DESIGN AND ANALYSIS OF THE SUPPORT STRUCTURE FOR AN OPEN CHANNEL FLUME

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BORANG PENGESAHAN STATUS TESIS♦

JUDUL: **DESIGN AND ANALYSIS OF THE SUPPORT STRUCTURE FOR AN OPEN CHANNEL FLUME**

SESI PENGAJIAN: **2013/2013**

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

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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.

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Specially dedicated to

My beloved family and those who have guided and inspired me

Throughout my journey of learning

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ABSTRACT

Open channel flumes which will be built on the ground level need a support structure to minimize the displacement at the sidewall due to the hydrostatic and dynamic pressure of water. The objectives of the study are to evaluate the pressure at the sidewall of the flume, and to design a supports structure for the sidewall of the flume under certain flow conditions. Three basic designs were selected and drawn using Solidwork software and solved with the Autodesk Simulation Multiphysics solver. From the data obtain it shows that Design 1 with 0.5 m breadth, 0.44 m length and 21 of support structure by using Ready Mix Concrete Normal Mix Grade 30 gave the smallest value of wall displacement, and 81.73% effectiveness of the support structure. Simulation result shown that the flume did need a support structure to reduce the displacement of the sidewall. As a conclusion, Design 1 as it gave the desirable result with the acceptable cost involved, effectiveness and economically.

ABSTRAK

Saluran air terbuka yang akan dibina di atas paras tanah memerlukan struktur sokongan untuk mengurangkan anjakan di sisi akibat tekanan hidrostatik dan dinamik air. Objektif kajian ini adalah untuk menilai tekanan pada dinding sisi saluran air, dan mereka bentuk struktur sokongan untuk sisi saluran air di bawah keadaan aliran tertentu. Tiga reka bentuk asas telah dipilih dan direka menggunakan perisian Solidwork dan diselesaikan dengan penyelesai Simulasi Multiphysics Autodesk. Dari data yang diperolehi menunjukkan bahawa Reka Bentuk 1 dengan 0.5 m lebar, 0.44 m panjang dan 21 struktur sokongan dengan menggunakan Konkrit Sedia Bancuh Bancuhan Biasa Gred 30 memberi nilai terkecil anjakan pada dinding, dan keberkesanan 81.73% kepada struktur sokongan. Hasil simulasi menunjukkan bahawa saluran air memerlukan struktur sokongan untuk mengurangkan anjakan sisi. Kesimpulannya, Reka Bentuk 1 kerana ia memberikan hasil yang diingini dengan melibatkan kos yang boleh diterima, keberkesanan dan dari segi ekonomi.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A	Area
Pa	Pressure
g	Gravity
a	Acceleration
F	Force
l	Length
n	Number
V	Volume
ρ	Density
ħ	height
%	Percentage
m	Meter
v	velocity

LIST OF ABBREVIATIONS

2D	2 Dimensional
3D	3 Dimensional
CIDB	Construction Industry Development Board Malaysia
FEA	Finite Element Analysis
UMP	University Malaysia Pahang
SSF	Sliding Safety Factor
TNB	Tenaga Nasional Berhad

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Renewable energy refers to the energy which comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat which is naturally replenished. Renewable energy can be particularly suitable for developing countries. In the rural areas, the transmission and distribution of energy generated from fossil fuels can be difficult and expensive. Therefore by producing the renewable energy resources locally, it can offer a viable alternative.

Renewable energy projects in many developing countries have shown that the renewable energy can contribute directly to poverty alleviation by providing the energy needed for creating businesses and employment. Through renewable energy also, it can contribute to education by supplying electricity to schools.

1.2 BACKGROUND OF STUDY

In this modern era, vast amount of energy required to generate electricity. The energy is used to power up machines, supplying electricity to the residential area, and to move vehicle. Since the finding of fossil fuel, it's being started to use it until now as main source of energy. In Malaysia, in the early eighties, oil-fired generators were used to produce electricity. As years passing by Tenaga Nasional Berhad (TNB) had found alternative resources, and the oil requirement has reduced over the years. Most of the time, fossil fuels were depends too much; therefore renewable energy resources must be obtained. In this chapter, the problem statement, objective, hypothesis and scope of study will be explain in detail.

1.3 PROBLEM STATEMENT

In rural and remote areas, it is always hard to supply the continuously stable electricity to the population. A steady supply of fuel would be required to generate electricity as generator was using fuel. This will be a problem in term of cost as nowadays the price of fuel is increasing. Therefore, as an alternative, a micro-hydro turbine will be installed to supply electricity in these areas.

Before an actual size of the mini-hydro turbine could be fabricated, a model scale of micro-hydro turbine would be required to be built and tested. Therefore, a flume needs to be developed in order to simulate the river flow, and test the turbine to find the potential amount electricity to be generated, and the efficiency of the system.

