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## JUDUL: Design, fabrication \& testing of water channel

SESI PENGAJIAN: 2009/2013

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MELAYU 2, 11500,
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Dr. Rizalman Mamat
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## LOH CHONG SEAN

Report submitted in partial fulfilment of requirements for award of the Degree of Bachelor of Mechanical Engineering

## FACULTY OF MECHANICAL ENGINEERING UNIVERSITI MALAYSIA PAHANG

JUNE 2013

## EXAMINER'S DECLARATION

I certify that the project entitled "Design, fabrication \& testing of water channel" is written by Loh Chong Sean. I have examined the final copy of this report and in my opinion, it is fully adequate in terms of language standard and report formatting requirement for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

Dr. Gan Leong Ming
Examiner
Signature

## SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature
Name of Supervisor: DR. RIZALMAN MAMAT
Position : ASSOCIATE PROFESSOR
Date : 27 JUNE 2013

## STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries, which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature $\qquad$
Name : LOH CHONG SEAN
ID Number : MA09023
Date : 27 JUNE 2013

Dedicated to my beloved parents, Loh Eng Soon and Lim Ah Tiew. Without them, my pursuit of higher education would not have been possible and I would not have had the chance to study for a mechanical course. To my brother, Loh Chong Aik for his encouragements when I doing this project. Also to my supervisor, Dr Rizalman for his guide and help especially in finishing this project report.

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Thank you.


#### Abstract

Fossil fuel generates most of the energy in Malaysia. However, oil and gas in Malaysia are depleting now. Government of Malaysia has been identified renewable energy as fifth fuel under New Five-Fuel Diversification Strategy. Tidal energy is a renewable energy, which is also pollutant free, predictable, and has huge energy density. The scene of tidal energy extraction can be investigated through small-scale model using a water channel. In order to simulate tidal energy extraction, dimensional analysis method is used when designing the water channel. Pump of maximum flow rate $0.0125 \mathrm{~m}^{3} / \mathrm{s}$ at 2 m head is used. After fabrication, the water channel is tested to ensure it fulfill the design requirement. The vertical velocity profiles are also investigated by current meter and compare to the vertical velocity profiles of real tidal field. After testing, the water channel shows that it approaches the vertical velocity profiles of real tidal field at certain flow rate.


#### Abstract

ABSTRAK

Kebanyakan tenaga di Malaysia dihasilkan oleh bahan api fosil. Walau bagaimanapun, petroleum dan gas asli di Malaysia semakin berkurangan sekarang. Kerajaan Malaysia telah mengenal pasti tenaga boleh diperbaharui sebagai bahan api kelima di bawah Strategi Kepelbagaian Lima Bahan Api. Tenaga pasang surut adalah tenaga boleh diperbaharui, yang merupakan pencemar percuma, diramal, dan mempunyai ketumpatan tenaga yang besar. Keadaan pengeluaran tenaga pasang surut boleh disiasat melalui model kecil-kecilan dengan menggunakan saluran air. Dalam usaha untuk meniru pengeluaran tenaga pasang surut, kaedah analisis dimensi digunakan apabila mereka bentuk saluran air. Pump maksimum kadar aliran 0.0125 $\mathrm{m}^{3} / \mathrm{s}$ di kepala 2 m digunakan. Selepas fabrikasi, saluran air diuji untuk memastikan ia memenuhi keperluan reka bentuk. Profil halaju menegak juga disiasat oleh meter aliran air dan dibandingkan dengan profil halaju menegak di tempat pasang surut sebenar. Selepas ujian, saluran air menunjukkan bahawa ia menghampiri profil halaju menegak di tempat pasang surut sebenar pada kadar aliran tertentu.


## TABLE OF CONTENTS

Page
EXAMINER'S DECLARATION ..... ii
SUPRVISOR'S DECLARATION ..... iii
STUDENT'S DECLARATION ..... iv
DEDICATIONS ..... v
ACKNOWLEDGEMENTS ..... vi
ABSTRACT ..... vii
ABSTRAK ..... viii
TABLE OF CONTENTS ..... ix
LIST OF TABLES ..... xii
LIST OF FIGURES ..... xiii
LIST OF SYMBOLS ..... xvii
LIST OF ABBREVIATIONS ..... xx
CHAPTER 1 INTRODUCTION
1.1 Background ..... 1
1.2 Problem Statement ..... 2
1.3 Objectives of Study ..... 2
1.4 Scopes of the Study ..... 2
1.5 Significances of the Study ..... 2
CHAPTER 2 LITERATURE REVIEW
2.1 Introduction ..... 3
2.2 Tidal ..... 3
2.3 Tidal Energy ..... 5
2.4
Tidal Barrage ..... 6
2.4.1 Tidal Barrage in Malaysia ..... 7
2.5 Tidal Current Turbine ..... 8
2.5.1 Horizontal Axis Tidal Turbine ..... 8
2.5.2 Vertical Axis Tidal Turbine ..... 10
2.5.3 Tidal Current Energy in Malaysia ..... 12
$2.6 \quad$ Dimensional Analysis and Similarity ..... 14
2.7 Dimensional Analysis of Open Channel Flow ..... 16
2.8 Scaling Methods in Tidal Energy Researches ..... 17
2.8.1 Scaling of Tidal Energy Conversion Device ..... 17
2.8.2 Scaling of Wake In Tidal Energy Extraction ..... 19
2.9 Design of Water Channel ..... 21
$2.10 \quad$ Overview of Open Channel Flow ..... 27
2.10.1 Classification of Open Channel Flows ..... 27
2.10.2 Froude Number ..... 28
2.10.3 Specific Energy of Open Channel Flow ..... 29
2.10.4 Conservation of Mass and Energy Equations ..... 30
2.10.5 Numerical Solution of Surface Profile ..... 31
2.10.6 Vertical Velocity Profile of Open Channel Flow ..... 32
CHAPTER 3 METHODOLOGY
3.1 Introduction ..... 33
3.2 Flow Chart ..... 34
3.3 Scaling of Tidal in Malaysia ..... 35
3.4 Drawing of Water Channel ..... 40
3.5 Analysis Criteria ..... 43
3.5.1 Pipe and Channel Head Loss ..... 43
3.5.2 Surge Pressure of Pipe ..... 46
3.5.3 Support on Water Channel ..... 48
3.5.4 Surface Profile along Water Channel ..... 51
3.6 Testing of Water Channel ..... 52
3.6.1 Maximum Volume Flow Rate ..... 52
3.6.2 Vertical Velocity Profile of Flow ..... 52
3.6.3 Surface Profile ..... 54
3.7 Fabrication Process ..... 55
3.7.1 Preparation of Raw Materials ..... 55
3.7.2 Fabrication of Components for Water Channel ..... 56
3.7.3 Assembly of Water Channel ..... 57

## CHAPTER 4 RESULTS AND DISCUSSION

4.1 Introduction ..... 61
4.2 Results ..... 61
4.3 Vertical Velocity Profile at Maximum Flow Rate ..... 63
4.4 Vertical Velocity Profile at Flow Froude Number 0.05 ..... 67
4.5 Vertical Velocity Profile at Flow Froude Number 0.81 ..... 72
4.6 Surface Profile along Water Channel ..... 76
CHAPTER 5 CONCLUSION AND RECOMMENDATIONS
5.1 Conclusion ..... 77
5.2 Recommendations ..... 77
REFERENCES ..... 79
APPENDICES
A Gantt Chart ..... 81
B Specification of Pump ..... 82
C Performance Chart of Pump ..... 83
D Moody Diagram ..... 84
E Surface Profile Programming in EES Software ..... 85
F Bills of Materials ..... 86

## LIST OF TABLES

Table No. Title Page
2.1 Tidal range (MHWS-MLWS) of year 2005 for the six highest ..... 7 sites in Malaysia
2.2 Power availability for six sites using barrage approaches ..... 7
2.3 Power availability of the 4 sites in Malaysia ..... 13
3.1 Varying of Froude number with dimension of water channel ..... 38
3.2 Dimensions available of water channel for Froude number 0.15 ..... 39
3.3 Parts of water channel ..... 42
3.4 Loss coefficients of pipe fittings ..... 43

## LIST OF FIGURES

Figure No. Title Page
2.1 Causes of tides ..... 5
2.2 Design of tidal barrage ..... 6
2.3 Marine Current Turbine ..... 9
2.4 Lunar Energy Tidal Turbine ..... 10
2.5 Gorlov Helical Turbine ..... 11
2.6 Tidal Fence Davis Gydro Turbine ..... 11
2.7 Tidal current speed on the day with highest speed in year 2007 ..... 12 at 4 sites around Malaysia
2.8 The output power assuming that the turbine sweeping area is ..... 13 $1 \mathrm{~m}^{2}$
2.9 Geometry similarity ..... 15
2.10 Power coefficient $\mathrm{C}_{\mathrm{p}}$ vs TSR with different turbine diameter ..... 18 and flow speed
2.11 Model turbine is tested in a water tunnel ..... 19
2.12 The actuator disk theorem ..... 20
2.13 Experiment set-up in Chilworth flume ..... 20
2.14 Wake simulation by actuator disk in experiment ..... 21
2.15 Chilworth hydraulic flume ..... 23
2.16 Loughborough University Flume during construction ..... 24
2.17 Flow profiler at inlet tank ..... 24
2.18 S6 MKII Glassed Sided Tilting Flume ..... 25
2.19 Daniel Sabatino Water Channel ..... 26
$2.20 \quad$ Water Distributor at inlet tank ..... 26
2.21 Specific energy $E_{S}$ of a liquid in an open channel ..... 29
2.22 Variation of specific energy with depth ..... 30
2.23 Vertical velocity profile at Seaflow installation site ..... 32
3.1 Flow chart ..... 34
3.2 Distribution of tidal currents for Peninsular Malaysia by POM ..... 35 software
3.3 Distribution of tidal current in Sabah and Sarawak by POM ..... 36 software
3.4 Graph Froude Number VS Width of Water Channel at different ..... 39 water depth
3.5 Isometric view of water channel ..... 40
3.6 Dimension of the water channel ..... 41
3.7 Explode view for water channel ..... 42
3.8 Displacement of pipe ..... 47
3.9 Safety factor of pipe ..... 47
3.10 Displacement of beam and wall ..... 49
3.11 Stress on each beam ..... 49
3.12 Displacement of the beam and wall ..... 50
3.13 Stress on each beam ..... 50
3.14 Surface profile of water channel calculated by EES ..... 51
3.15 Current meter ..... 54
3.16 Washing of reservoir tank ..... 55
3.17 Testing of pump ..... 55
3.18 Wood pieces cut by band saw ..... 56
3.19 Acrylic supports cut by acrylic cutter and band saw ..... 56
3.20 Cutting of water channel wall ..... 57
3.21 Testing for leaking after drilling and installing tank adapters ..... 57
3.22 Building of base ..... 58
3.23 Alignment of water channel with tank reservoir ..... 58
3.24 Installing of pipe ..... 59
3.25 Building of water channel ..... 59
3.26 Testing leakage for water channel ..... 60
3.27 Fabrication of weir ..... 60
4.1 Design of water channel ..... 61
4.2 Fabricated water channel ..... 62
4.3 Running of water channel ..... 62
4.4 Vertical velocity profile at 0.1 m when maximum flow rate ..... 63
4.5 Vertical velocity profile at 0.2 m when maximum flow rate ..... 63
4.6 Vertical velocity profile at 0.3 m when maximum flow rate ..... 64
4.7 Vertical velocity profile at 0.4 m when maximum flow rate ..... 64
4.8 Vertical velocity profile at 0.5 m when maximum flow rate ..... 65
4.9 Vertical velocity profile at 0.6 m when maximum flow rate ..... 65
4.10 Vertical velocity profile at 0.7 m when maximum flow rate ..... 66
4.11 Vertical velocity profile at 0.8 m when maximum flow rate ..... 66
4.12 Vertical velocity profile at 0.1 m when Froude number 0.05 ..... 67
4.13 Vertical velocity profile at 0.2 m when Froude number 0.05 ..... 68
4.14 Vertical velocity profile at 0.3 m when Froude number 0.05 ..... 68
4.15 Vertical velocity profile at 0.4 m when Froude number 0.05 ..... 69
4.16 Vertical velocity profile at 0.5 m when Froude number 0.05 ..... 69
4.17 Vertical velocity profile at 0.6 m when Froude number 0.05 ..... 70
4.18 Vertical velocity profile at 0.7 m when Froude number 0.05 ..... 70
4.19 Vertical velocity profile at 0.8 m when Froude number 0.05 ..... 71
$4.20 \quad$ Vertical velocity profile at 0.1 m when Froude number 0.81 ..... 72
$4.21 \quad$ Vertical velocity profile at 0.2 m when Froude number 0.81 ..... 72
4.22 Vertical velocity profile at 0.3 m when Froude number 0.81 ..... 73
$4.23 \quad$ Vertical velocity profile at 0.4 m when Froude number 0.81 ..... 73
$4.24 \quad$ Vertical velocity profile at 0.5 m when Froude number 0.81 ..... 74
$4.25 \quad$ Vertical velocity profile at 0.6 m when Froude number 0.81 ..... 74
4.26 Vertical velocity profile at 0.7 m when Froude number 0.81 ..... 75
4.27 Vertical velocity profile at 0.8 m when Froude number 0.81 ..... 75
$4.28 \quad$ Surface profile at $0.0114 \mathrm{~m}^{3} / \mathrm{s}$ ..... 76

