation to drill a stable lateral.[2]

1.6 FEASIBILITY STUDY

This project mostly related to rock mechanics study. The experiment run was related to point load test to determine the strength of the cylindrical shape rock samples that were drilled with parent hole and lateral hole to simulate a rock formation that is drilled with vertical hole and lateral hole. Some calculations were done when dealing with this equipment especially when calculating the rock strength. This project was completed within the time frame since the procedure was followed thoroughly.

CHAPTER 2

THEORY AND LITERATURE REVIEW

2.1 THEORY

2.1.1 Multilateral Well Junctions

The Technology Advancement Multi- Lateral operators group (TAML) introduced a classification system for multilateral completions based on the amount and type of support provided at the junction which is the area of the well where the lateral departs from the trunk. These levels increase in complexity from Level 1 through Level 6. The strength of the rock formation plays a very important role in maintaining the stability of multilateral well junctions especially in multilateral level 1 and 2.

2.1.1.1 Level 1

This is the simplest of all multilateral systems. Neither the main bore nor the lateral is cased. A Level 1 junction is an open- hole horizontal completion with no seal, or special treatment at the junction between the vertical and horizontal wellbores. A Level 1 junction is best suited for formation with hard rock in the mainbore, at the junction and in the laterals. It means that this junction depends on the strength of the rock formation around to maintain its stability. [5]

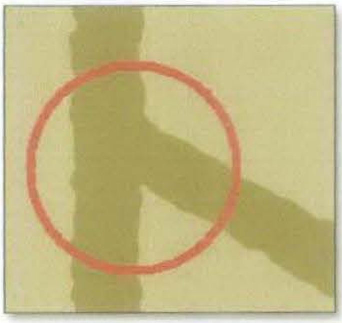


Figure 5: ML level 1. Parent hole and lateral hole are not supported by cemented casing [3]

2.1.1.2 Level 2

For Level 2, the multilateral junction that connects a cased and cemented mainbore with open or simple (slotted liners, pre-packed screens) lateral bores. The mainbore casing minimizes the chances for borehole collapse, and provides hydraulic isolation between lateral zones. This level is best suited for hard junctions, and hard laterals, with low potential for cross- flow control, low potential for re- entry, low need for production isolation between laterals, and comingled production from various zones. The stability of the rock around the multilateral junction is still play an important role for this level. [5]

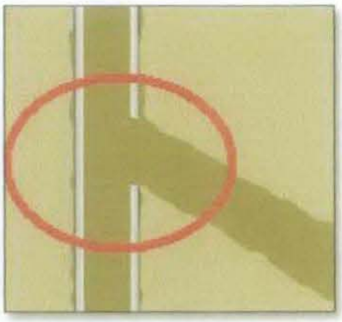


Figure 6: ML level 2. Parent hole is supported by casing but lateral hole is not. [3]

2.1.2 Stress

Stress is expressed by:

$$\sigma = \frac{F}{A} \text{.............................. } (2.1)^{[9]}$$

2.1.2.1 Compressive Stress

It is defined as the stress state caused by an applied load that acts to reduce the length of the material (compression member) in the axis of the applied load, in other words the stress state caused by squeezing material. [18]

Compressive stress can be determined by using applied loads act towards each other to the cross- sectional area of the specimen, which will make the cross section area typically increases. The force applied and the cross sectional area can be recorded and added in equation (2.1) so the value of the compressive stress can be calculated.

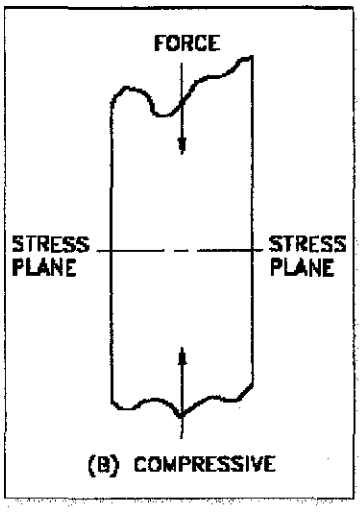


Figure 7: Compressive forces acted on a material [18]

2.1.3 Strength

2.1.3.1 Compressive strength

It is defined as the value of unaxial compressive stress reached when the materials fails completely. [24]

$$\sigma^*_e = \frac{F^*}{A_O} \quad \text{.............................. (2.2)}^{[18]}$$

Compressive strength can be determined by recording the maximum load that can be applied on a specimen before the load start to decrease and failure occurs on the specimen.

2.1.4 In- Situ Earth Stress

At any point below the earth's surface, there are 3 independently acting stresses which are perpendicular to each other. The three normal stresses are known as vertical stress (σ_V), and two horizontal stresses (σ_H and σ_h). The horizontal stress will act in two dimensions which are from x-axis and y- axis. In most cases, the maximum principal stress will be vertical due to the pressure overlying rock. [19]

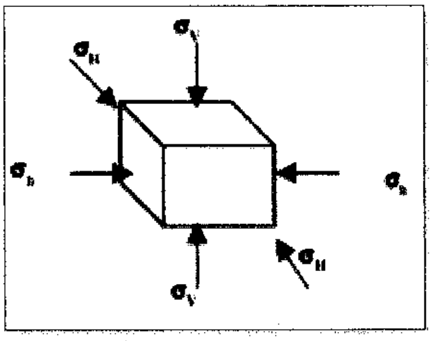


Figure 8: The 3-D stresses that act on a rock formation underground [19]

For most oil well applications, the rock under consideration are subjected to in- situ stresses which have no shear stresses. The normal stresses which have no associated shear stresses are described as principle stresses which are perpendicular to each other. Figure 9 will illustrate about this.

- The maximum principal stress (σ_1)
- The intermediate principal stress (σ_2)
- The minimum principal stress (σ_3)

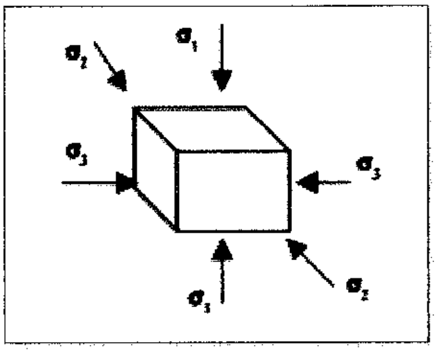


Figure 9: The position of maximum principal stresses to minimum principal stress [19]

2.1.5 Vertical Stress/ Overburden Pressure

In most cases, the maximum principal stress will be vertical due to the pressure of the overlying rock. Vertical stress in the ground, also known as overburden pressure which acts on a rock formation underground is the total vertical stress approximately equal to the average specific weight of the overlying sediments. [19]

2.1.6 Point Load Test

The point load test equipment known as point load tester is designed to carry out compression strength/ strength index. This equipment is used to obtain quick information concerning rock strength. A rock core piece is subjected to a compression load along its diameter with two opposite conical platens. The index of rock strength is calculated using the formula;

$$IS = \frac{P}{D^2} \qquad (2.3)$$

Using the point load test, the compressive stress which acts from the vertical direction will simulate the main principal stress act in a rock formation underground known as overburden pressure.