The flume will be built on the ground; therefore, it has no support structure to sustain the pressure of water at the wall. Hence, building the side support structure to sustain the hydrostatic and dynamic pressure of the water and analysis of it will essential to consider.

1.4 OBJECTIVE

The objectives of the study are:

i) To evaluate the pressure distribution at the sidewall of the flume.

ii) To design a support structure for the sidewall of the flume.

iii) To analyse the effect of support structure on the displacement of sidewall of the flume.

1.5 SCOPE OF PROJECT

The scope of the study are:

i) To evaluate the pressure distribution at the sidewall of the flume.
ii) To perform a structural analysis upon the support structure.
iii) Run a simulation of static and dynamic pressure of water upon the flume wall.
iv) To analyse the possible three design of the flume support structure.
v) Concrete will be used as the material of support structure.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter includes the study of the water flume from various sources. In this chapter also, the design for a support structure of the flume could be determined

2.2 OPEN WATER CHANNEL FLOW FLUME

In order to simulate the flow of a river, an open water channel flow flume need to be build. The open water channel had been used in the Otago University for aquatic research such as swimming. The swimmer will not move if he/she swim in the swimming flume, as the water being pumped into the swimming flume. The amount of water will be constant as the water move in a circulation flow. Therefore, thorough research being done by Robbin Britton (1998) to keep the water flow stable. Besides that, according to Robbin Britton (1998), the swimming flume can be used to test kayak and canoe. In the upcoming research, this water channel could be used to simulate a lab scale wave or tsunami.

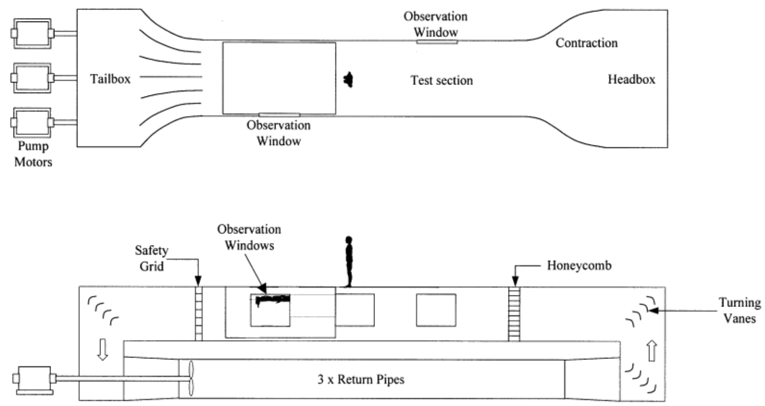


Figure 2.1: Schematic views of the swimming flume at Otago University

Source: Britton (1998)

Figure 2.1 shows the schematic views of the swimming flume at the Otago University. The test section of the swimming flume used by Otago University is rectangular shape channel and material used is fiberglass, stainless steel and mild steel. Even though, fiberglass has the advantage of lightweight and easy to install but the cost is high. Therefore we have come to an option to choose concrete as our material in term of cost.

In the early days, water channel were used to transport log from the cutting area to the processing area. Now, the water channels are widely used in the drainage system as shown in Figure 2.2. This will help to flush out the rain water during rain and prevent flash flood in a larger city. For example in Kuala Lumpur, when it is raining a flash flood always occur due to the poor drainage system, therefore the building of the open water channel help the flow of rain water and preventing the flash during raining season.

Figure 2.2: Water channel for Klang River in Kuala Lumpur

Sources: HUME Concrete Marketing

2.3 COUNTERFORT RETAINING WALLS

The water channel will be place at the ground level. As being told before, the water channel is similar to the drainage system which uses concrete as their main material to build it. Figure 2.3 shows the drainage system and the outer sidewall of the drain is being supported by the soil. Meanwhile in our case there will be no soil to support the sidewall as shown in figure 2.4. As we know the pressure at the bottom of the water channel will be the highest. Since the thickness of the wall of the water channel is the same therefore a counterfort retaining wall had been considered in our design to support the sidewall of the water channel.