## LIST OF SYMBOLS

| $F_{d}$ | Tidal force |
| :---: | :---: |
| G | Gravitational constant |
| M | Mass of body |
| $R_{e}$ | Radius of the Earth |
| $d$ | Distance between Earth with the body |
| $v_{p}$ | Velocity of prototype |
| $v_{m}$ | Velocity of model |
| $a_{p}$ | Acceleration of prototype |
| $a_{m}$ | Acceleration of model |
| $F_{p}$ | Forces on prototype |
| $F_{m}$ | Forces on model |
| $\Pi$ | Non-dimensional parameter |
| $u_{i}$ | Velocity in 3 dimensions, $u$, v, w |
| $t$ | Time |
| $p$ | Pressure |
| $\rho$ | Density |
| $\mu$ | Dynamic viscosity |
| $L$ | Independent length scale |
| V | Independent velocity scale |
| $\tau$ | Independent time scale |
| $P$ | Power |
| D | Diameter of turbine |

$\omega$
$v$
$C_{p}$
$R e$

TSR
$A_{1}$
$A_{d}$
$A_{2}$
$U \infty$
$U_{2}$
$U_{d}$
$R_{h}$
$V_{c}$
$g$
$L_{c}$
z

Ac
$S_{o}$
$S_{f} \quad$ Frictional slope along the channel
Angular velocity
velocity
Power coefficient
Reynolds number
Tip speed ratio
Cross section area of upstream stream tube
Area of actuator disk
Cross section area of the downstream stream tube
Free stream velocity
Far wake velocity
Velocity at actuator disk
Hydraulic radius of the channel
Average liquid velocity at cross section
Gravitational acceleration
Characteristic length
Elevation head
Gauge pressure head
Cross section area
Total head of water channel
Specific energy of water channel
Width of cross section
Darcy friction factor
Distance at x direction

Bottom slope along the channel

| $v_{\text {max }}$ | Maximum flow velocity taken at the surface |
| :---: | :---: |
| $y_{\text {channel }}$ | Bed-normal distance measured upwards from the profile datum |
| $h$ | Flow depth |
| $1 / m$ | Power law exponent or index |
| Fr | Froude number |
| $L_{p}$ | Length of pipe |
| $L_{\text {channel }}$ | Length of channel |
| $h_{L, p i p e}$ | Head loss in pipe |
| K | Loss coefficient |
| $D_{p}$ | Diameter of pipe |
| $Q$ | Volume flow rate |
| $h_{L, \text { channel }}$ | Head loss in channel |
| $P_{c}$ | Wetted perimeter |
| $h_{L, \text { Toalal }}$ | Total head loss |
| $H_{\text {required }}$ | Required head for pump |
| $\alpha$ | Kinetic energy correction factor |
| $P_{S}$ | Surge pressure |
| $D_{i}$ | Inner diameter |
| $E$ | Modulus elasticity of pipe material |
| $T_{p}$ | Wall thickness of pipe |
| $P_{T}$ | Total pressure |
| $P_{\text {Static }}$ | Static pressure |
| F | Force |
| $\dot{m}$ | Mass flow rate |

## LIST OF ABBREVIATIONS

| RE | Renewable energy |
| :--- | :--- |
| MHWS | Mean high water spring |
| MLWS | Mean low water spring |
| MCT | Marine Current Turbine |
| RTT | Rotech Tidal Turbine |
| POM | Princeton Ocean Model |
| TPXO | OSU TOPEX/POSEIDON Crossover |
| EES | Engineering Equation Solver |

## CHAPTER 1

## INTRODUCTION

### 1.1 BACKGROUND

Most of the energy in Malaysia is generated by fossil fuel. However, according to Haris and Omar's study, oil in Malaysia would be finished by 2015 and gas would be finished by 2048 (Lee \& Seng, 2008). Malaysia would become a net energy importer when oil in Malaysia is depleted. Energy consumption in Malaysia also keeps increasing due to the development of the country. Malaysia has been introducing New Five-fuel Diversification Strategy in order to solve this energy issue. Renewable energy (RE) has been identified and finalized by the government as the fifth fuel under the New Five-Fuel Diversification Strategy (Al-Amin et al. 2009)

Tidal energy is a renewable energy. The tidal power plant is pollutant free. Tidal is predictable and has huge energy density (Sun, 2008). However, tidal energy technology is still very fresh to Malaysia. The research about tidal energy in Malaysia is very few (Lim \& Koh, 2009). Therefore, more researches are going to do in recent future. In future, tidal energy most likely will be harnessed by tidal turbine farm, like wind turbine farm today (Bahaj et al. 2007). The effect of tidal turbine to the tidal current must be known before start building the tidal turbine (Sun, 2008). This is convenient and cost saving to simulate the tidal energy extraction in small-scale model first before building a prototype. In doing this, a water channel that able to simulate the tidal energy extraction has to be built.

### 1.2 PROBLEM STATEMENT

It is possible that the tidal turbine farm is used to harass the tidal energy in future. The effect of tidal turbine to the tidal current must be known in order to determine the best orientation of tidal turbines inside the farm (Bahaj et al. 2007). The scene of tidal energy extraction must also be investigated so that it would not raise any environment and safety issues in future (Sun, 2008). It is possible to investigate the tidal energy extraction in small-scale. However, a water channel that has the capability to simulate the tidal energy extraction is needed for doing this.

### 1.3 OBJECTIVES OF STUDY

The objectives of this study is designing, fabricating and testing a water channel that able to simulate the tidal energy extraction in Malaysia.

### 1.4 SCOPES OF STUDY

a) Study on tidal in Malaysia.
b) Dimensional analysis on tidal energy extraction.
c) Pump of maximum flow rate $0.0125 \mathrm{~m}^{3} / \mathrm{s}$ at 2 m head is used.
d) Design and fabricate water channel.
e) Experimentally analysis on flow profile of water channel.

### 1.5 SIGNIFICANCES OF THE STUDY

Fossil fuel in Malaysia is depleting now. Therefore, it is the time for Malaysia to look for new energy resources. Tidal energy has a huge potential because it is a renewable energy and is predictable. It is important to build a water channel that can simulate the tidal energy extraction so that more research can be conducted to this field.

## CHAPTER 2

## LITERATURE REVIEW

### 2.1 INTRODUCTION

This chapter will discuss about the tidal, methods in harnessing tidal energy and tidal energy potential in Malaysia. After discussing about the tidal and tidal energy, this chapter will discuss about dimensional analysis method and scaling methods of tidal energy extraction. After that, this chapter will discuss about the water channel design and properties of open channel flow.

### 2.2 TIDAL

Vertical rise and fall of seawater is call tide while the horizontal water flow that causes the tide is called tidal current. When the tide rises, the tidal current floods the area. When the tide falls, the tidal current ebbs from the area.

Tidal forces caused by the gravitational force of the Sun and moon, and the earth rotation. Therefore, the tides on the earth are never-ending and predictable (Hassan et al. 2012). Newton's law of gravitation is used to calculate the force caused by the gravitational attraction between the earth with the moon and earth with the sun. Newton's second law of motion can be used to calculate centrifugal force produced on the earth by the earth's rotation. The tidal force of any location of the earth can be calculated by combining Newton's law of gravitation and Newton's second law of motion. The combined formula is as following (Services):

$$
\begin{equation*}
F_{d}=\frac{G M R_{e}}{d^{3}} \tag{2.1}
\end{equation*}
$$

From this formula, one can know that tidal force is inversely proportional to cube of the distance between the mass and earth. Because of this, sun's effect on tidal is only 46 percent of the moon's effect.

There are many types of tide on the earth due to the different geometry of each location. Semidiurnal tide means there are two high tides and two low tides each day. The tidal cycle of semidiurnal tide is 12 hours 25 minutes. Diurnal tide means only one high tide and one low tide each day. The tidal cycle of diurnal tide is 12 h 24 min . Mixed tide is the combination of semidiurnal and diurnal tides (Services; Lim \& Koh, 2009).

The tidal range is the difference between high tide and low tide. The tidal ranges vary according to the location of the moon and the sun. When new moon and full moon, the earth, moon, and Sun are on the same line. Therefore, the resultant tidal force is very strong; the tidal range becomes larger than usual. This tide is called spring tides. In first quarter and third quarter, the tidal force caused by the moon is at right angles to the tidal force caused by the sun, the tidal range becomes smaller. This is called neap tide (Services).