2.2 LITERATURE REVIEW

Physical experiments to understand the stability of a multilateral junction was carried out in the true triaxial machine at Lille University. The tested blocks are cubes of 40 cm sides. Tests were carried out of parent and lateral holes drilled at different orientations and for different applied stress paths. The tested rock is weak sandstone called 'Gres des Vosges'. At the end of the tests, the blocks were cut in planes perpendicular to the parent hole axis in order to observe the integrity of the rock at different distances from the junction. [2]

Figure 10 shows the variation of elastic modulus vs. applied deviatoric stress obtained from standard triaxial tests with different confining pressure. They observed that there is significant increase with increasing confining pressure, but small variations with applied load in each test of constant confining pressure. In addition, there is no strong variation for confining pressures higher than 10 MPa. In the simulations they used the average saturation value of 22.5 GPa.[2]

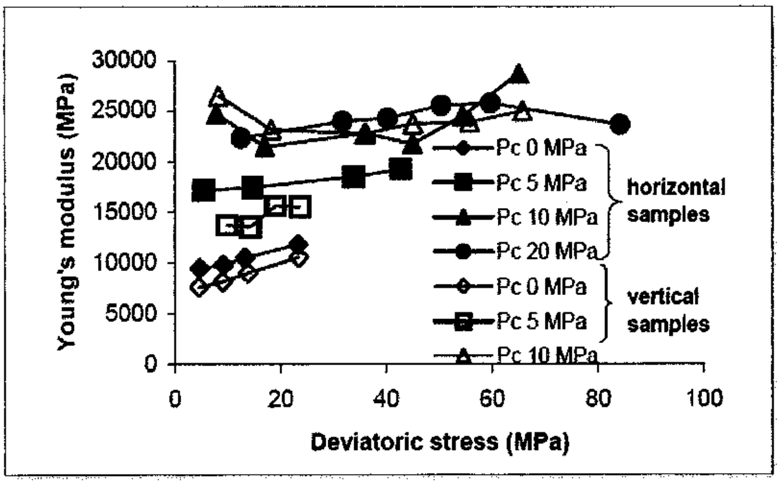


Figure 10: Young's Modulus vs. Deviatoric Stress [2]

The triaxial compression tests showed a slight anisotropy with strength difference about 2 to 5 MPa; horizontal samples are the weaker. Unaxial compression tests, with loading- unloading cycles, showed a degree of strength anisotropy, with vertical UCS= 36 MPa and horizontal UCS= 28 MPa. Figure 11 shows that there is almost a linear variation of peak stress with confining pressure. The estimated Mohr- Coulomb parameters are 8.5 MPa for the cohesion and 28.5 degrees for the friction angle. [2]

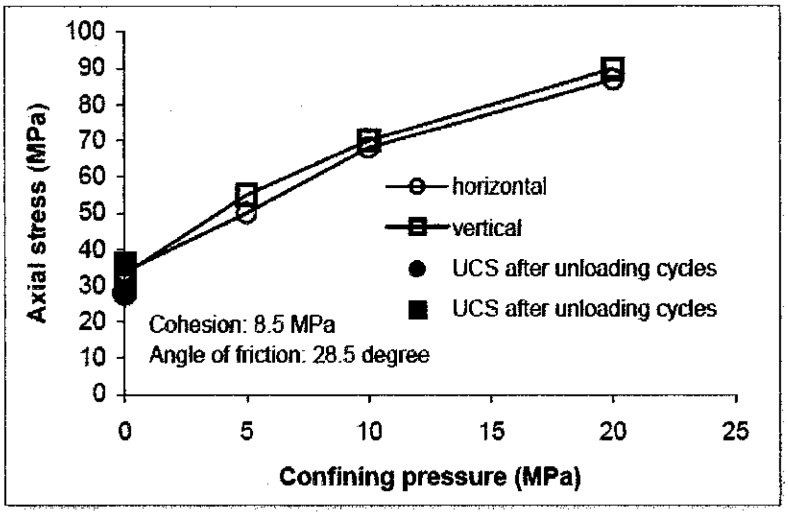


Figure 11: Peak Stress vs. Confining pressure in triaxial test [2]

Figure 12 shows the geometrical configuration of the true triaxial test. The parent hole diameter of 37 mm was drilled through the centre of the block. The lateral hole has a diameter of 31 mm and was drilled with 22.5 degrees inclination from the parent hole but with different orientation. [2]

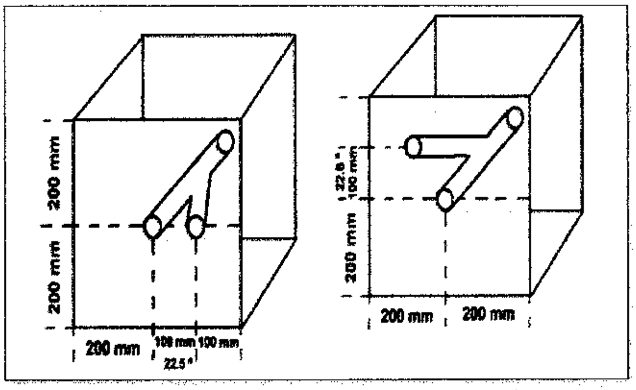


Figure 12: Geometrical Configurations of the Test [2]

Six experiments have been conducted. Five of these were experiments with a lateral borehole and one was done with a single borehole. Figure 13 shows the different geometries of the blocks and the stress condition under which the six experiments were carried out. The symbol σ_H,σ_h, and σ_v refer to the stress directions applied by the triaxial machine on the samples. σ_v is oriented parallel to the axis of the main borehole and during the experiments with anisotropic stress conditions its value was always 0.6 times the maximum stress.[2]