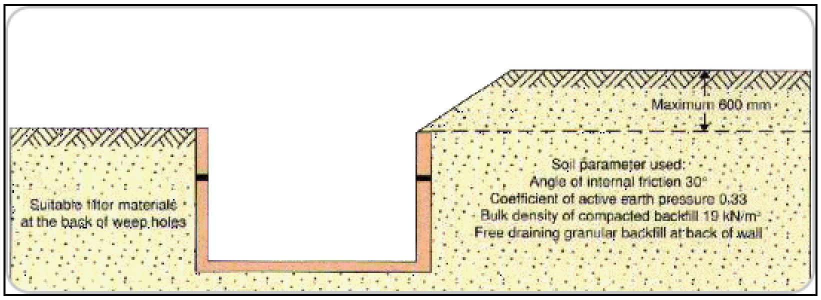


Figure 2.3: Water channel for drainage system

Sources: HUME Concrete Marketing

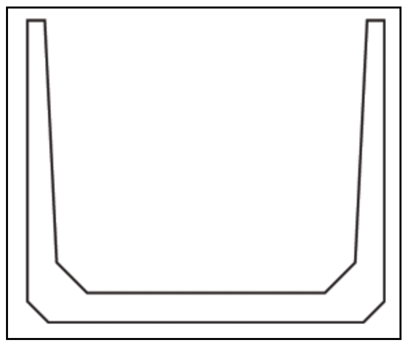


Figure 2.4: Water channel on a ground level without counterfort wall

Sources: HUME Concrete Marketing

According to M. Ghazavi (2003), in his journal he stated that to design a counterfort retaining wall there is some standard that must be followed to determine the stem thickness, base thickness, distance between counterfort, counterfort thickness and lengths of toe and heel. By following the method and parameter suggest by M. Ghazavi as shown in table 2.5 we could determine the size and design of our counterfort retaining wall. Table below shows the lower and upper bound of the design variables for the counterfort walls

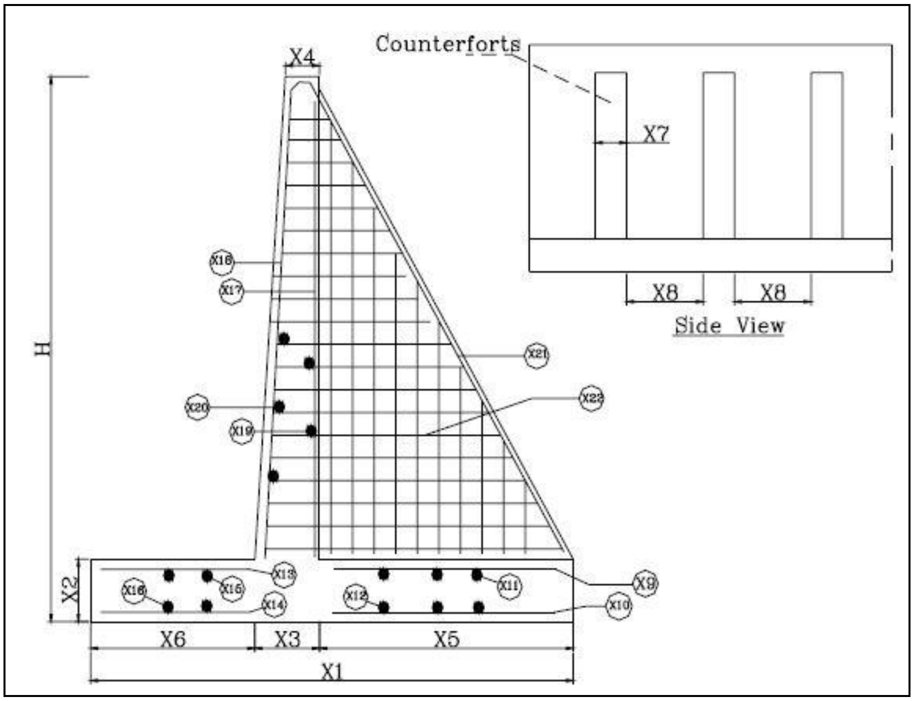


Figure 2.5: Design variable for typical reinforced concrete counterfort retaining walls

Source: Ghazavi (2003)

Table 2.1: Lower and upper bounds of design variables

Lower bound	Upper bound
X_{1min}=0.3H	X_{1max}=3H
X_{2min}=H/10	X_{2max}=H/8.5
X_{3min}=H/10	X_{3max}=H/8.5
X_{4min}=20 cm	X_{4max}=30 cm
X_{5min}=0.1H	X_{5max}=2H
X_{6min}=0.1H	X_{6max}=H
X_{7min}=20 cm	X_{7max}= 50 cm
X_{8min}= 0.3H	X_{8max}= 0.7H
X_{9min}= minimum of shrinkage and temperature rebar at heel in x direction	X_{9max}= maximum of shrinkage and temperature rebar at heel in x direction
X_{10min}=minimum of shrinkage and temperature rebar at heel in x direction	X_{10max}= maximum of shrinkage and temperature rebar at heel in x direction
X_{11min}= minimum of shrinkage and temperature rebar at heel in y direction	X_{11max}= maximum of shrinkage and temperature rebar at heel in y direction
X_{12min}= minimum of shrinkage and temperature rebar at heel in y direction	X_{12max}= maximum of shrinkage and temperature rebar at heel in y direction