Figure 2.1: Causes of tides

Source: Hassan et al.( 2012)

### 2.3 TIDAL ENERGY

Global climate change is becoming serious. Tidal has huge amount energy and is a pollutant free energy resource. Renewable energy like solar and wind energy is unpredictable. Tidal is predictable and therefore it is more reliable. Tidal energy also reduces the fuel cost because it does not need any fuel (Denny, 2009). Tidal barrage and tidal current turbine are the methods to extract energy from tidal (Rourke et al. 2009).

### 2.4 TIDAL BARRAGE

Tides cause the variations in ocean level. A barrage is built to impound the water during high tide, and release it during the period of the tide recedes. The water flow through hydraulic turbines installed in the barrages before it flow out to the ocean. Open sea has the small average tidal fluctuations; the geometry of a place can significantly magnify the tidal fluctuations. For example, Cobequid Bay located in Fundy Bay can reach a 16 m swing during high tides. Water that moved in the tides of Fundy Bay is around 100 cubic kilometers per day, this is equals water discharged by all the rivers in the world (Rosa, 2009). A reversible water turbine can be used to generate electricity. This enables barrage to generate electricity at ebb and flood. However, building a tidal barrage is very costly and need a lot of time. Tidal barrage can cause some environmental issues. According to I. Ball study, the tidal barrages can reduce the mudflats needed by the birds (as cited in Sun, 2008). The tidal barrages also block the path of migratory fish, such as salmon and eels (Sun, 2008).


Figure 2.2: Design of tidal barrage

Source: Hassan et al. (2012)

### 2.4.1 Tidal Barrage In Malaysia

Sejingkat, Perlabuhan Klang, Pulau Langkawi, Tawau, Kutup and Johor Bahru are the six sites with the highest tidal range in Malaysia (Lee \& Seng, 2008).

Table 2.1: Tidal range (MHWS - MLWS) of year 2005 for the six highest sites in Malaysia

| Tidal Station | Tidal range $(\mathbf{m})$ |
| :---: | :---: |
| Sejingkat | 4.38 |
| Perlabuhan Klang | 4.2 |
| Pulau Langkawi | 2.5 |
| Tawau | 2.9 |
| Kutup | 2.6 |
| Johor Bahru | 2.6 |

Source: Lee \& Seng (2008)

A Fluent model is used to simulate the tidal barrage at these six sites. The speed gained in simulation results are used to calculate the power available at the sites (Lee \& Seng, 2008). They obtained the results as below:

Table 2.2: Power availability for six sites using barrage approaches

| Date | Monthly Availability (\%) |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Sejingkat | Perlabuhan <br> Kelang | Pulau <br> Langkawi | Tawau | Kukup | Johor <br> Bahru |
| Jan | 76.10 | 76.41 | 60.01 | 64.45 | 65.86 | 62.95 |
| Feb | 75.80 | 74.53 | 63.73 | 63.70 | 66.84 | 61.00 |
| Mar | 75.16 | 74.53 | 60.95 | 65.62 | 66.58 | 60.57 |
| Apr | 76.18 | 75.10 | 57.44 | 61.67 | 65.11 | 62.10 |
| May | 76.15 | 75.88 | 57.52 | 61.08 | 63.35 | 63.65 |
| Jun | 74.97 | 76.91 | 61.54 | 66.44 | 67.25 | 64.31 |
| Jul | 76.07 | 76.01 | 57.26 | 62.37 | 67.94 | 62.89 |
| Aug | 76.61 | 74.40 | 57.76 | 62.63 | 64.85 | 62.74 |
| Sep | 76.39 | 74.01 | 59.69 | 66.38 | 68.67 | 63.64 |
| Oct | 75.83 | 74.19 | 61.63 | 62.67 | 63.71 | 65.77 |
| Nov | 77.61 | 75.24 | 60.66 | 63.07 | 62.24 | 65.89 |
| Dec | 76.91 | 76.96 | 59.48 | 64.05 | 65.58 | 64.50 |


| Average | 76.15 | 75.35 | 59.81 | 63.68 | 65.67 | 63.33 |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |

Source: Lee \& Seng (2008)

Sejingkat show the highest average, which is 76.15 \%. Perlabuhan Kelang also has an average of $75.35 \%$. All locations has the average of beyond $55 \%$, this show that the potential sites of building a tidal barrage can be found around Malaysia (Lee \& Seng,2008).

### 2.5 TIDAL CURRENT TURBINE

Different with tidal barrage which use the potential energy between high and low tides, tidal current turbine use the kinetic energy of moving water to generate electricity (Rourke et al. 2009)

Many tidal current turbine prototypes are being built and tested in the ocean. In the future, these tidal turbines might be built in array like wind farms. Tidal is predictable and water is 832 times denser than air. These all make the tidal energy more reliable than wind energy. The tidal turbines rotate either in horizontal axis or in vertical axis (Rosa, 2009).

### 2.5.1 Horizontal Axis Tidal Turbine

Marine Current Turbine Ltd (MCT) has built a prototype called Seaflow rated at 300 kW . This single rotor turbine generates an average power of 100 kW and has a rotor diameter of 11 m . Then, in 2006, a 1.2 MW prototype Seagen was built. Seagen has the twin axial open rotors (Rosa, 2009). The photo of both Seaflow and Seagen are shown below.


Figure 2.3: Marine Current Turbine (a) Seaflow (b) Seagen

Source: (a) http://tpe.energiesdelamer.free.fr/hydrolienne.html\#intro
(b) http://www.alternative-energy-news.info/seagen-tidal-powerinstallation/

Besides MCT, Lunar Energy Ltd, a Britain tidal power company developed Rotech Tidal Turbine (RTT). Asymmetrical duct is installed to increase the speed of the flow in RTT design. The full-scale prototype is aimed to generate 1MW of electricity. However, RTT 2000 is designed to generate 2 MW from a $3.6 \mathrm{~m} / \mathrm{s}$ surface tidal current (Previsic, 2006). According to news released on Luner Energy Ltd website at 2008, Lunar Energy Ltd has received a deal to install 300 tidal current turbines at Korea with the cost 500 million pounds (Rourke et al. 2009).


Figure 2.4: Lunar Energy Tidal Turbine

Source: Rourke et al. (2009)

Besides Marie Current Turbine and RTT, there are many other types of horizontal axis turbine under development. For example, Evopod tidal turbine, Free Flow Tidal Turbine, Nepture Tidal Stream Device and etc. (Rourke et al. 2009).

### 2.5.2 Vertical Axis Tidal Turbine

GCK Technology Inc in USA developed Gorlov Helical Turbine. Three twisted blades form a helix shape. The efficiency of this turbine is recognized. A model with diameter 1 m was tested at 2002 (Rourke et al. 2009).


Figure 2.5: Gorlov Helical Turbine

Source: Rourke et al. (2009)

Blue Energy Ltd in Canada has designed a vertical axis turbine called Tidal Fence Davis Gydro Turbine. The design is building array of vertical axis turbines on a tidal fence. This system can be built on the river also (Rourke et al. 2009).


Figure 2.6: Tidal Fence Davis Gydro Turbine

### 2.5.3 Tidal Current Energy In Malaysia

Diurnal, semidiurnal and mixed tides are available in Malaysia (Lim \& Koh, 2009). Figure 2.8 shows the tides around Malaysia. According to Tidal Tables Malaysia, Malaysia has the average tidal speed of $1 \mathrm{~m} / \mathrm{s}$ (Hassan et al. 2012). Princeton Ocean Model (POM) is used to model the tidal current speed in Malaysia. The results obtained with this model are used to test the possibilities of installing twin horizontal axis turbine (MCT) in Malaysia Ocean. MCT need at least $1 \mathrm{~m} / \mathrm{s}$ of current speed to generate electricity, otherwise the electricity generated will be very small. Pulau Jambongan, Semporna, Barangbongan, Kuching, Kota Belud and Sibu are having the tidal current speed that exceeds $1 \mathrm{~m} / \mathrm{s}$. MCT need the water depth of at least 20 m . Only Pulau Jambongan, Kota Belud and Sibu have the water depth of beyond 20m and become the potential sites for MCT installation (Lim \& Koh, 2009).

Tidal current speed in Malaysia is also being found using TPXO software. Sandakan, Pulau Pangkor, Melaka and Perlabuhan Klang are the places that found to have high tidal current speed (Lee \& Seng, 2008).


Figure 2.7: Tidal current speed on the day with highest speed in year 2007 at 4 sites around Malaysia

The power density and power availability are calculated using the velocity obtained.


Figure 2.8: The output power assuming that the turbine sweeping area is $1 \mathrm{~m}^{2}$

Source: Lee \& Seng (2008)

Table 2.3: Power availability of the 4 sites in Malaysia

| Month | Total Monthly Availability |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
|  | Kelang | Melaka | Pulau <br> Pangkor | Sandakan |
| Jan | 16.73 | 41.81 | 56.24 | 78.48 |
| Feb | 20.31 | 42.75 | 54.75 | 77.74 |
| Mar | 21.71 | 44.56 | 55.67 | 81.17 |
| Apr | 20.68 | 43.90 | 55.74 | 80.23 |
| May | 17.05 | 42.06 | 57.41 | 79.95 |
| Jun | 13.38 | 40.97 | 57.29 | 78.80 |
| Jul | 17.34 | 43.34 | 57.29 | 79.28 |
| Aug | 23.36 | 45.60 | 58.12 | 80.85 |
| Sep | 23.84 | 45.28 | 57.03 | 81.48 |
| Oct | 20.78 | 44.71 | 56.90 | 81.45 |
| Nov | 15.17 | 43.53 | 58.87 | 80.31 |
| Dec | 13.24 | 41.33 | 58.79 | 50.61 |
| Average | 18.62 | 43.32 | 57.01 | 80.03 |

From the figure above, it shows that Sandakan has the very high-energy availability, which has the average of $80.03 \%$. This shows that Sandakan has the potential to establish tidal power plant (Lee \& Seng, 2008).

Until 2009, only Seagen, Seaflow, Open Center Turbine, Tidal Stream Turbine and Free Flow Turbine operate at full scale and successfully generate electricity. Others were still in the stages of design or model testing (Rourke et al. 2009).

### 2.6 DIMENSIONAL ANALYSIS AND SIMILARITY

In most experiments, scaled model rather than full prototype is tested to save time and money. In this situation, dimensional analysis is used for the following purposes (Cengel \& Cimbala, 2010):
a) Generate non-dimensional parameters that will help the design of the experiment later.
b) Obtain scaling laws that will help predict the results of prototype later.
c) Predict relationships between parameters.

Similarity between the prototypes and models is necessary. There are 3 types of similarity (Cengel \& Cimbala, 2010):
a) Geometric Similarity:

Ratios between corresponding lengths in model and prototype should be same.