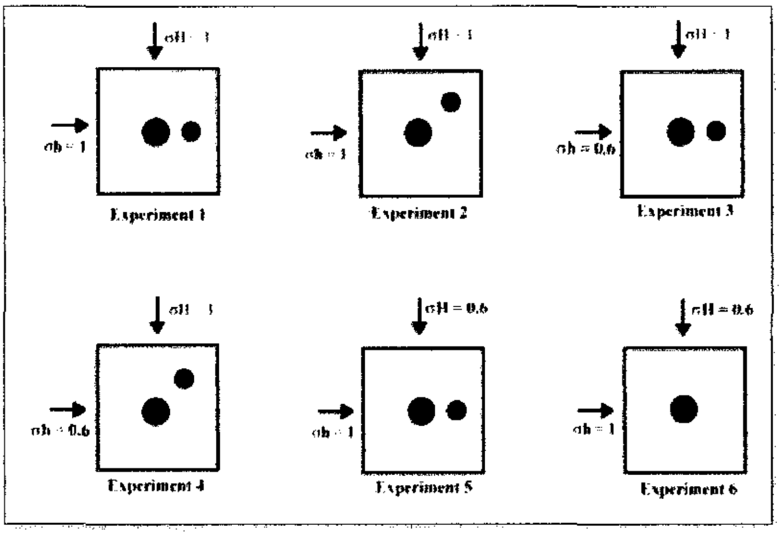


Figure 13: Geometrics and stress conditions of six experiments [2]

During the experiments, the main borehole and parts of the junction were observed using an endoscopic camera and a light guide, which projects a ring of light on the borehole wall. From the recorded video tapes, the borehole deformation and the stress at which failures occurs can be determined. Comparison of experiments 3 and 5 shows that the junction with lateral hole drilled parallel to the maximum stress (experiment 5) is more stable than when the lateral is drilled perpendicular to the maximum stress. [2]

The failure stress and mode in experiment 2 are very similar to those in experiment 1, as expected from isotropic stress. The junction of a lateral drilled at 45^o to the principal stress directions and subjected to anisotropic stresses, fails at much lower stresses than under isotropic stress conditions. [2]

The failure stress of the single hole (experiment 6) is relatively low, especially compared to experiment 5. [2]

Besides, single, digital snapshots were taken from the video tapes at each load step or when a new failure had occurred and analysed for the deformation of the main borehole. Using software, the reduction of borehole size was determined either by measuring the length of single diameters (experiment 1), or by measuring the reduction of the area (experiments 2 to 6). Figure 14 summarized the analysis. [2]

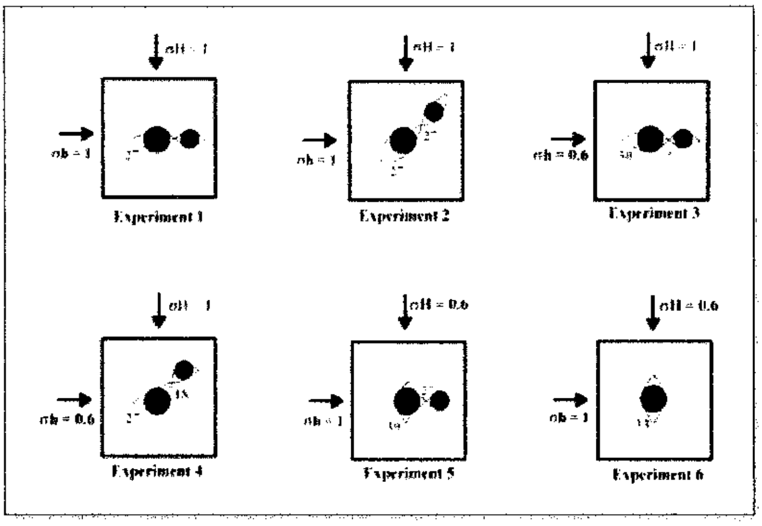
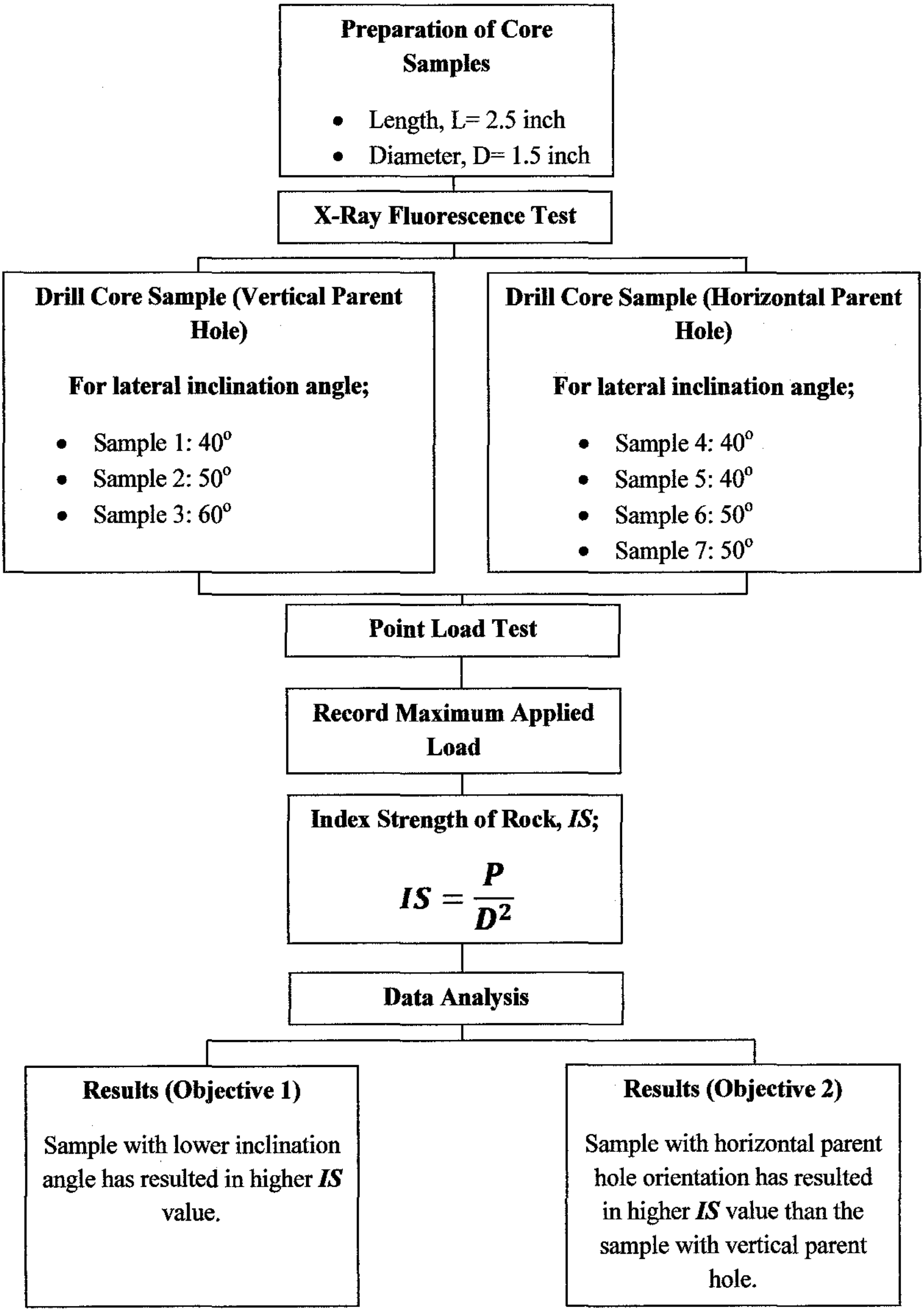


Figure 14: Sketch of the breakout shapes observed after the experiments. The numbers in red give maximum stresses (MPa) at which the failure of the main borehole and the junction started [2]

CHAPTER 3

METHODOLOGY

3.1 EXPERIMENT METHODOLOGY



3.2 POINT LOAD TEST

Place cylindrical shape rock sample vertically at the place and below the centre of the conical platen.