X_{13min}= minimum of shrinkage and temperature rebar at toe in x direction	X_{13max}= maximum of shrinkage and temperature rebar at toe in x direction
X_{14min}= minimum of shrinkage and temperature rebar at toe in x direction	X_{14max}= maximum of shrinkage and temperature rebar at toe in x direction
X_{15min}= minimum of shrinkage and temperature rebar at toe in y direction	X_{15max}= maximum of shrinkage and temperature rebar at toe in y direction
X_{16min}= minimum of shrinkage and temperature rebar at toe in y direction	X_{16max}= maximum of shrinkage and temperature rebar at toe in y direction
X_{17min}= minimum of shrinkage and temperature rebar at stem in z direction	X_{17max}= maximum of shrinkage and temperature rebar at stem in z direction
X_{18min}= minimum of shrinkage and temperature rebar at stem in z direction	X_{18max}= maximum of shrinkage and temperature rebar at stem in z direction
X_{19min}= minimum of shrinkage and temperature rebar at stem in y direction	X_{19max}= maximum of shrinkage and temperature rebar at stem in y direction
X_{20min}= minimum of shrinkage and temperature rebar at stem in y direction	X_{20max}= maximum of shrinkage and temperature rebar at stem in y direction
X_{21min}= minimum of inclined rebar at counterfort	X_{21max}= maximum of inclined rebar at counterfort
X_{22min}= minimum of shear rebar at counterfort	X_{22max}= maximum of shear rebar at counterfort

Source: Ghazavi (2003)

With the parameter obtained from the research of M. Ghazavi (2003), not all of it will be used in the study to design the support structure of the sidewall of the water channel. With the useful information, we could design the counterfort easily and later we could run a simulation to test the design whether the counterfort wall could sustain he pressure from the water.

2.4 SLIDING SAFETY FACTOR

In Figure 2.6 show the front view of the water channel which is similar to concept of a wall of a dam. Wall of a dam is thicker at the bottom compared at the surface. This due to the concept of pressure, as we go deeper in the water, the pressure will increase. Therefore, that’s why the wall is always thick at the bottom to sustain pressure.

But even though, the bottom of the wall is thick, we should never neglect the possible damage that might affect the design. One of the potential threats to the design is crack. According to Farrokh Javanmardi (2004) whenever there is a crack at the inner of dam, the pressure which comes from the water will push the water into the crack hence making a new crack opening and filling the void. As this process continues, the crack will be increasing and the length of crack is denoted as L_{cr}

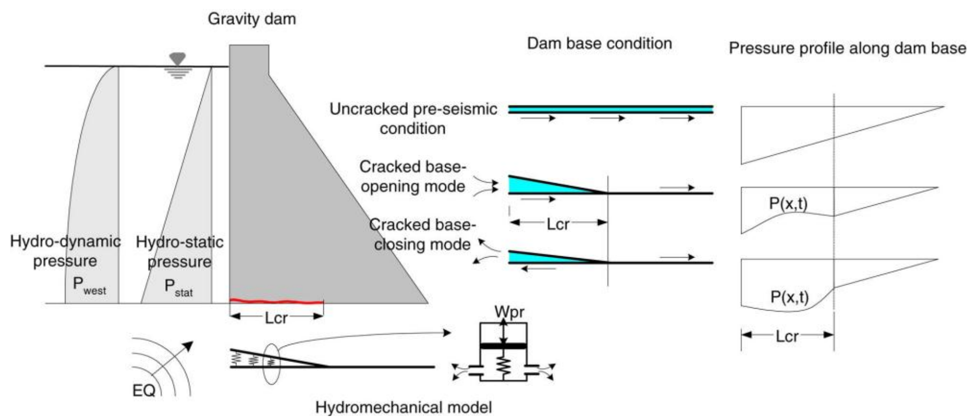


Figure 2.6: Static and transient uplift pressure

Source: Javanmardi (2004)

Sliding Safety Factor (SSF) is the factor of safety against sliding on the sand layer beneath the footing (J. Michael Duncan, 1999). From Farrokh Javanmardi research he applied the SSF in his study to show the movement of the dam when there is a crack. Therefore we could use this method to determine whether the wall of the retaining wall will crack or not. The shape of the flume is U-shape, therefore is does not have a sand layer footing as stated by Farrokh Javanmardi (2004) in his journal. Even though it does not have a sand layer footing, but the method could be applied to this study

2.5 FLUID STRUCTURE INTERACTION PROBLEMS

In this paper, Damodar Maity (2003) discuss about the finite element analysis of the fluid structure system by considering the couple effect of elastic structure of fluid. The study was held to determine the condition of the dam structure. Due to the complex topographical condition of dam structure, finite element method is recognized as one of the powerful numerical tools in most practical problem (Maity, 2003)