Figure 2.9: Geometry similarity

Source:<br>http://en.wikiversity.org/wiki/Fluid_Mechanics_for_MAP_Chapter_7._Dimensi onal_Analysis

b) Kinematic Similarity

Prototype and model have the same shape and the ratios of corresponding velocities and accelerations are same.

$$
\begin{align*}
& \frac{v_{1 p}}{v_{1 m}}=\frac{v_{2 p}}{v_{2 m}}  \tag{2.2}\\
& \frac{a_{1 p}}{a_{1 m}}=\frac{a_{2 p}}{a_{m}} \tag{2.3}
\end{align*}
$$

c) Dynamic Similarity

The ratio between forces in prototypes and model must be same.

$$
\begin{equation*}
\frac{F_{1 p}}{F_{1 m}}=\frac{F_{2 p}}{F_{2 m}} \tag{2.4}
\end{equation*}
$$

From dimensional analysis,

$$
\begin{equation*}
\Pi_{1}=f\left(\Pi_{2}, \Pi_{3}, \ldots, \Pi_{k}\right) \tag{2.5}
\end{equation*}
$$

To ensure complete similarity, all $\Pi$ must be same between model and prototype (Cengel \& Cimbala, 2010).

### 2.7 DIMENSIONAL ANALYSIS OF OPEN CHANNEL FLOW

Geometry similarity and kinematic similarity are needed to be considered when simulates the open channel flow. Geometry similarity in this case means that the boundary of the laboratory should be same with the boundary at the field. Kinematic similarity means that the water speed of the laboratory should be same with the speed at field (Nowell \& Jumars, 1987).

Dynamic similarity is the similarity of forces between laboratory and field; therefore equation that expressing balances of force within the fluid, Newton's second law is used here (Nowell \& Jumars, 1987).

The conservation of momentum equation

$$
\begin{equation*}
\rho \frac{\partial u_{i}}{\partial t}+\rho u_{j} \frac{\partial u_{i}}{\partial x_{i}}=-\frac{\partial \rho}{\partial x_{i}}+\mu \nabla^{2} u_{j}+\rho g_{i} \tag{2.6}
\end{equation*}
$$

In order to find out the physical represented by these equations, each term of Eq. (2.6) is transformed into a dimensionless form.

The method of repeating variables is used, let define (Nowell \& Jumars, 1987):

$$
X^{*}=\frac{x}{L} \quad U^{*}=\frac{u}{V} \quad T=\frac{t}{\tau} \quad \Pi=\frac{p}{\rho V^{2}}
$$

The defined dimensionless groups are substituted into the Eq. (2.6) and multiplying through by $\mathrm{L} / \mathrm{V}^{2}$

$$
\begin{equation*}
\frac{L}{\tau V} \frac{\partial U^{*}}{\partial T}+U^{*} \frac{\partial U^{*}}{\partial X^{*}}=-\frac{\partial \prod}{\partial X^{*}}+\frac{\mu}{\rho V L} \frac{\partial^{2} U^{*}}{\partial X^{2}}+\frac{g L}{V^{2}} \tag{2.7}
\end{equation*}
$$

Where $\frac{L}{\tau V}=$ Strouhal number

$$
\begin{aligned}
& \frac{g L}{V^{2}}=\text { Inverse of Froude number } \\
& \frac{\mu}{\rho V L}=\text { Inverse of Reynold number } \\
& \frac{p}{\rho V^{2}}=\text { Euler number }
\end{aligned}
$$

Each term is now dimensionless. The Strouhal number is to measure the unsteadiness of the flow. Froude number is important when dealing with free surface. The Reynolds number is the ratio of inertia to viscous forces. Euler number is used for the measure of the pressure gradient (Nowell \& Jumars, 1987).

All dimensionless parameter must be considered to simulate the field. However, Strouhal number can be ignored when the water channel only simulates the steady flow (Nowell \& Jumars, 1987).

## 2. 8 SCALING METHODS IN THE TIDAL ENERGY RESEARCHES

### 2.8.1 Scaling Of Tidal Energy Conversion Device

For horizontal axis tidal stream turbine (Mason-Jones et al. 2012),

$$
\begin{equation*}
P=f(D, \omega, \rho, \mu, v) \tag{2.8}
\end{equation*}
$$

Through dimensional analysis, the final functional relationship is as following (MasonJones et al. 2012):

$$
\begin{equation*}
C_{p}=f(R e, T S R) \tag{2.9}
\end{equation*}
$$

Where $\begin{aligned} C_{p} & =\frac{P}{\frac{1}{2} \rho v^{3}}\end{aligned} \quad$ (Power Coefficient) $\quad \begin{aligned} & \operatorname{Re}=\frac{\rho v D}{\mu} \\ & \text { (Reynolds number) } \\ & T S R=\frac{\omega D}{v} \\ & \text { (Tip Speed Ratio) }\end{aligned}$

It happens frequently in the dependent variable group to finally become independent of the Reynolds number when the Reynolds number is reaching certain values. Horizontal axis tidal turbine has been investigated that it will reach Reynolds number independence when the Reynolds number exceeds $5 \times 10^{5}$. The investigation uses Computational Fluid Dynamic (CFD) to test different diameters in different flow velocity. The results of CFD are then validated by experiment running a 0.5 m diameter horizontal axis tidal turbine in water flume. The experimental results show the clear correlation between experiment and CFD data (Mason-Jones et al. 2012). This means the results obtained in CFD is reliable. The results of CFD analysis are shown in Figure 2.12.


Figure 2.10: Power coefficient $C_{p}$ vs TSR with different turbine diameter and flow speed

This graph clearly shows that $\mathrm{C}_{\mathrm{p}}$ only changes with TSR when the Reynolds number exceeds $5 \times 10^{5}$.


Figure 2.11: Model turbine is tested in a water tunnel

Source: Mason-Jones et al. (2012)

### 2.8.2 Scaling Of Wake In Tidal Energy Extraction

Any devices that extract energy from flow will cause reduction of momentum at downstream flow. The flow affected by the device is called as wake. The specific forms of wakes are depending on the devices. It is impractical to model horizontal axis rotor in small scale in the investigation of wake because it is very hard to scaling channel flow properties while maintaining the motor thrust, tip speed and power of the tidal turbine. For example, a tidal turbine model of diameter 100 mm requires rotation rate of 1500 RPM to scale the tip speed ratio of real turbine. Such rotational speed will induce a big swirl and large pressure gradients to the wake. Such wake is different with the real wake in tidal energy extraction (Bahaj et al. 2007).

In order to simulate the wake in tidal energy extraction, some researchers use the actuator disk to generate the wake instead of turbine rotors (Bahaj et al. 2007; Myers et al. 2008; Harrison et al. 2009; Myers \& Bahaj, 2010). The actuator disk theorem is common in wind turbine simulation. In this theorem, a semi-permeable disk replaces the rotor. The actuator disk theorem can be explained as following (Sun, 2008):


Figure 2.12: The actuator disk theorem

Source: Sun (2008)

The actuator disk represents the turbine. It drops the pressure and velocity of flow when they pass through it. In the situation of real turbine, these drops in pressure and velocity are caused by the energy extraction from the flow (Sun, 2008).


Figure 2.13: Experiment set-up in Chilworth fume


Figure 2.14: Wake simulation by actuator disk in experiment

Source: Giles et al. (2011)

In the simulation of the wake of tidal energy extraction, the flow is governed by 2 scaling parameters which are Froude number and Reynolds number. Reynolds number similarity is usually to be tolerated for the scaling of the water channel, for Froude number similarity to be achieved. Froude number scaling is critical in the experiment because there is a free surface above the turbine rotor and thus the gravitational effect is important. The high Froude number also will cause the unsteady surface profile. However, the Reynolds number of model water channel and real sea must be lying within the same turbulent classification in order to simulate the wake accurately (Bahaj et al. 2007).

### 2.9 DESIGN OF WATER CHANNEL

The design of water channel should consider of 4 parts (Nowell \& Jumars, 1987):
a) Entrance conditions that need to provide

Most of the flow will form the center jet, which will take many long distances to decay. Based on observations, the flow will take at least 20
times of the pipe diameter to decay totally. Therefore, a diffuser has generally been built on the upstream of the water channel. The motion of fluid is being broken and distributed by the diffuser. Then, a honeycomb is used to break up the flow further. The honeycomb mesh cannot be too dense because it will cause the pressure drop of the water. This pressure drop will consequently cause the mesh result in very downstream.
b) Exit condition that needs to provide

In this section, a smooth exit is desired to reduce the effect to test section. Normally, the flow falls free. The Froude number of the flow is needed to be monitored carefully. This is because when the flow is becoming supercritical, it will impose significant impact to upstream.
c) Driving of the flow

The pump will be used to discharge the water. The pump is selected wisely to avoid unsteadiness in low velocity and changing the discharge in high rate when voltage change is small.
d) Condition the flow before it enters the test section

Nonuniformity of flow should be avoided in the test section. The test section also should not be too far from upstream until the result of flow produced at upstream is missing.

The researches of the wake in tidal energy extraction were being conducted at laboratory water channel as following (Myers et al. 2008):

- Chilworth hydraulic laboratory at the University of Southampton, UK

This laboratory flume has a test section of 21 m length, 1.35 m wide and maximum depth of 0.4 m for steady operation. 3 centrifugal pumps are
used to lift water to deposit in the sump at the upstream of the test section. The water enters the sump through 2 diffusers. Then, water in upstream sump flow along test section by gravity. Flow rate is controlled by control valves on feeder pipes of each pump. At downstream of the test section, an overflow tailgate is installed to control the water level.


Figure 2.15: Chilworth hydraulic flume

Source: Daly et al. (2011)

- IFREMER circulation channel at Boulogne sur Mer, France.

This channel has a working section of 18 m length, 4 m wide and 2 m deep. This channel is a closed loop system. It utilizes 2 large variable speed axial pump for providing the thrust to circulate the water.

There are some other examples of water channel as following:
a) Loughborough University Flume (Armfield, 2012)


Figure 2.16: Loughborough University Flume during construction

Source: Armfield (2012)


Figure 2.17: Flow profiler at inlet tank

Source: Armfield (2012)
b) S6 MKII Glassed Sided Tilting Flume (Armfield 2012):


Figure 2.18: S6 MKII Glassed Sided Tilting Flume

## Source: Armfield (2012)

The test section is 350 mm wide, 400 mm deep and the standard working length of $5 \mathrm{~m}, 7.5 \mathrm{~m}, 10 \mathrm{~m}$ and 15 m can be chosen. The stilling and smoothing device in the inlet tank provide the excellent velocity profile at test section. An overshoot tilting weir is used to control the water level in the test section. It uses a centrifugal pump to circulate the water. The flow rate is controlled by a hand wheel butterfly valve and is measured by electromagnetic flow meter and display on the control panel. The maximum flow of this water channel is $30 \mathrm{~L} / \mathrm{s}$ (Armfield, 2012).
c) Daniel Sabatino Water Channel (Sabatino, 2010)


Figure 2.19: Daniel Sabatino Water Channel

Source: Sabatino (2010)


Figure 2.20: Water distributor at inlet tank

Source: Sabatino (2010)

### 2.10 Overview of Open Channel Flow

Open channel flow refers to the flow of liquids in channels open to the atmosphere or in partially filled conduits and is characterized by the presence of a liquid-gas interface called free surface. There are many of open channel flows can be encountered in this world, like river, ocean, dam, and sewer lines (Cengel \& Cimbala, 2010).