↓

Enter the diameter of the cylindrical shape rock sample at the digital meter

↓

Apply compressive stress by using the hydraulic jack until the cylindrical shape rock sample breaks.

↓

Set the meter to give the value of maximum applied stress.

↓

Record the maximum applied load.

↓

Calculate the value of Index Strength of Rock

3.3 TOOLS AND EQUIPMENTS

The main equipment used for this project was point load tester. The point load tester was used to determine the strength of the cylindrical shape rock samples. This equipment is located at laboratory block 14.

Coring machine was used to convert a large rock samples into several cylindrical shape rock samples. Trimming equipment was used to trim each cylindrical shape rock sample into the desired length. These equipments are located at block 15.

The next equipment used was drilling machine. Drilling machine used to drill parent hole and lateral hole for each cylindrical shape rock sample. This equipment is located at laboratory block 14.

Oven was also used to dry every cylindrical shape rock sample before the drilling process took place. This was done to make sure the dry core sample regained its strength since coring process used water and might weaken the rock sample. This equipment is located at laboratory block 16.

3.4 GANTT CHART

ACTIVITIES / WEEK	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Research on method to conduct experimental study on stability of multilateral junction using point load test.	■	■	■	■																						
Cut and form raw sandstone into core cylindrical shape sandstone samples					■	■																				
X- Ray Fluorescence Test					■	■																				
Drill the core sample as per planned using drilling machine.							■	■																		
Rock strength test for samples drilled with different geometrical configuration.									■																	
Data analysis										■	■	■														
Rock strength test for samples drilled with different orientation													■													
Data analysis														■	■	■										
Data comparison, Conclusion																	■	■								
Project documentation																			■	■	■					

MILESTONE / WEEK	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Completion of preparation of sandstone samples										■																
Completion of strength test for samples drilled with different geometrical configuration of samples													■													
Completion of strength test for each core sample drilled with different orientation																	■									
Project Completion																						■				

Table 1: Gantt chart for FYP 1 and FYP 2

CHAPTER 4

RESULTS AND DISCUSSION

4.1 RESULTS

4.1.1 Rock Sample Identification using XRF (Results and Discussion)

Elements	MgO	Al2O3	SiO2	P2O5	SO3	K2O	CaO
Percentage	1.81	12.2	74.91	1.17	0.612	2.19	0.395
Elements	TiO2	MnO	Fe2O3	ZnO	Rb2O	SrO	ZrO2
Percentage	0.477	0.012	6.188	0.0029	0.0069	0.0071	0.0290

Table 2: Chemical Elements Composed in the Rock Sample

The result above was obtained after the X- Ray Fluorescence (XRF) test done at the block 17 laboratory. It shows the percentage of chemical elements that the rock sample composed.

Based on the result, the most abundant chemical element that the rock sample composed is Silicon Oxide (SiO_2) which is 74.91 %. The second most abundant chemical element is Aluminium Oxide (Al_2O_3) which contributes to 12.2 % of chemical element that the rock sample composed. The sum of these two most abundant chemical elements which are SiO_2 and Al_2O_3 is 87.11 %. It means that the other 13 out of 15 chemical elements that the rock sample composed contribute only 12.89 % from the total of 100 %.

From this result, the best type of rock that suits the information obtained from the XRF test is granite. Below are listed the nominal chemical elements of granite.

Nominal Chemical Composition	Percentage Range (%)
Silicon Oxide (SiO_2)	70- 77
Aluminium Oxide (Al_2O_3)	11- 14
Potassium Oxide (P2O5)	3- 5
Sodium Oxide (Na2O)	3-5
Calcium Oxide (CaO)	1
Iron Oxide (Fe2O3)	1- 2
Magnesium Oxide (MgO)	0.5- 1

Table 3: Normal Percentage Range of Granite

After comparing the results of from the XRF test and the nominal chemical composition of granite, it is clearly shown that the percentage of the chemical elements that were obtained using the XRF test are within the range that suits the chemical composition of granite. For example, the percentage of Silicon Oxide (SiO2) that was obtained using XRF test was 74.91 % which is within the range of 70 % to 77%. The next best example is Aluminium Oxide (Al2O3). The percentage of Aluminium Oxide (Al2O3) that was obtained using the XRF test was 12.2 % which is within 11 % to 14%. Besides, most of the chemical elements for the rock sample that were identified using the XRF test contribute to the nominal chemical composition of granite.

Advance analysis was made by comparing the chemical elements between sandstone and granite. Below are listed the nominal chemical elements of sandstone.

Nominal Chemical Composition	Percentage Range (%)
Silicon Oxide (SiO2)	93- 94
Aluminium Oxide (Al2O3)	1.4- 1.5
Iron Oxide (Fe2O3)	1.5- 1.6
Calcium Oxide(CaO)	0.8- 0.9
Sodium Oxide (Na2O)	1.0- 1.2
Magnesium Oxide (MgO)	0.2- 0.25

Table 4: Normal Percentage Range of Sandstone

Based on the data above, it is clearly shown that some the chemical elements range for the rock sample not suits the sandstone type of rock. For example, the range of Silicon Oxide (SiO2) for sandstone is 93 % to 94 % which is higher than the percentage obtained for the rock sample using the XRF test which is 70 % to 77 %. Another example is by comparing the Aluminium Oxide (Al2O3). The range of Aluminium Oxide (Al2O3) that a sandstone sample should have is within 1.4 % to 1.5 % but for the tested rock sample, the percentage of the Aluminium Oxide (Al2O3) is 12.2 %. This leads to about 87 % of error. Therefore, the best type of rock based on the XRF result is granite which is in igneous rock group.