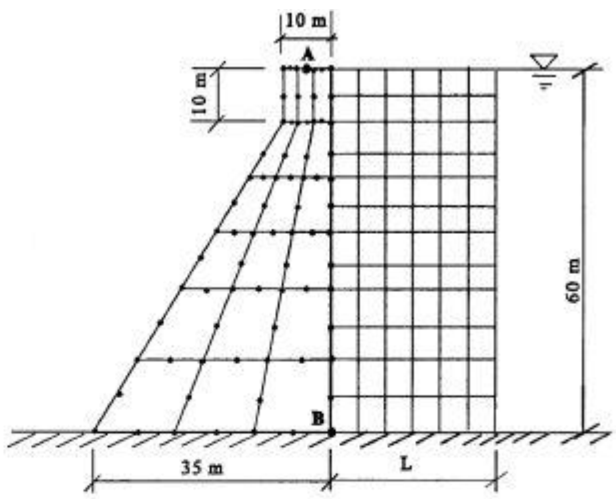


Figure 2.7 Geometry and finite element discretization of dam

Source: Maity (2003)

Damodar Maity (2003), stated that at the top of the dam is made slightly thicker. This is to prevent greater displacement at the top of the dam. Figure 2.7 shows the thickness the top of the dam wall. This design could be used as one of the design for the support structure of the flume. The concept of the dam could be used to adapt at the flume. This will enhance the support structure of the flume hence, more design could be proposed. Even though the M. Ghazavi (2003) did not consider the displacement at the top of the sidewall, new design could be develop to compare with the design recommended by M. Ghazavi.

2.6 DESIGN CONSIDERATION FOR COUNTERFORT WALL

There are various designs of the counterfort wall design. Some were suggesting building the support structure along the flume. This type is known as mass concrete and the material used are concrete. Mass concrete could be used as the support structure of the flume. In term of effectiveness of the support structure, mass concrete would give a similar result to the counterfort wall design. In 1908, John Monash proved that a significant financial saving could be achieved overall.

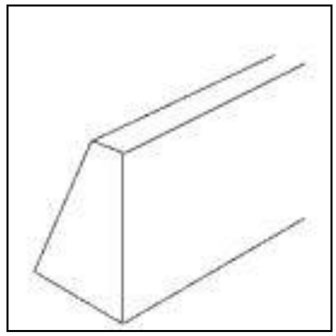


Figure 2.8: Mass concrete

Source: www.vicnet.net.au

Mass concrete also shown that it would require high volume compared to counterfort wall. Therefore, volume of support structure was taken as consideration as it will determine the cost building the support structure. Other than the volume of the support structure, the design from M. Ghazavi will be compared with the new design by changing the parameters of the breadth of support structure, the amount support structure and the length the support structure. Different design will give different result on the displacement of the sidewall of the flume.

All the designs will be referring to the M. Ghazavi counterfort design in Table 2.1. The result of displacement due to changing parameter will be compared to Table 2.1 either the minimum and maximum parameter in M. Ghazavi (2003) is acceptable.

2.6.1 Breadth of support structure

By referring to Table 2.1 the minimum breadth of the support structure is 0.2 m, meanwhile the maximum breadth of support structure is 0.5 m. The hydrostatic and dynamic pressure of the flume used, will be constant. Therefore, from the pressure obtain, the suitable breadth of the support structure could be determine. The breadth of support structure of 0.1 m, will be tested, to prove that 0.2 m is the minimum breadth allowed for the support structure.

2.6.2 Amount of support structure

M. Ghazavi (2003) stated in his journal one of the parameter being studied is the length between the support structures. Therefore, due to the fixed length of the flume, it is difficult to make the amount of support structure is equivalent at the front and at the end of the flume. By using the same concept, parameter of length between the support structures being change to the amount of support structure. By changing the amount of support structures, it is easier to design and analyse.

2.6.3 Length of support structure

Besides that, length of the support structure is also one of the parameter in designing a support structure. By referring to Table 2.1, the minimum length of the support structure is determined by using 0.1H and for the maximum length it is determined by using 2H. H is being referred as the height of the flume. From the parameter, the suitable length of the support structure will be determined.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The project starts off with project planning by using a Gantt chart as shown in appendix B & C and a flow chart as shown in Figure 3.10. The flow chart acts as a guide to successfully carry out this case study step by step while the Gantt chart helps to make sure that the project is within its timeframe. It is then furthered with the literature review throughout the whole project. Followed by designing procedure and continued with simulation setup.

Calculation and formulas are used to measure the pressure that the sidewall might exert. The design will be drawn using Solidwork and further analysis will be done using other analysing software.