### 2.10.1 Classification of Open Channel Flows

Flow in open channel can be classified as following (Cengel \& Cimbala, 2010):

- Steady or unsteady flow

It is steady if there is no depth or average velocity change with time at a given location

- Uniform or varied flow

It is uniform if the flow depth remains constant along the channel. Otherwise, it is varied flow. The variable flow is rapidly varied flow (RVF) if the flow depth changes markedly over a relatively short distance in flow direction. If the flow depth changes gradually over a long distance along a channel, it is gradually varied flow (GVF).

- Laminar or turbulent flow

One must calculate the Reynolds number to know whether the flow is laminar or turbulent. The Reynolds number of water channel is:

$$
\begin{equation*}
R e=\frac{\rho V_{c} R_{h}}{\mu} \tag{2.10}
\end{equation*}
$$

If the $\operatorname{Re} \leq 500$, it is laminar flow. If the $500 \leq \operatorname{Re} \geq 2500$, It is transition flow. If the $\mathrm{Re} \geq 2500$, it is turbulent flow.

### 2.10.2 Froude Number

Open channel is classified as subcritical, critical and supercritical depending on the value of the dimensionless Froude number (Cengel \& Cimbala, 2010).

$$
\begin{equation*}
F r=\frac{V_{c}}{\sqrt{g L_{c}}} \tag{2.11}
\end{equation*}
$$

The Froude number is an important parameter that governs the character of flow in open channel. The Froude number is classified as following (Cengel \& Cimbala, 2010):

$$
\begin{array}{ll}
\mathrm{Fr}<1 & \text { Subcritical flow } \\
\mathrm{Fr}=1 & \text { Critical flow } \\
\mathrm{Fr}>1 & \text { Supercritical flow }
\end{array}
$$

The Froude number is the ratio of flow speed to the wave speed.

### 2.10.3 Specific Energy of Open Channel Flow



Figure 2.21: Specific energy $E_{S}$ of a liquid in an open channel

## Source: Cengel \& Cimbala (2010)

The total mechanical energy of liquid in open channel in term of heads is expressed as following (Cengel \& Cimbala, 2010):

$$
\begin{equation*}
H=z+\frac{p}{\rho g}+\frac{V_{c}^{2}}{2 g}=z+y+\frac{V_{c}^{2}}{2 g} \tag{2.12}
\end{equation*}
$$

In rectangular flow, the volume flow rate is $\mathrm{Q}=\mathrm{A}_{\mathrm{c}} \mathrm{V}_{\mathrm{c}}=\mathrm{hb}_{\mathrm{c}} \mathrm{V}_{\mathrm{c}}$. Therefore, the specific energy becomes (Cengel \& Cimbala, 2010):

$$
\begin{equation*}
E_{c}=z+y+\frac{Q^{2}}{2 g b_{c}^{2} h^{2}} \tag{2.13}
\end{equation*}
$$

This equation can be transformed to graph below:


Figure 2.22: Variation of specific energy with depth

Source: Cengel \& Cimbala (2010)

From graph above, one can observe the specific energy at a each depth when Q is constant.

### 2.10.4 Conservation of Mass and Energy Equations

In a water channel, the density of liquid is constant. When the flow is steady, the volume flow rate remains constant along the water channel. Therefore, continuity equation can be applied to water channel as following (Cengel \& Cimbala, 2010):

$$
\begin{equation*}
A_{c 1} V_{c 1}=A_{c 2} V_{c 2} \tag{2.14}
\end{equation*}
$$

The energy in water channel is conserved. Therefore, the energy equation is as following (Cengel \& Cimbala, 2010):

$$
\begin{equation*}
z_{1}+y_{1}+\frac{V_{c 1}{ }^{2}}{2 g}=z_{2}+y_{2}+\frac{V_{c 2}{ }^{2}}{2 g}+h_{L, \text { channel }} \tag{2.15}
\end{equation*}
$$

The head loss due to frictional effects in water channel is expressed as following (Cengel \& Cimbala, 2010):

$$
\begin{equation*}
h_{L, \text { channel }}=f \frac{L_{\text {chamnel }}}{R_{h}} \frac{V_{c}^{2}}{8 g} \tag{2.16}
\end{equation*}
$$

### 2.10.5 Numerical Solution of Surface Profile

Consider the steady flow in a rectangular open channel of width $b_{c}$, the total head of the liquid at any cross section is $H=z+y+\frac{V_{c}{ }^{2}}{2 g}$ (Cengel \& Cimbala, 2010).

Differentiating H with respect to x gives

$$
\begin{equation*}
\frac{d H}{d x}=\frac{d}{d x}\left(z+y+\frac{V_{c}^{2}}{2 g}\right)=\frac{d z}{d x}+\frac{d y}{d x}+\frac{V_{c} d V_{c}}{g d x} \tag{2.17}
\end{equation*}
$$

In Eq. (2.17), $\frac{d H}{d x}=-\frac{d h_{L, \text { channel }}}{d x}=-S_{f}$ and $\frac{d z}{d x}=-S_{0}$. Therefore, Eq. (2.17) becomes:

$$
\begin{equation*}
S_{0}-S_{f}=\frac{d y}{d x}+\frac{V_{c}}{g} \frac{d V_{c}}{d x} \tag{2.18}
\end{equation*}
$$

According to conservation of mass equation, the steady flow in water channel is $\mathrm{Q}=\mathrm{y}_{\mathrm{c}} \mathrm{b}_{\mathrm{c}} \mathrm{V}_{\mathrm{c}}=$ constant. Differentiating with respect to x gives (Cengel \& Cimbala, 2010):

$$
\begin{equation*}
\frac{d V_{c}}{d x}=-\frac{V_{c}}{y} \frac{d y}{d x} \tag{2.19}
\end{equation*}
$$

Substituting equation 2.20 into 2.19, yield (Cengel \& Cimbala, 2010):

$$
\begin{equation*}
\frac{d y}{d x}=\frac{S_{0}-S_{f}}{1-F r^{2}} \tag{2.20}
\end{equation*}
$$

By integrating the equation above over desired dx value and the depth of water channel at that location is being known, one can plot the surface profile of water channel by integrating the equation over different x values (Cengel \& Cimbala, 2010).

### 2.10.6 Vertical Velocity Profile of Open Channel Flow



Figure 2.23: Vertical velocity profiles at Seaflow installation sites

Source: DTI report (2005)

Figure 2.24 shows the vertical velocity profile at Seaflow installation site. The vertical velocity profile of real site is compared with $1 / 7$ Power Law boundary layer profile form the surface to seabed. Standard offshore for velocity shear generally uses a 1/7 Power Law for the velocity profile at lower part of the water column, but have uniform velocity at upper layer. Measured curves are proved to be quite variable, but approximately fall between the models (DTI report, 2005).

The power law for uniform equilibrium flow in wide-open channel is expressed as following (Cheng, 2007):

$$
\begin{equation*}
\frac{v}{v_{\max }}=\left(\frac{y_{\text {channel }}}{h}\right)^{\frac{1}{m}} \tag{2.21}
\end{equation*}
$$

## CHAPTER 3

## METHODOLOGY

### 3.1 INTRODUCTION

This chapter will describe the detail of the methodology used in this study. Finding researches about tidal energy, Malaysia tidal and laboratory water channels is the first step. This step is important because the information from researches will help designing a good quality water channel that fulfils all the requirements. Then, the water channel is designed. The design need to ensure the similarity is achieved between water channel and tidal. After that, all the design criteria will be analysed. Fabrication will be begun after the analysis is done. After fabrication, the water channel will be tested to check whether it performs as expectation or not. If not, then the root of problems will be found and solved. After all are done, report will be written.

### 3.2 FLOW CHART



Figure 3.1: Flow chart

### 3.3 SCALING OF TIDAL IN MALAYSIA

The flow in water channel must be able to simulate the tidal of Malaysia. The open channel flow is governed by Froude number in dimensional analysis (Bahaj et al. 2007). Therefore, the flow enables to simulate the tidal in Malaysia once it can produce the similar Froude number as tidal in Malaysia.


Figure 3.2: Distribution of tidal currents for Peninsular Malaysia by POM software


Figure 3.3: Distribution of tidal current in Sabah and Sarawak by POM software

Source: Lim \& Koh (2009)

The cut in speed of Marine Current Turbine is $1 \mathrm{~m} / \mathrm{s}$. Figure 3.2 and Figure 3.3 show that tidal turbine can be installed at certain ocean at Sarawak and Sabah. Before designing a tidal turbine, a designer needs to decide the design speed for the tidal turbine (Batten et al. 2007). The design speed is the tidal current speed used to design the turbine that can maximize the power extraction at the field. From Figure 3.3, the turbine design speed might be expected to be between $1 \mathrm{~m} / \mathrm{s}$ to $2 \mathrm{~m} / \mathrm{s}$. Beyond $2 \mathrm{~m} / \mathrm{s}$, the frequency is too low therefore unlikely to use as the design speed.

The Marine Current Turbine can only be installed at the field that water depth is greater than 20 m (Lim \& Koh, 2009). Assuming that the maximum water depth for installing tidal turbine is 40 m . Actually it is not important for the maximum depth in this case, the wake of tidal energy extraction still can be simulated even the depth is larger than 40 m . It will be shown later.

Therefore, the tidal turbines at Malaysia are expected to operate in tidal current speed and water depth as following:

$$
\begin{gathered}
1 m / s<v<2 m / s \\
20 m<h<40 m
\end{gathered}
$$

From the speed and water depth above, Froude number of tidal in Malaysia is in the range as following:

$$
0.05<\operatorname{Fr}<0.15
$$

The pump of water channel is taken from automotive laboratory at university. It has the maximum flow rate of $0.0125 \mathrm{~m}^{3} / \mathrm{s}$ at 2 m head. The specification and performance chart of pump are attached at Appendix B and C.

The next step is to determine the dimension of water channel. The suitable dimension of water channel can be decided base on following:
a) Size of specimens

For typical first generation site of depth 30 m , the rotor can be $12 \mathrm{~m}-15$ m (Myers et al. 2008). The size of rotor is depending on many factors, like requirement of power generation and situation of field. Therefore, the range of rotor to depth ratio is estimated at $1 / 2$ to $1 / 4$ in this design.
b) Froude number of flow

The Froude number of channel flow should cover the range 0.05 to 0.15 to model the tidal at Malaysia.
c) Capacity of pumps

The capacity of pump is around $0.0125 \mathrm{~m}^{3} / \mathrm{s}$. This limits the size of water channel.

Table 3.1 shows the varying of Froude number with the width and depth of water channel based on maximum capacity of pump, $0.0125 \mathrm{~m}^{3} / \mathrm{s}$.