4.1.2 Results of Samples with Vertical Parent Hole and Different Inclination Angle

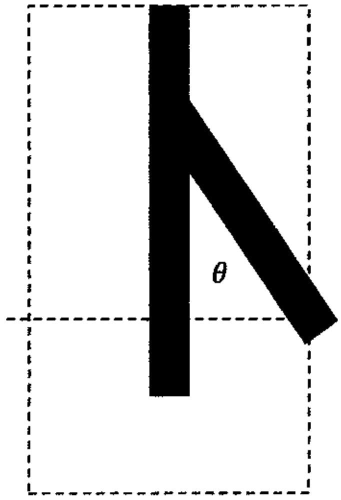


Figure 15: Side view of sample 1 in real scale (1:1) before Point Load Test

Sample 1

Degree of inclination (θ)	= 40°
Length of lateral junction	= 29.643 mm
Maximum applied load, P	= 5.10 MPa
Diameter along platen, D	= 63.5 mm

$$IS = \frac{5.10\ MPa}{(63.5\ mm)^2} = 0.0013\ MPa/mm^2$$

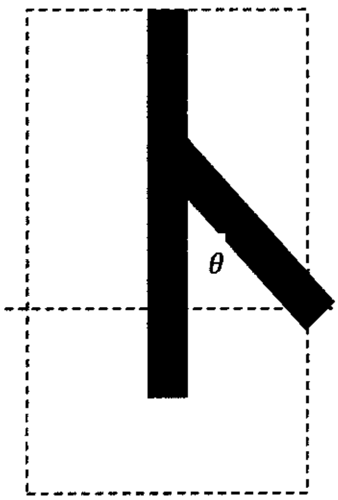


Figure 16: Side view of sample 2 in real scale (1:1) before Point Load Test

Sample 2

Degree of inclination (θ)	= 50°
Length of lateral junction	= 24.895 mm
Maximum applied load, P	= 3.79 MPa
Diameter along platen, D	= 63.5 mm

$$IS = \frac{3.79\ MPa}{(63.5\ mm)^2} = 0.0009\ MPa/mm^2$$

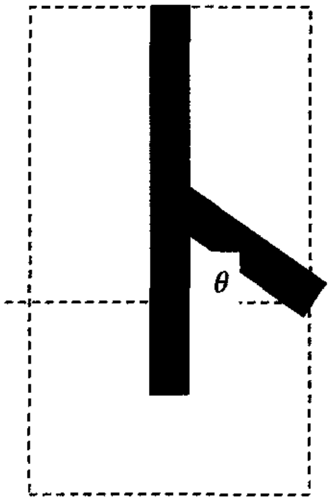


Figure 17: Side view of sample 3 in real scale (1:1) before Point Load Test

Sample 3

Degree of inclination (θ)	= 60°
Length of lateral junction	= 21.997 mm
Maximum applied load, P	= 2.99 MPa
Diameter along platen, D	= 63.5 mm

$$IS = \frac{2.99\ MPa}{(63.5\ mm)^2} = 0.0007\ MPa/mm^2$$

4.1.3 Results of Samples Drilled with Horizontal Parent Hole and Different Inclination Angle

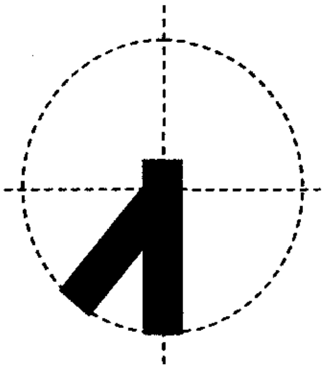


Figure 18: Top view of sample 5 in real scale (1:1) before point load test

Sample 4

Degree of inclination (θ)	= 40°
Length of lateral junction	= 18.5 mm
Maximum applied load, P	= 7.52 MPa
Diameter along platen, D	= 63.5 mm

$$IS = \frac{7.52\ MPa}{(63.5\ mm)^2} = 0.0019\ MPa/mm^2$$

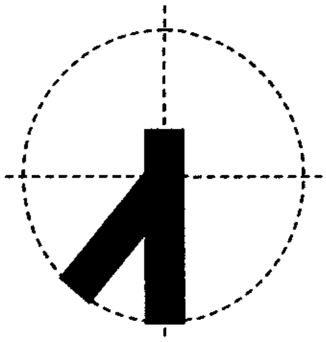


Figure 19: Top view of sample 6 in real scale (1:1) before point load test

Sample 5

Degree of inclination(θ)	= 40°
Length of lateral junction	= 18.5 mm
Maximum applied load, P	= 6.78 MPa
Diameter along platen, D	= 63.5 mm

$$IS = \frac{6.78\ MPa}{(63.5\ mm)^2} = 0.0017\ MPa/mm^2$$

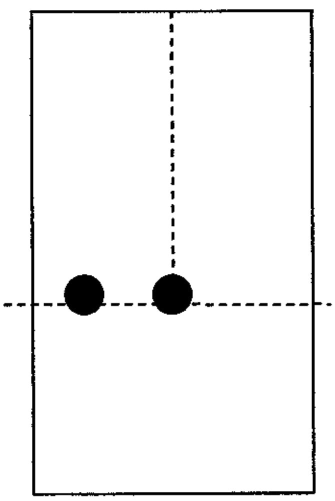


Figure 20: Side view of sample 4 & 5 in real scale (1:1) before point load test

Average value of Maximum Applied Load for sample 4 and 5, P;

$$\frac{7.52\ MPa + 6.78\ MPa}{2} = 7.15\ MPa$$

Average Value of Rock Strength Index for sample 4 and 5, IS;

$$\frac{0.0019 + 0.0017}{2} = 0.0018\ MPa/mm^2$$

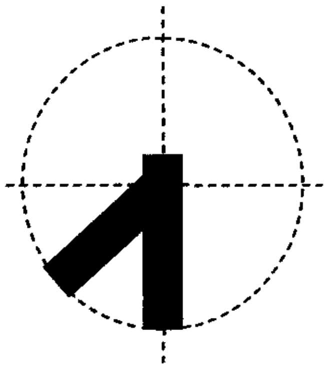


Figure 21: Top view of sample 6 in real scale (1:1) before point load test

Sample 6

Degree of inclination (θ)	= 50°
Length of lateral junction	= 18.999 mm
Maximum applied load, P	= 7.85 MPa
Diameter along platen, D	= 63.5 mm

$$IS = \frac{7.85\ MPa}{(63.5\ mm)^2} = 0.0020\ MPa/mm^2$$

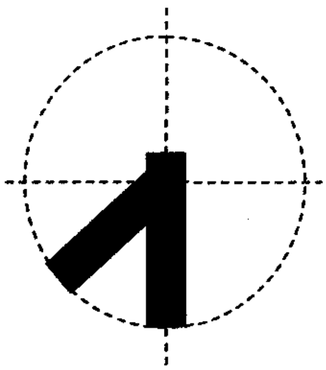


Figure 22: Top view of sample 7 in real scale (1:1) before point load test

Sample 7

Degree of inclination (θ)	= 50°
Length of lateral junction	= 18.999 mm
Maximum applied load, P	= 6.84 MPa
Diameter along platen, D	= 63.5 mm

$$IS = \frac{6.84\ MPa}{(63.5\ mm)^2} = 0.0017\ MPa/mm^2$$

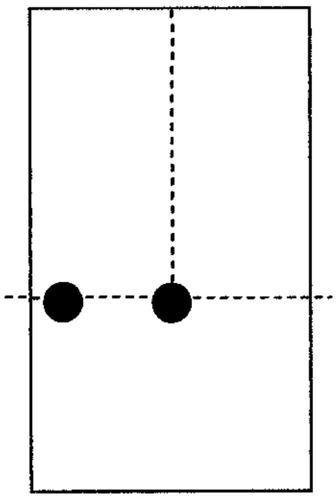


Figure 23: Side view of sample 6 and 7 in real scale (1:1) before point load test