3.2 COMPUTER AIDED DESIGN (CAD)

3.2.1 Solidwork

Solidwork which is owned by the Dassault Systeme SolidWork Corp. provide a 3D software tools that let the user create simulate, publish and manage their data. Solidwork products are easy to learn and use which will help you to design product better, faster, and more cost-effectively. Solidwork software are user friendly that allows more engineers, designers and any other technology professionals to take advantage of 3D in bringing their design to life.

Solidworks also could be used to draw 2D drawing. Its mechanical assembly and tool helps the engineer to design the product more efficiently. Furthermore, the file that has been saved in solidwork type is compatible with other software for further analysis. This will save time needed to convert the file to make it compatible with other software. Besides that, other than 2D and 3D drawing, solidwork also able to run a simulation on the product and the data obtain could be use further analysis.

3.3 FINITTE ELEMENT ANALYSIS (FEA)

3.3.1 Autodesk Simulation Multiphysics

Autodesk is also one of the top software developers and helps to visualize, simulate, and analyse the performance and to incorporate green design principle into the design. Autodesk Simulation Multiphysics is widely used for finite element analysis in the higher education institution due to its user friendly.

The Autodesk Simulation Multiphysics will be used to analyse the support structure of the water channel. With the data obtain from the solidwork flow simulation; the pressure that acts upon the water could be used to apply the pressure exerted by the sidewall of the inner water channel. By applying the pressure upon the sidewall of the water channel, we might get the displacement that might be occurring at the sidewall.

This result will be representing the actual value that might be obtained through experimental. Via this FEA software we will be able to run an analysis without rupturing the product. Furthermore, through this analysis we will be able to detect the stress and strain along the water channel and also crack if there is any.

3.3.2 Solidwork (Flow Simulation)

Solidwork flow simulation could easily simulate fluid flow, heat transfer, and fluid forces that are critical to the success of the design. It is fully embedded with SolidWorks 3D CAD, a SolidWorks Flow Simulation intuitive Computational Fluid Dynamics (CFD) tool enables us to simulate liquid and gas flow in real world conditions.

In this project, fluid flow simulation must be run inside the drawn water channel by key in all the boundary condition that we required. From the simulation, the result that required will be obtain, which is the pressure exerted by the sidewall. The data extracted from simulation result, will be used in Autodesk Simulation Multiphysics for further analysis. Fluid flow being simulates using Solidworks Flow Simulation instead of Autodesk Simulation Multiphysics because the Autodesk software does not have fluid flow application.

3.4 CONCEPTUAL DESIGN

In designing the support structure for the water channel the parameters that change are the breadth of support structure, amount of support structure and length of support structure. For further analysis, the material of the water channel and support structure will be the same, but only the grade of concrete will change. Two grade will be tested for building of the water channel and support structure which are Ready Mix Concrete-Normal Mix-Grade 20 Granite and Grade 30 Granite

The Price of each material will be refer to Table 2 which provided by Construction Industry Development Board Malaysia (CIDB). CIDB is a statutory body under Minister of Works, Malaysia. Established in July 1994 to coordinate all activities in the construction industry and increase its competitiveness.

3.4.1 Dimension

Information below shows the dimension of the open channel flume:

Width: 2 meter
Height: 2 meter
Length: 30 meter
Thickness: 0.2 meter
Material: Concrete

3.4.2 Design

Figure 3.1 shows the conceptual design of the open channel flume. The flume is the part where the river flow is simulated.

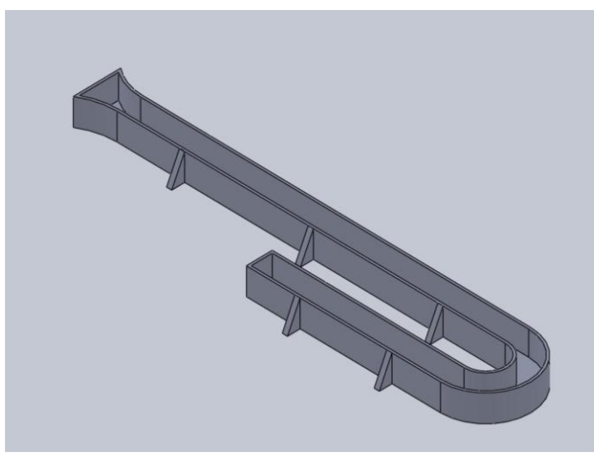


Figure 3.1: Conceptual design of the open water channel flow flume

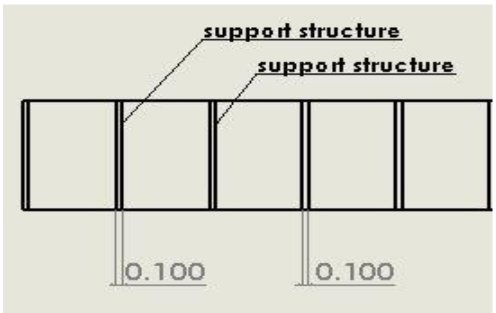
3.5 PROCEDURE

To design the support structure of the wall three designs had been proposed, and there are few parameters that had been considered. There the breadth of the support structure, the amount of structure, and the width of the support structure.