Table 3.1: Varying of Froude number with dimension of water channel

| Width | Froude Number |  |  |  |
| :---: | ---: | ---: | ---: | ---: |
| $(\mathbf{m})$ | Water depth $(\mathbf{m})$ |  |  |  |
|  | $\mathbf{0 . 1 5}$ | $\mathbf{0 . 2}$ |  |  |
| 0.1 | 1.262 | 0.2429 | 0.319 | 0.3 |
| 0.15 | 0.841333 | 0.161933 | 0.212667 | 0.458 |
| 0.2 | 0.631 | 0.12145 | 0.1595 | 0.3435 |
| 0.25 | 0.5048 | 0.09716 | 0.1276 | 0.2748 |
| 0.3 | 0.420667 | 0.080967 | 0.106333 | 0.229 |
| 0.35 | 0.360571 | 0.0694 | 0.091143 | 0.196286 |
| 0.4 | 0.3155 | 0.060725 | 0.07975 | 0.17175 |
| 0.45 | 0.280444 | 0.053978 | 0.070889 | 0.152667 |
| 0.5 | 0.2524 | 0.04858 | 0.0638 | 0.1374 |



Figure 3.4: Graph of Froude Number VS width of water channel at different water depth

From Figure 3.4, the dimensions available of water channel for Froude number 0.15 are listed at table below:

Table 3.2: Dimensions available of water channel for Froude number 0.15

| Depth (m) | Width $(\mathbf{m})$ |
| :---: | :---: |
| 0.3 | 0.15 |
| 0.25 | 0.2 |
| 0.2 | 0.3 |
| 0.15 | 0.45 |

Size of actuator disk mainly depends on the depth of water channel. It will be difficult to collect data if the disk is too small. In most of researches before, actuator disks of 10 cm diameter are used. The width of channel should also be carefully designed so that the wall would not affect the experiment. Most of the flumes designs have larger width compared to height. In field, there is no wall around the tidal turbine; therefore the channel should be wide in order to simulate similar effect in field. The size of 0.2 m height and 0.3 m width is chosen for the water channel. In $1 / 2$ rotor to depth ratio, the disk of 10 cm can be used to collect data. In $1 / 3$ rotor to depth ratio, the disk of 7 cm can be used. The size of 0.15 m height and 0.45 m width is not being chosen because the size of disk will be too small in this case.

### 3.4 DRAWING OF WATER CHANNEL



Figure 3.5: Isometric view of water channel

Figure 3.5 shows the isometric view of water channel. The test section of water channel is 1.25 m in length, 0.3 m in width, and maximum depth of 0.2 m at steady operation. The water flows into water channel through a distributor. The function of distributor is to diffuse the water. At the entrance of test section, a flat plate's flow conditioner is designed. This flow conditioner is aim to flatten the flow and avoid separation of flow. A sharp edge weir is used to control the water level in the water channel. The flow rate is controlled by a ball valve at feeder pipe.


Figure 3.6: Dimension of the water channel

Figure 3.6 shows the 2D drawing and dimension of water channels. Figure 3.7 shows the exploded view and parts of the water channel.


Figure 3.7: Explode view for water channel

Table 3.3: Parts of water channel

| 1 | Table |
| :---: | :---: |
| 2 | Pump |
| 3 | Bush |
| 4 | Reducer |
| 5 | Ball valve |
| 6 | Pipe and fittings |
| 7 | Water distributor |
| 8 | Water channel |
| 9 | Water channel supports |
| 10 | Pulley |
| 11 | Sharp edge weir |
| 12 | Door knot |
| 13 | Base |
| 14 | Supports |
| 15 | Reservoir tank |

### 3.5 ANALYSIS CRITERIA

### 3.5.1 Pipe And Channel Head Loss

The design require pump to supply $0.0125 \mathrm{~m}^{3} / \mathrm{s}$ water into the water channel. The head loss of pipe and channel need to be calculated to ensure the pump able to fulfil the requirement.

The head loss at pipe can be calculated by equation below:

$$
\begin{equation*}
h_{L, p i p e}=\left(f \frac{L_{p}}{D_{p}}+\sum K\right) \frac{v^{2}}{2 g} \tag{3.1}
\end{equation*}
$$

Loss coefficients of various components are as following:

Table 3.4: Loss coefficients of pipe fittings

| Pipe inlet | $\mathbf{9 0}^{\mathbf{0}}$ elbow | Expansion | Contraction | Ball <br> valve | Tee |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 0.8 | 0.9 | 0.1 | 0.04 | 0.05 | 2 |

Velocity in pipe can be calculated as following:

$$
\begin{equation*}
v=\frac{Q}{A_{c}} \tag{3.2}
\end{equation*}
$$

Darcy friction factor is depending on Reynolds number of the flow in the pipe.

$$
\begin{equation*}
\operatorname{Re}=\frac{\rho v D_{p}}{\mu} \tag{3.3}
\end{equation*}
$$

After Reynolds number is calculated, the Darcy friction factor can be determined from Moody chart (Appendix D).

The head loss of pipe is calculated as following:

$$
\begin{gathered}
v=\frac{0.0125}{0.007854} \\
=1.59 \mathrm{~m} / \mathrm{s} \\
\operatorname{Re}=\frac{(1000)(1.59)(0.1)}{1.04 \times 10^{-3}} \\
=1.5288 \times 10^{5}
\end{gathered}
$$

From Moody chart, Darcy friction factor, $\mathrm{f}=0.0165$. The total length of pipe is 4 m . Therefore, the head loss in pipe can be calculated as following:

$$
\begin{aligned}
h_{L, p i p e} & =\left[0.0165\left(\frac{4}{0.1}\right)+0.8+2(0.9)+0.1+0.04+0.05+2\right]\left(\frac{1.59^{2}}{2(9.81)}\right) \\
& =0.7023 \mathrm{~m}
\end{aligned}
$$

The head loss at channel can be calculated by equation below:

$$
\begin{equation*}
h_{L, \text { channel }}=f \frac{L}{R_{h}} \frac{V_{c}^{2}}{8 g} \tag{3.4}
\end{equation*}
$$

The equation of hydraulic radius is as following:

$$
\begin{equation*}
R_{h}=\frac{A_{c}}{P_{c}} \tag{3.5}
\end{equation*}
$$

The method to calculate head loss in channel is almost same as those in the pipe, just replace the pipe dimension to channel dimension.

$$
\begin{aligned}
V_{c} & =\frac{0.0125}{0.06} \\
& =0.2083 \mathrm{~m} / \mathrm{s}
\end{aligned}
$$

$$
\begin{gathered}
R_{h}=\frac{0.06}{0.7} \\
=0.0857 \mathrm{~m} \\
\operatorname{Re}=\frac{(1000)(0.2)(0.0857)}{1.04 \times 10^{-3}} \\
=1.6481 \times 10^{4}
\end{gathered}
$$

From Moody chart, Darcy friction factor, $f=0.0273$. The total length of channel is 1.29 m . The head loss in water channel is calculated as following:

$$
\begin{aligned}
h_{L, \text { channel }} & =0.0273 \frac{1.29}{0.0857} \frac{0.2^{2}}{8 \times 9.81} \\
& =0.0002 \mathrm{~m}
\end{aligned}
$$

Therefore, the total head loss for the design is:

$$
\begin{align*}
h_{L, \text { Total }} & =h_{L, \text { pipe }}+h_{L, \text { channel }}  \tag{3.6}\\
h_{L, \text { Total }} & =0.7023+0.0002 \\
& =0.7025 \mathrm{~m}
\end{align*}
$$

The required head for the pump is:

$$
\begin{gather*}
H_{\text {required }}=\frac{p_{2}-p_{1}}{\rho g}+\frac{\alpha_{2} v_{2}^{2}-\alpha_{1} v_{1}^{2}}{2 g}+\left(z_{2}-z_{1}\right)+h_{L, \text { Total }}  \tag{3.7}\\
H_{\text {required }}=0+0+1+0.7025 \\
\quad=1.7025 \mathrm{~m}
\end{gather*}
$$

According to pump performance curve, the pump supplies $0.0125 \mathrm{~m}^{3} / \mathrm{s}$ water at 2 meter head. The required head for the design is smaller than 2 m , therefore the pump is able to supplies more than $0.0125 \mathrm{~m}^{3} / \mathrm{s}$ into the water channel. This means the pump fulfil the requirement of the design.

### 3.5.2 Surge Pressure Of Pipe

Surge pressure due to water hammer is a major factor contributing to pipeline failure. A moving fluid contains certain amount of energy. When the fluid hit a suddenly closed valve, it produce huge amount of pressure. This is called water hammer. Surge pressure of pipes in the design need to be calculated so that he pipes does not fail when running. Surge pressure of PVC pipe can be calculated by equation as following:

$$
\begin{equation*}
P_{S}=v \sqrt{\left(\frac{E t 3960}{E t+3 \times 10^{5} D_{i}}\right)} \tag{3.8}
\end{equation*}
$$

The total pressure for the pipe in design can be calculated as following:

$$
\begin{equation*}
P_{T}=P_{\text {Static }}+P_{S} \tag{3.9}
\end{equation*}
$$

The common pipe thickness can be found in market is 2 mm . The surge pressure and total pressure in the pipe is as following:

$$
\begin{aligned}
P_{S} & =(5.2165) \sqrt{\frac{(400000.0007)(0.0784)(3960)}{(400000.0007)(0.0784)+\left(3 \times 10^{5}\right)(3.9370)}} \\
& =52.7936 \mathrm{psi} \\
P_{T} & =1.422+52.7936 \\
& =54.2156 \mathrm{psi} \\
& =373803.4027 \mathrm{~Pa}
\end{aligned}
$$

Autodesk Algor Simulation Professional is used to simulate the 2 m pipe. The purpose of doing this is to ensure the pipe can withstand the maximum pressure of water flow. The parameters of simulation are as following:

- Analysis Type: Static Stress with Non-linear Materials Model
- Element Type: Pipe element
- Thickness Pipe: 2 mm
- Materials: PVC Mould
- Applied Load: Internal pressure of 373803.4027 Pa
- Boundary Condition: Fixed at both end and centre of pipe


Figure 3.8: Displacement of pipe


Figure 3.9: Safety factor of pipe

The output from this analysis includes the end forces of the pipe the axial stress and the associated shear stresses. Figure 3.8 show that the pipe displaces 0.0001 m only. Figure 3.9 shows that the pipe has minimum safety factors of 17.422 , therefore the pipe would not fail when running.