Average value of Maximum Applied Load for sample 7 and 8, P;

$$P = \frac{7.85\ MPa + 6.84\ MPa}{2} = 7.345\ MPa$$

Average Value of Rock Strength Index for sample 7 and 8, IS;

$$IS = \frac{0.0020 + 0.0017}{2} = 0.00185\ MPa/mm^2$$

4.2 DISCUSSIONS

Table 3 shows the result obtained for the vertically drilled parent hole cylindrical shape rock samples with different geometrical configurations (different inclination angle of lateral hole).

Sample	Inclination Angle	Lateral Length (mm)	Maximum Applied Load (MPa)	*IS* (MPa/mm^2)
1	40	29.643	5.10	**0.0013**
2	50	24.895	3.79	**0.0009**
3	60	21.997	2.99	**0.0007**

Table 5: Results for samples of vertical parent hole orientation drilled with different inclination angle

Table 4 shows the result obtained for the horizontally drilled parent hole cylindrical shape rock samples with different geometrical configurations (different inclination angle of lateral hole).

Sample	Inclination Angle	Lateral Length (mm)	Maximum Applied Load (MPa)	Average *IS* (MPa/mm^2)
4	40	18.5	7.52	**0.0018**
5			6.78	
6	50	18.999	7.85	**0.00185**
7			6.84	

Table 6: Results for samples of horizontal parent hole orientation drilled with different inclination angle

Graph 1 represents the information obtained from table 1.

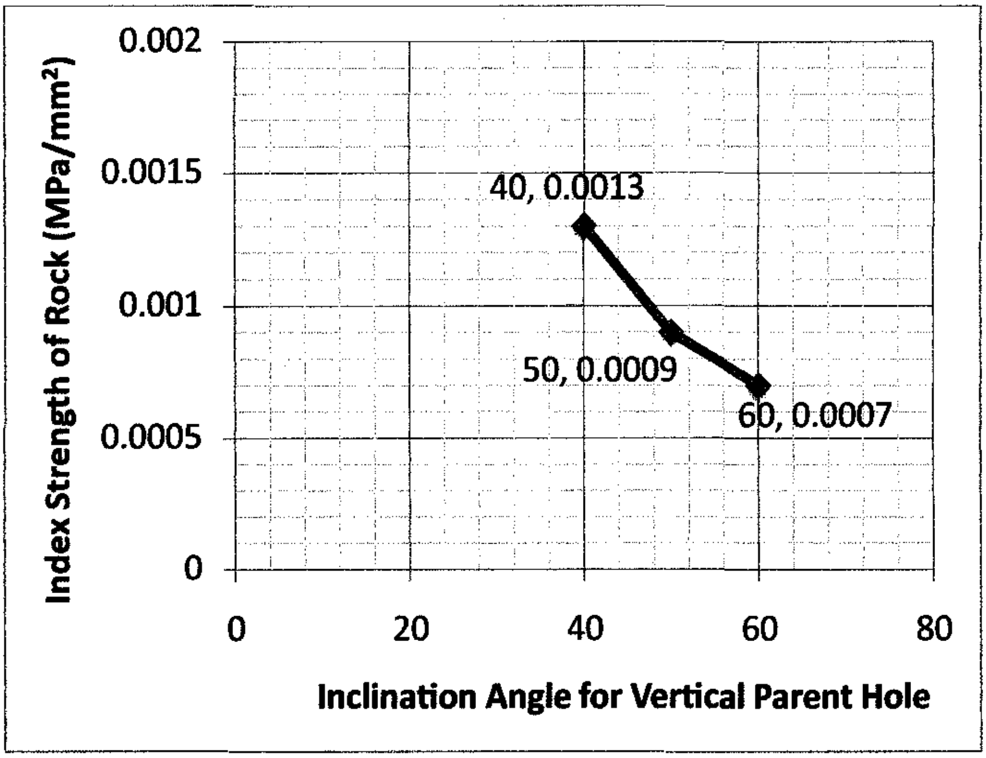


Figure 24: Index of Rock Strength vs. Degree of Inclination Angle for Vertical Parent Hole

Graph 2 represents the information obtained from table 2.

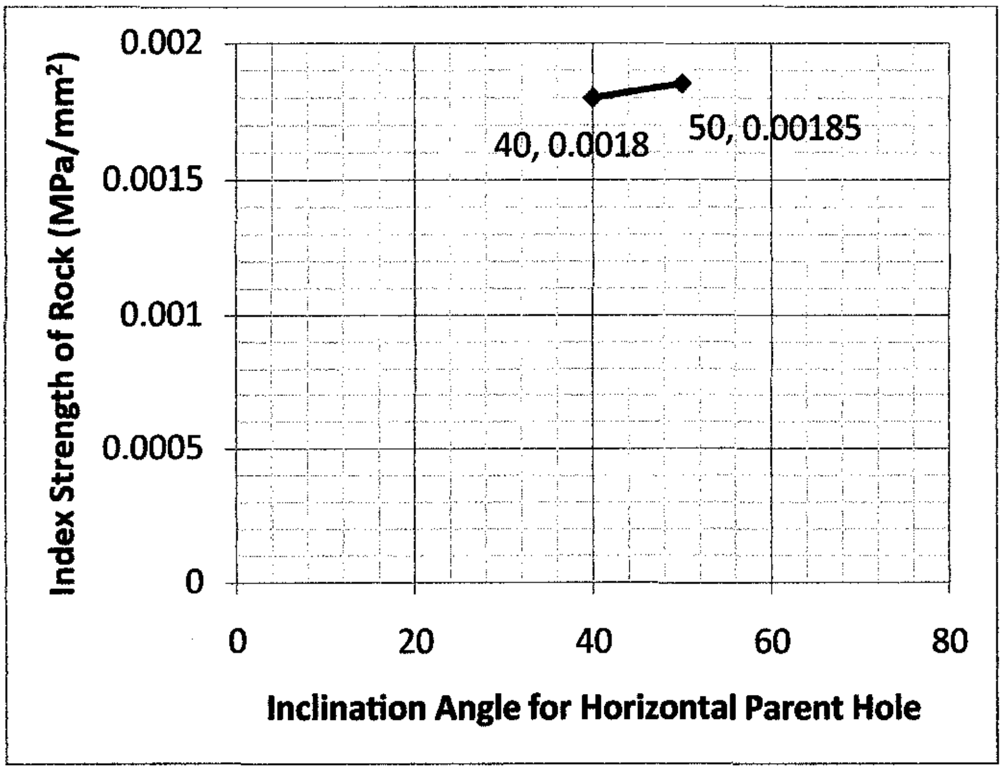


Figure 25: Index of Rock Strength vs. Degree of Inclination Angle for Horizontal Parent Hole