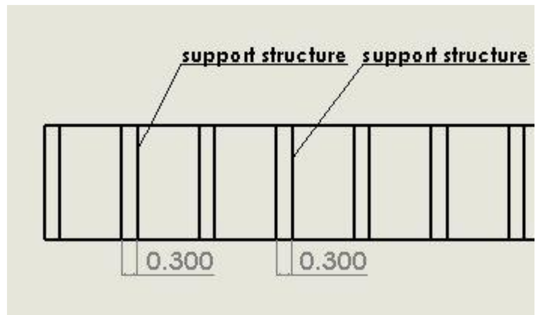
i) Each support structure is drawn using Solidwork with a standard of 0.44m width, 0.22m height, and 0.5m breadth
ii) The designs are name accordingly; Ghazavi design, Design 1 and Design 2.
iii) Later, each design is modified according to the parameter use.
iv) Changing breadth of support structure; 0.1m, 0.3m, and 0.3
v) Amount of support structure; 6, 11 and 21
vi) Width of support structure; 220mm, 330mm, and 440mm.
vii) Then each design is will undergo simulation to determine the displacement of the sidewall.
viii) Pressure of the of the side wall is obtain from the Solidwork Fluid Flow Simulation
ix) Later it will be used in the Autodesk Simulation Multiphysics, to obtain the displacement of each design.
x) The materials used to test each design are Ready Mix Concrete-Normal Mix-Grade 20 Granite and Grade 30 Granite
xi) Later, the data obtain will be tabulated according to the parameters.
xii) The best design from each parameter will be pick and compared
xiii) Finally from the data obtain, the best design will be determined.

3.5.1 Breadth of support structure

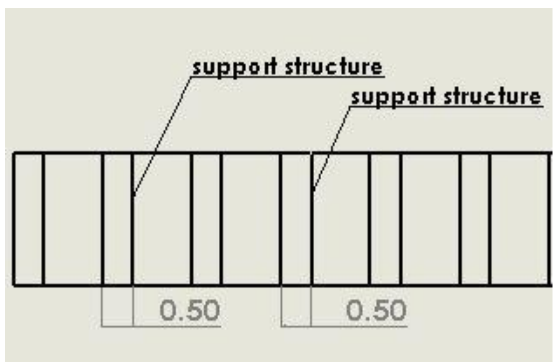
In this part, the parameter that will be change is the breadth of the support structure. The value that going to be tested is breadth of 0.1 m, 0.3 m and 0.5 m. The height, the width and the amount of support structure are kept constant. This will determine the suitable breadth of the support structure for the flume Figure 3.2 shows the changes of breadth of the support structure that will be applied to the three designs.



(a)



(b)

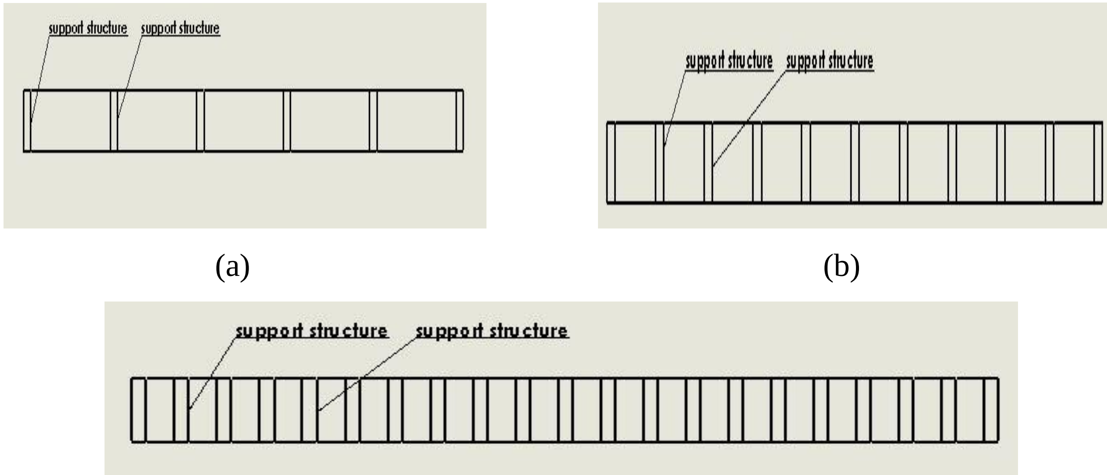


(c)

Figure 3.2: Side view-example of changes of breadth of the support structure (a) 0.1 m (b) 0.3 m (c) 0.5 m

3.5.2 Amount of support structure

In this section the parameter that will undergo testing is the amount of support structure used for the flume. The amount of support structure that going to be used are six, eleven and twenty-one. The height, the width and the breadth of support structure are kept constant. This will determine suitable amount of support structure for the flume. Figure 3.3 show the example of changes of amount of the support structure that will be applied to the three designs.