### 3.5.3 Support On Water Channel

The water in channel will exert hydrostatic force to the wall of channel. Support is needed to ensure the channel would not corrupt as water level reach its maximum. In this simulation, only hydrostatic force is considered because the force of water column from distributor hit the wall is very small. The force can be calculated from equation below:

$$
\begin{equation*}
F=\dot{m} v \tag{3.10}
\end{equation*}
$$

The distributor has 24 holes a side. Therefore the force of water column is as following:

$$
\begin{aligned}
F & =\left(2.6042 \times 10^{-4}\right)(0.53)(24) \\
& =0.0033 \mathrm{~N}
\end{aligned}
$$

Autodesk Algor Simulation Professional is used to simulate the supports of the wall. The parameters for simulation are as following:
a) Delivery Plenum Support

- Analysis Type: Static Stress with linear Materials Model
- Element Type: Plate element and beam element
- Thickness plate: 5 mm
- Materials: Acrylic
- Applied Load: Surface Hydraulic pressure of 0.3 m
- Boundary Condition: Fixed at bottom of every beam support and also edges of wall


Figure 3.10: Displacement of the beam and wall


Figure 3.11: Stress on each beam

The output of the simulation is the stress on wall and support and the displacement on each support. Figure 3.10 shows that the maximum displacement of wall is $2.2259 \times 10^{-5} \mathrm{~m}$, which is very small. The channel will use epoxy to glue the beam at base with the channel Therefore, worst stresses on supports is investigated to ensure the epoxy would not fail. As can be seen from Figure 3.11, the maximum stress at the support is $183981 \mathrm{~N} / \mathrm{m}^{2}$. The epoxy used can withstand the stress of 48263300.96 $\mathrm{N} / \mathrm{m}^{2}$, which have safety factor of 262 over the worst stress of support.
b) Water Channel Support

- Analysis Type: Static Stress with linear Materials Model
- Element Type: Plate element and beam element
- Thickness plate: 3 mm
- Materials: Acrylic
- Applied Load: Surface Hydraulic pressure of 0.23m
- Boundary Condition: Fixed at bottom of every beam support and2 edges of wall


Figure 3.12: Displacement of the beam and wall


Figure 3.13: Stress on each beam

The output of the simulation is the stress on wall and support and displacement and on each support. Figure 3.12 show that the maximum displacement of wall is 0.0014 m . As can be seen from Figure 3.13, the maximum stress at the support is 3.456 X $10{ }^{6} \mathrm{~N} / \mathrm{m}^{2}$. The epoxy used can withstand stress of $48263300.96 \mathrm{~N} / \mathrm{m}^{2}$, which have safety factor of 16 over the worst stress of support.

### 3.5.4 Surface Profile along Water Channel

The prediction of the surface profile $\mathrm{h}(\mathrm{x})$ is an important part of the design of water channel. It ensures the surface profile of fabricated water channel is same as the design. The surface profile can be determined through Eq. (2.20). The equation is nonlinear after substituting Froude number and friction slope into it. Therefore, EES (Engineer Equation Solver) is used to calculate the nonlinear equation. The programming in EES is attached at Appendix E. The surface profile calculated from EES is shown as following:


Figure 3.14: Surface profile of water channel calculated by EES

In the Figure 3.14, Y axis presents the water depth and X axis presents the length of water channel. It shows that the water depth will be 0.2 m along the water
channel when water flow rate is $0.0125 \mathrm{~m}^{3} / \mathrm{s}$ Water flow rate of $0.0125 \mathrm{~m}^{3} / \mathrm{s}$ is chosen because the friction of the channel is largest at highest flow rate. The result predict uniform flow along the channel. This is because the channel is short therefore the friction from the channel is small.

### 3.6 TESTING OF WATER CHANNEL

### 3.6.1 Maximum Volume Flow Rate

According to design consideration in Section 3.1, volume flow rate has to be 0.0125 $\mathrm{m}^{3} / \mathrm{s}$ to fulfil the design requirement. The maximum volume flow rate is measured by steps as following:
a) The reservoir was filled in with water.
b) The weir was put at the lowest position.
c) The ball valve was fully opened.
d) Water channel was run.
e) Volumetric tank was put at the end of water channel to collect the water.
f) Time to fill up the volumetric tank was measured by stop watch.
g) The volume flow rate was calculated by equation below:

$$
\begin{equation*}
Q=\frac{\text { Volume of volumetric tank }}{\text { Time to fill the tank }} \tag{3.11}
\end{equation*}
$$

### 3.6.2 Vertical Velocity Profile Of Flow

The vertical velocity profiles of flows were tested to ensure the flow profile of water channel is same as the real tidal site. The vertical velocity profile of flow at Seaflow installation site is shown at Figure 2.23. The figure shows that the vertical
velocity profile of Seaflow installation site is approaches $1 / 7$ Power Law. This enable a comparison between vertical velocities profiles of the designed water channel with the vertical velocity profile of real tidal site. The vertical flow profiles of flows at minimum Froude number and maximum Froude number in the design requirement were tested. The steps of experiment are as following:
a) Reservoir was filled in with water.
b) The weir was put at the lowest position.
c) Water channel was run.
d) Volumetric tank was used to measure the volume flow rate.
e) Ball valve was adjusted until the volume flow rate is $0.0042 \mathrm{~m}^{3} / \mathrm{s}$. This is the volume flow rate corresponding to flow minimum Froude number, which is 0.05 .
f) The weir was adjusted to lift the water level to 0.2 m .
g) The water velocity of $0.025 \mathrm{~m}, 0.05 \mathrm{~m}, 0.1 \mathrm{~m}, 0.125 \mathrm{~m}, 0.15 \mathrm{~m}$ and 0.175 m at normal distance measured upwards from water channel bed were measured by current meter shown at Figure 3.15 at distance 0.1 m from entrance of test section.
h) Step g was repeated for location $0.2 \mathrm{~m}, 0.3 \mathrm{~m}, 0.4 \mathrm{~m}, 0.5 \mathrm{~m}, 0.6 \mathrm{~m}, 0.7 \mathrm{~m}$ and 0.8 m from entrance of test section in water channel.
i) Step a-g was repeated for volume flow rate $0.0125 \mathrm{~m}^{3} / \mathrm{s}$, which is the volume flow rate corresponding to flow maximum Froude number 0.15.


Figure 3.15: Current meter

### 3.6.3 Surface Profile Of Flow

The surface profile is also tested to ensure water depth is same along the water channel. The step of measuring surface profile is as following:
a) Reservoir was filled in with water.
b) The weir was put at the lowest position.
c) Water channel was run.
d) Volumetric tank was used to measure the volume flow rate.
e) Ball valve was adjusted until the volume flow rate is $0.0125 \mathrm{~m}^{3} / \mathrm{s}$.
f) The weir was adjusted to lift the water level to 0.2 m .
g) The water depth at location 0.1 m form entrance of test section was measured by ruler.
h) Step 7 was repeated for location $0.2 \mathrm{~m}, 0.3 \mathrm{~m}, 0.4 \mathrm{~m}, 0.5 \mathrm{~m}, 0.6 \mathrm{~m}, 0.7 \mathrm{~m}$ and 0.8 m from entrance at test section in water channel.

### 3.7 FABRICATION PROCESS

### 3.7.1 Preparation Of Raw Materials

The materials were brought from hardware shops. The bill of materials is attached at Appendix F. The reservoir tank was taken from the automotive laboratory at university. The reservoir tank was washed as shown in Figure 3.16 before it can be used as reservoir tank. The pump was also taken from the automotive laboratory of university. The pump was tested as shown in Figure 3.17 to ensure it can function normally.


Figure 3.16: Washing of reservoir tank


Figure 3.17: Testing of pump

### 3.7.2 Fabrication Of Components For Water Channel

After the materials were prepared, fabrications of components for water channel were started. The plywood was cut by band saw as shown in Figure 3.18. The acrylic sheet was cut by acrylic cutter and band saw as shown in Figure 3.19.


Figure 3.18: Wood pieces cut by band saw


Figure 3.19: Acrylic supports cut by acrylic cutter and band saw

The water channel was also built by acrylic sheet. Before cutting, the acrylic sheet was carefully measured and marked as shown in Figure 3.20. A hole was drilled on the reservoir tank to adapt pipe of diameter 0.1 m . After installing the tank adapter, the reservoir tank was tested for leakage as shown in Figure 3.21.


Figure 3.20: Cutting of water channel wall


Figure 3.21: Testing for leaking after drilling and installing tank adapters

### 3.7.3 Assembly Of Water Channel

After all the components were completed, the base of water channel was built as shown in Figure 3.22. The delivery plenum of water channel of water channel was also built at the same time. The acrylic sheet was glued together by chloroform, a type of plastic solvent glue. This solvent glue was used because it can fuse the 2 piece of plastic sheet together and therefore prevent leaking at the joining. After that, the delivery plenum was aligned with reservoir tank as shown in Figure 3.23.


Figure 3.22: Building of base


Figure 3.23: Alignment of water channel with tank reservoir

After alignment for the water channel and reservoir tank, the pipe was started to install as shown in Figure 3.24. After that, the water channel was also built as shown in Figure 3.25. The supports were attached to water channel and base by epoxy.


Figure 3.24: Installing of pipe


Figure 3.25: Building of water channel

After the water channel was built, a leakage testing was conducted as shown in Figure 3.26. Then, the piping was fully installed. After the piping was completed, the distributor was installed. Finally, the weir was built at the end of test section as shown in Figure 3.27.


Figure 3.26: Testing leakage for water channel


Figure 3.27: Fabrication of weir

## CHAPTER 4

## RESULTS AND DISCUSSION

### 4.1 INTRODUCTION

In this chapter, photos of the complete water channel will be shown. Then, maximum flow rate for the water channel will be investigated. After that, vertical velocity profile of flow at the flow Froude number 0.05 and 0.15 will be measured and compared to vertical velocity profile of real tidal field. Finally, surface profile of flow at flow Froude number 0.15 will be investigated.

### 4.2 RESULTS



Figure 4.1: Design of water channel


Figure 4.2: Fabricated water channel

Figure 4.1 shows the design of water channel. The water channel was designed based on the dimensional analysis of tidal energy extraction. The water channel can generates flow of Froude number 0.05 to 0.15 , which simulate the open channel flow of the possible tidal turbine installation sites in Malaysia. Figure 4.2 shows the fabricated water channel. Figure 4.3 shows the scene of water channel running.


Figure 4.3: Running of water channel

### 4.3 VERTICAL VELOCITY PROFILE AT MAXIMUM FLOW RATE



Figure 4.4: Vertical velocity profile at 0.1 m when maximum flow rate


Figure 4.5: Vertical velocity profile at 0.2 m when maximum flow rate


Figure 4.6: Vertical velocity profile at 0.3 m when maximum flow rate


Figure 4.7: Vertical velocity profile at 0.4 m when maximum flow rate


Figure 4.8: Vertical velocity profile at 0.5 m when maximum flow rate


Figure 4.9: Vertical velocity profile at 0.6 m when maximum flow rate


Figure 4.10: Vertical velocity profile at 0.7 m when maximum flow rate


Figure 4.11: Vertical velocity profile at 0.8 m when maximum flow rate

Figure 4.4 until Figure 4.11 show the vertical velocity profile at difference location from the entrance of test section at maximum flow rate.

The maximum flow rate is $0.0114 \mathrm{~m}^{3} / \mathrm{s}$, which flow Froude number is 0.135 . The flow rate unable to reach the desired flow rate, $0.0125 \mathrm{~m}^{3} / \mathrm{s}$ may be caused by the extra reducers and distributor. Extra reducers and distributors increase the head loss and thus reduce the flow rate of pump. Figure 4.4, Figure 4.5 and Figure 4.6 show that the flow within 0.3 m from the entrance does not follow the trend of power law. After 0.3m, the flow become smoother and approach the trend of $1 / 7$ power law. The velocity is not consistent along the water channel. This shows that the flow is unstable.