Before interpreting the graphs, several assumptions needed to be made:

1. The strength of each cylindrical shape granite sample is identical since each of the samples is from the same source of rock.
2. Drilling parent hole and lateral hole in each cylindrical shape granite sample weaker the original strength of the cylindrical shape granite sample to a certain point compared to the undrilled sample.

From graph 1, an approximately linear decrease in index strength of rock from 0.0013 MPa/mm^2 to 0.0007 MPa/mm^2 observed as the inclination angle of the lateral junction with respect to the parent hole drilled in the cylindrical shape granite sample increase from 40° until 60°.

Referring to figure 15 to figure 17, it is shown that as the inclination angle of lateral hole with respect to the parent hole decreases, the length of lateral hole for each cylindrical shape granite sample increases. Relating this to the pressure formula which is $P = F/A$, we can assume that as the length of the lateral junction increases, the area covered by the lateral junction will increase too.

As a result, relating to the pressure equation, more vertical compressive force needed to be applied by the point load tester on the cylindrical shape granite sample that has higher length of the lateral junction before breaking the sample.

In a real situation underground, when drilling is done into the rock formation, it changes the original characteristic of the rock formation in this case is strength. The three dimensional stress now will act on the drilled hole, which is previously applied on the rock formation. For this case, the main concern is about the overburden pressure or vertical stress that is usually the main principal stress that act on a formation underground. The vertical stress now will act on the parent hole and lateral hole.

For a vertical parent hole orientation of a well, overburden pressure does not give a great effect on the parent hole because its orientation is parallel to the vertical compressive force, but the pressure gives a great effect to the lateral hole. This is due to the orientation of the lateral hole which is nearly perpendicular to the overburden pressure. In this case, the pressure acts solely on the lateral hole.

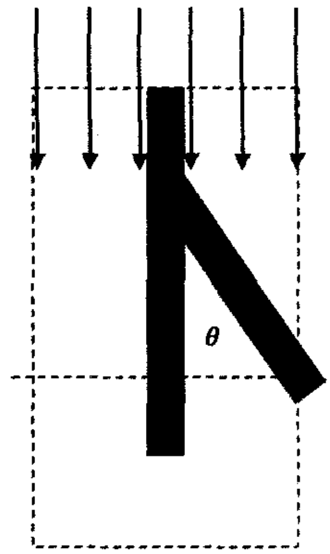


Figure 26: Illustration on the vertical compressive forces reacted on the lateral junctions but not on the vertical parent hole

From this project's result, for a vertical orientation of multilateral wells, assuming that the depth of interest is same, the best way to increase the stability of the multilateral well junctions is by drilling a lateral hole with the lowest degree as possible.

Referring on graph 2, the difference of ***IS*** value observed between the horizontal value of well with different inclination angle is only 2.7% and can be assumed as insignificant. By comparing graph 2 and graph 1, for an identical inclination angle, a significant increase of ***IS*** observed. For example, ***IS*** of vertical parent hole with 50° of lateral inclination angle increases from 0.0009 MPa/mm^2 to 0.00185 MPa/mm^2 for the horizontal parent hole with 50° of inclination angle. This result in 105 % of increasing in ***IS*** value.

The significant increase in ***IS*** value is due to the orientation of the drilled parent hole and lateral hole. The horizontal orientation of parent hole and lateral hole distributes the vertical compressive force evenly compared to the vertical orientation where the vertical compressive force was absorbed only by the lateral. Due to this, more vertical compressive force must be applied to break the sample.

From this result, it shows that a horizontal parent hole and lateral hole will increase the stability of the multilateral well junctions in the rock formation underground in case of the stress that is taken into account is the overburden pressure.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

The best geometrical configuration of vertical parent hole drilled sample was for 40^{o} inclination angle sample where the ***IS*** value was 0.0013 MPa/mm^2.

The best orientation was for horizontal parent hole samples where the ***IS*** value obtained was 105% higher for the best case compared to vertical orientation samples.

From the first objective, for vertically drilled parent hole samples, the stability of the formation around the multilateral well junction is higher when the lateral well junction has lower inclination angle with respect to the vertical parent hole until a certain point assuming that the depth of interest for the lateral hole is identical.

From the second objectives, in case of identical lateral inclination angle, a horizontally drilled parent hole led to more stable multilateral well junctions in case the significant stress reacts on the multilateral wells is overburden pressure.

5.2 RECOMMENDATION

For a more detail study on the stability of multilateral well junctions, a triaxial test should be used. A triaxial test applies stress in 3 dimension compared to the point load test where the stress applied only from vertical direction. Besides, triaxial test can simulates real reservoir pressure to the rock samples.

Cubic rock samples also can be used instead of the cylindrical shape rock samples. The advantages of using cubic rock samples is different stress can be applied on each side of the cubic sample which leads to more accurate and detail result.

REFERENCES

1. Son K. Hoang and Younane N. Abousleiman, "Multilaterals Drilling and Sustainable Openhole Production from Theory to Field Case Studies", SPE116138, pp. 878- 892, Denver, 2010.
2. P. Papanastasiou, M. Sibai, J. Heiland, J-F Shao, J. Cook, D. Fourmaintraux, A. Onaisi, B. Jeffryes, P. Charlez, "Stability of Multilateral Junction: Experimental Results and Numerical Modeling", SPE78212, Texas, 2002.
3. Steve Bosworth, Hussein Saad El- Sayed, Gamal Ismail, Herve Ohmer, Mark Stracke, Christ West, Albertus Retnanto, "Schlumberger Oilfield Review: Key Issues in Multilateral Technology", pp.14- 28, 1998.
4. Jose Fraija, Herve Ohmer, Mike Jordon, Mirush Kaja, Ramiro Paez, Gabriel P. G Sotomayor, Kenneth Umudjoro, "Schlumberger Oilfield Review: New Aspects of Multilateral Well Constructions", pp. 52- 69, 2002.
5. Ali A. Garrouch, Haitham M. S Lababidi, Abdullah S. Ebrahim, "An Integrated Approach for the Planning and Completion of Horizontal and Multilateral Wells", Journal of Petroleum Science and Engineering, 2004.
6. Nikola Maricic, Shabab D. Mohaghegh, Emre Artun, " A Parametric Study on the benefits of Drilling Horizontal and Multilateral Wells in Coalbed Methane Reservoirs", SPE96018, pp. 976- 983, Dallas, 2008.
7. Shuichi Kikuchi, Abdulla S. Fada'q, "Challenges, Lessons Learned, and Successful Implementations of Multilateral Completion Technology Offshore Abu Dhabi", SPE101385, pp. 181- 190, Abu Dhabi, 2008.
8. Bernard Montaron, Tim O' Rourke, John Algeroy, "Middle East Oil Review: Multiple Questions and Intelligent Answers", pp. 25- 45, 2001.
9. Yip- Wah Chung, "Introduction to Materials Science and Engineering", CRC Press, ISBN 0849392632, 2007.
10. David K. Felbeck, Anthony G. Atkins, "Strength and Fracture of Engineering Solids", 2nd Edition, Prentice Hall, ISBN 0138561133, 1996.
11. Charlie R. Brooks, Ashok Choudhury, "Failure Analysis of Engineering Materials", McGraw- Hill, ISBN 0071357580, 2002.
12. Fritz Rummel, "Rock Mechanics with Emphasis on Stress", A. A. Balkema Publishers, ISBN 0415374650, 2005.

13. R. J Sanford, "Principles of Fracture Mechanics", Prentice Hall, ISBN 0130929921, 2003.
14. Kiyoo Mogi, "Experimental Rock Mechanics", Taylor & Francis, ISBN 0415394430, 2007.
15. V. M Sharma, K. R Saxena, "In- Situ Characterization of Rocks:, A. A Balkema Publishers, ISBN 9058092372, 2002.
16. Ming Lu, Charlie C. Li, Halvor Kjorholt, Halgeir Dahle, "In- Situ Rock Stress Measurement, Interpretation and Application", A. A Balkema Publishers, ISBN 0415401631, 2006.
17. Stephen King, "UTS010: Software Reference Manual for Materials Strength Test", 2004.
18. http://en.wikipedia.org/wiki/Strength_of_materials (Data Gained 02/2011)
19. http://composite.about.com/library/glossary/a/bldef-a477.htm (Data Gained 02/2011)
20. http://metalab.uniten.edu.my/~Halina/EXP1~1.pdf (Data Gained 02/2011)
21. http://www.engineersedge.com/material_science/stress_definition.htm (Data Gained 02/2011)
22. http://en.wikipedia.org/wiki/Yield_%28engineering%29 (Data Gained 02/2011)
23. http://www.physicsforums.com/showthread.php?t=63726 (Data Gained 02/2011)
24. http://www.scribd.com/doc/53756691/Pore-Pressure-and-Fracture-Gradient (Data Gained 07/2011)
25. http://petroleumsupport.com/wp-content/uploads/2011/05/multilateral-well-.jpg (Data Gained 07/2011)

APPENDIX I (Detail Methodology)

Step	Illustration
1) Obtain a rock sample A large rock sample with dimension of $30\,cm \times 15\,cm \times 10\,cm$ was collected.	 (Large rock sample)
2) Run XRF test to identify the type of rock sample A small solid piece of the rock sample was cut and ground into powder form. The powder was used to undergo an XRF test to determine the type of chemical elements that the rock sample consists. The chemical elements of the rock that were determined by using the XRF test were used to identify the type of the rock sample.	 (Rock Sample in crushed form for XRF test)
3) Convert the rock sample into 7 cylindrical core samples The large rock sample was converted into 7 cylindrical core samples by using coring machine. The diameter of each cylindrical core sample was 1.5 inch. *Reason: To maximize the number of cylindrical core samples that can be obtained from the rock sample.*	 (Converting large rock sample into 8 cylindrical core samples)

Assumption :
The physical properties of each cylindrical core samples (in this case is strength) is equivalent.

4) Dry the cylindrical core sample

The cylindrical core samples were placed for 2 days in an oven to dry them.

Reason: To regain the strength of each cylindrical core samples after the coring process and before the drilling process take part.

5) Drill and trim the cylindrical core samples

5.1 Drill each core sample with different inclination angle (Objective 1)

A vertical parent hole was drilled for each cylindrical core sample (3 samples) using a drilling machine. The length of the parent hole was 1.5 inch. The diameter of the parent hole was 5 mm.

(Drilling vertical parent hole)

Lateral hole was drilled for each core sample with different inclination angle with respect to the parent hole. The inclination angles used were $40°, 50°$ *and* $60°$. The diameter of the lateral hole drilled was 5 mm.

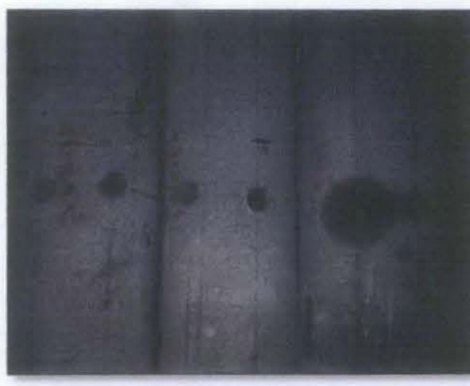
(Drilling lateral hole with different inclination angle)

Drilling rate (r.p.m) = 1280 r.p.m

The cylindrical core samples were trimmed until the length of each sample was 2.5 inch using trimming machine.

5.2 Drill each core sample with different orientation (Objective 2)

A 0.8 inch horizontal parent hole was drilled for each core samples (4

samples). 2 cylindrical core samples were drilled with the degree of the lateral hole with respect to the parent hole was 40°, while another 2 cylindrical core samples were drilled with the degree of the lateral hole with respect to the horizontal parent hole was 50°. Drilling Rate (r.p.m) = 1280 r.p.m	 (Top view of the drilled vertical parent hole)  (Side view of the drilled lateral hole)  (Side view of the drilled horizontal parent hole and lateral hole)
6. Run point base load test Each core sample was placed vertically on the testing equipment. Using hydraulic jack, the conical platen above was lowered slowly on the cylindrical shape rock sample until the sample broke.	

The reading that showed on the meter was read and the maximum applied load was recorded for each cylindrical core sample.	(Experiment setup for point base load test)  (The breakage of the cylindrical core sample observed)  (The value of the peak stress recorded)  (Top view of sample breakage- Vertical parent hole) 

	(Side view of sample breakage- Vertical Parent hole)  (Side view of sample breakage- horizontal parent hole)  Side view of sample breakage- horizontal parent hole)
7) Data analysis Data analysis was done based on the results obtained from each cylindrical shape rock sample.	