### 4.4 VERTICALVELOCITY PROFILE AT FLOW FROUDE NUMBER OF 0.05



Figure 4.12: Vertical velocity profile at 0.1 m when Froude number 0.05


Figure 4.13: Vertical velocity profile at 0.2 m when Froude number 0.05


Figure 4.14: Vertical velocity profile at 0.3 m when Froude number 0.05


Figure 4.15: Vertical velocity profile at 0.4 m when Froude number 0.05


Figure 4.16: Vertical velocity profile at 0.5 m when Froude number 0.05


Figure 4.17: Vertical velocity profile at 0.6 m when Froude number 0.05


Figure 4.18: Vertical velocity profile at 0.7 m when Froude number 0.05


Figure 4.19: Vertical velocity profile at 0.8 m when Froude number 0.05

Figure 4.12 until Figure 4.19 show the vertical velocity profile at difference location from the entrance of test section at flow Froude number 0.05. The volume flow rate at this Froude number is $0.0042 \mathrm{~m}^{3} / \mathrm{s}$.

In Froude number 0.05, the flow shows the same vertical velocity profile along the water channel. The vertical velocity profiles are match with the characteristic of open channel flow, which has highest velocity at top and lowest velocity at bottom. However, the vertical flow profiles are different from $1 / 7$ power law. The measured vertical flow profile show relatively low velocity at the center and bottom of water channel compared to $1 / 7$ power law. The flow is slightly unstable because the velocity is slightly different along the water channel.

### 4.5 VERTICAL VELOCITY PROFILE AT FLOW FROUDE NUMBER OF 0.81



Figure 4.20: Vertical velocity profile at 0.1 m when Froude number 0.81


Figure 4.21: Vertical velocity profile at 0.2 m when Froude number 0.81


Figure 4.22: Vertical velocity profile at 0.3 m when Froude number 0.81


Figure 4.23: Vertical velocity profile at 0.4 m when Froude number 0.81


Figure 4.24: Vertical velocity profile at 0.5 m when Froude number 0.81


Figure 4.25: Vertical velocity profile at 0.6 m when Froude number 0.81


Figure 4.26: Vertical velocity profile at 0.7 m when Froude number 0.81


Figure 4.27: Vertical velocity profile at 0.8 m when Froude number 0.81

Although the vertical velocity profile at maximum flow rate approach the $1 / 7$ power law after 0.3 m from the entrance of test section, but it show a totally different vertical velocity profile before 0.3 m from the entrance of test section. Therefore, the maximum Froude number where the flow has the same vertical velocity profile along the water channel was found. This was at where the flow is at Froude number 0.81. The volume flow rate of flow at this Froude number is $0.0071 \mathrm{~m}^{3} / \mathrm{s}$.

Figure 4.20 until Figure 4.27 show the vertical velocity profile at difference location from the entrance of test section at Froude number 0.81. The vertical velocity profiles approach the $1 / 7$ power law along the channel. The flow is slightly unstable because the velocity is slightly different along the channel.

### 4.6 SURFACE PROFILE ALONG WATER CHANNEL



Figure 4.28: Surface profile at $0.0114 \mathrm{~m}^{3} / \mathrm{s}$

Figure 4.28 shows that the surface profile of water channel is same with the calculated result. The water depth is uniform along the channel at maximum flow rate.

## CHAPTER 5

## CONCLUSION AND RECOMMENDATION

### 5.1 CONCLUSION

The water channel was successfully designed, fabricated, and tested. The water channel functions properly during the testing. However, it cannot reach the desired maximum flow rate of $0.0125 \mathrm{~m}^{3} / \mathrm{s}$. The maximum Froude number can be reached in the water channel is $0.0135 \mathrm{~m}^{3} / \mathrm{s}$. The flow at minimum Froude number shows the characteristic of open channel flow along the water channel but do not obey the $1 / 7$ Power Law. This means the vertical velocity profile is different with the real tidal site. At maximum flow rate, the vertical velocity profile only approach $1 / 7$ Power Law after 0.3 m from the entrance. The maximum Froude number where the flow approach $1 / 7$ Power Law along the water channel was found to be Froude number of 0.81 , which at the volume flow rate of $0.0071 \mathrm{~m}^{3} / \mathrm{s}$. No flows were stable because the velocities of flow were changing along the channel.

### 5.2 RECOMMENDATIONS

- Length of water channel

The water channel is designed longer so the flow has enough time to disperse undesired effect from delivery plenum.

- Entrance of flow

The flow is designed to enter the water channel in the same direction of the flow of test section. One can easily control the flow in this way and reduce the unsteadiness of flow.

- Flow diffuser

A better flow diffuser is designed to provide the better profile. Honeycomb can be used to further diffuse the flow so the flow can become smooth at short distance.

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## APPENDIX A <br> GANTT CHART

|  | Activities | Week |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| No. |  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 1 | Identify problem |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2 | Identify objective, scope and problem statement |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 3 | Literature Review |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 4 | Design of water channel |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 4 | Writing report |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

PSM 2

|  | Activities | Week |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| No. |  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 1 | Finalise design |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2 | Fabricate water channel |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 3 | Testing of water channel |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 4 | Data analysis |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 5 | Writing report |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

## APPENDIX B

## SPECIFICATION OF PUMP

| Brand | SAER |
| :---: | :---: |
| Type | CMK |
| Volume Flow Rate (m³/s) | $0.005-0.0125$ |
| Head (m) | $2-11.5$ |
| Operating Voltage (V) | 240 |
| Horsepower (hp) | 2 |
| Power (kW) | 1.5 |
| Rotating Speed (RPM) | 2850 |

## APPENDIX C

PERFORMANCE CHART OF PUMP


## APPENDIX D

## MOODY CHART



## APPENDIX E

## SURFACE PROFILE PROGRAMMING IN EES SOFTWARE

```
Vol=0.005[m^3/s]
b=0.3[m]
n=0.01
g=9.81[m/s}/2
x1=0
y1=0.1[m]
f_xy=(-(Vol/b)^2*n^2/y*(10/3))/(1-(Vol/b)^2/(g*y^3))
y=y1+integral(f_xy,x,x1,x2)
```


## APPENDIX F

BILL OF MATERIALS

| Date | Item | Category | Amount | Prices(RM) |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 3-Feb | Arylic 5mm | Channel | $1060 \mathrm{~mm} \mathrm{\times 300mm}$ | 50 |  |
| S-Feb | Chloroform(Plastic Glue) | Accessories | 1 | 6.5 |  |
| 3-Feb | Acrylic 5 mm | Channel | $900 \mathrm{~mm} \mathrm{\times 600mm}$ | 84 |  |
| 25-Feb | Acrylic 3mm | Channel | $230 \mathrm{~mm} \mathrm{\times 1440mm} \mathrm{\times 2}$ | 82 |  |
|  |  |  | 310 mmx 1290 mm |  |  |
|  |  |  | 200 mmx 1500 mm |  |  |
| 25-Feb | Plywoood 12mm (1.2m*2.4m) | Wood | 2 | 100 |  |
| 25 -feb | Paku | Accessories |  | 1 |  |
| $25-\mathrm{Feb}$ | Kertas Kasar | Accessories |  | 2 |  |
| 25-Feb | Silicone Sealant | Accessories | 1 | 10 |  |
| 12-Mar | Bolt nut | Accessories |  | 3 |  |
| $12-\mathrm{Mar}$ | Bolt nut Chromeal | Accessories |  | 3 |  |
| 12-Mar | L bracket | Accessories | 5 | 15 |  |
| 12-Mar | Angle Piece | Accessories | 10 | 5 |  |
| $12-\mathrm{Mar}$ | Epoxy | Accessories | 1 | 13 |  |
| $15-\mathrm{Mar}$ | PVC Reducer $4^{\prime \prime} \times 2^{\text {- }}$ | Piping | 2 | 24 |  |
| 15-Mar | PVC Reducer 4*x3* | Fiping | 2 | 24 |  |
| 15-Mar | Gl Busher $21 / 2^{\prime \prime}$ | Fiping | 2 | 36 |  |
| 15-Mar | PVC Adapter $\mathbf{2}^{*}$ | Piping | 2 | 12 |  |
| $15-\mathrm{Mar}$ | Tank Connector $\mathbf{4}^{\text {* }}$ | Piping | 1 | 32 |  |
| 15-Mar | Ball Valve $3^{*}$ | Fiping | 1 | 63 |  |
| 15-Mar | PVC Pipe $\mathbf{2}^{\text {- }}$ | Fiping |  | 2.5 |  |
| 15-Mar | PVC pipe $3^{*}$ | Piping |  | 4.5 |  |
| 15-Mar | Epoxy | Accessories | 1 | 13 |  |
| 15-Mar | PVC Gum | Accessories | 1 | 7 |  |
| 15-Mar | Piping Seal Tap | Accessories | 2 | 6 |  |
| 15-Mar | PVC Pipe 4* | Piping | 5 m | 29 |  |
| 15-Mar | PVC Elbow 4* | Piping | 3 | 15 |  |
| 15-Mar | PVC Tee 4* | Piping | 1 | 12 |  |
| 15-Mar | PVC Gum | Accessories | 1 | 3 |  |
| 20-Mar | Bolt Nut | Accessories |  | 2 |  |
| 20-Mar | PVC End Cap 4* | Fiping | 2 | 24 |  |
| 20-Mar | PVC 1 1/4* Tank Connector | Fiping |  | 3 |  |
| $20-\mathrm{Mar}$ | PVC 1 1/4** End Cap | Piping | 1 | 1.5 | For |
| 21-Mar | PVC 2"-1* Reducer | Fiping | 1 | 2 | Teating |
| 21-Mar | PVC 1" End Cup | Fiping | 1 | 1 | Pump |
| 21-Mar | PVC 1"Tank Connetor | Piping | 1 | 2 |  |
| 21-Mar | Bolt Nut | Accessories |  | 2 |  |
| 21-Mar | Screw | Accessories |  | 1 |  |
| 23-Mar | Ball Valve $11 / 4^{*}$ | Piping | 1 | 12.5 |  |
| 23-Mar | Rope | Accessories |  | 1 |  |
| 23-Mar | Fuse 13A | Accessories | 6 | 3 |  |
| 23-Mar | Fuse 15A | Accessories | 3 | 3 |  |
| 23-Mar | Plug Tool | Accessories | 1 | 4 |  |
| 11-Apr | Rubber Sheet | Accessories |  | 18 |  |
| 11-Apr | PVC Adspter[For connect hose] | Fiping | 3 | 3 |  |
| 11-Apr | Epoxy | Accessories | 1 | 12 |  |
| 11-Apr | Bolt Nut | Accessories |  | 3 |  |
| 11-Apr | Hose | Piping | 8 m | 32 |  |
| 11-Apr | Hose Clip | Piping | 1 | 2 |  |
|  |  |  | Total | 304.5 |  |