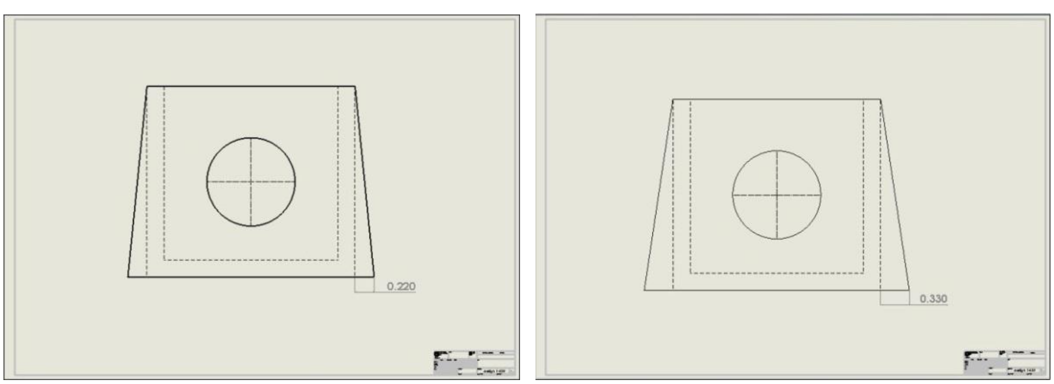
(a) (b)

(c)

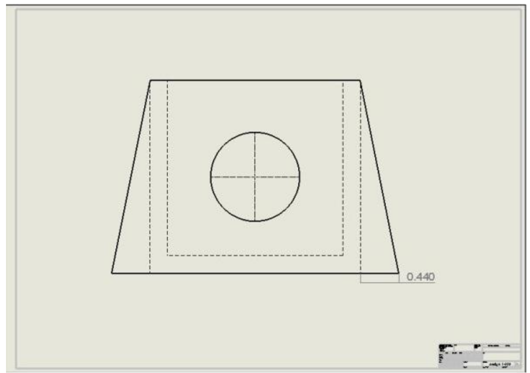
Figure 3.3: Side view-example of changes of amount of the support structure (a) six (b) eleven (c) twenty-one

3.5.3 Length of support structure

In this section the parameter that will undergo testing is the width of support structure used for the flume. The values that will be used in this test are 0.22 m, 0.33 m and 0.44 m. The height, the amount and the breadth of support structure are kept constant. This will determine how much the changing width of support structure will affects the displacement of the side wall of flume



(a) (b)



(c)

Figure 3.4: Front view-example of changes of length of the support structure (a) 0.22m (b) 0.33m (c) 0.44m

3.6 ACTUAL DESIGN

3.6.1 Water Channel without support

Figure 3.5: Water channel without support structure

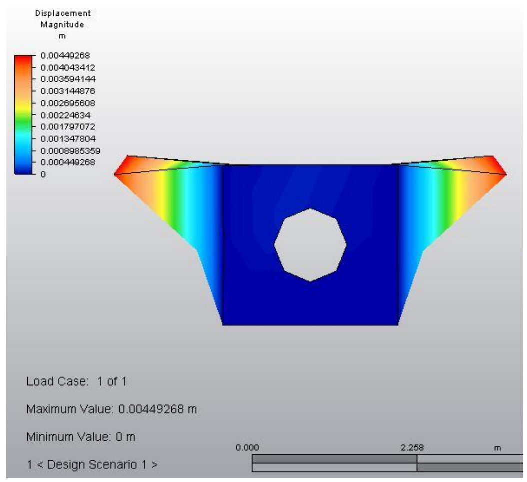


Figure 3.6: Example of displacement of the water channel without support

Preliminary results obtain for the water channel flow channel with, show that the displacement for Ready Mix Concrete-Normal Mix-Grade 20 Granite is 0.00623483m and for Ready Mix Concrete-Normal Mix-Grade 30 Granite is 0.00449268m. This value will be used for further analysis to calculate the percentage of effectiveness.

3.6.2 Ghazavi Design, Design 1 & Design 2

Ghazavi design is the design that followed the guideline of the Ghazavi (2003) journal to build the support structure. Basically all the designs are following this guideline. Figure 3.7 shows the initial dimension of Ghazavi Design in meter before undergoes the simulation and testing.

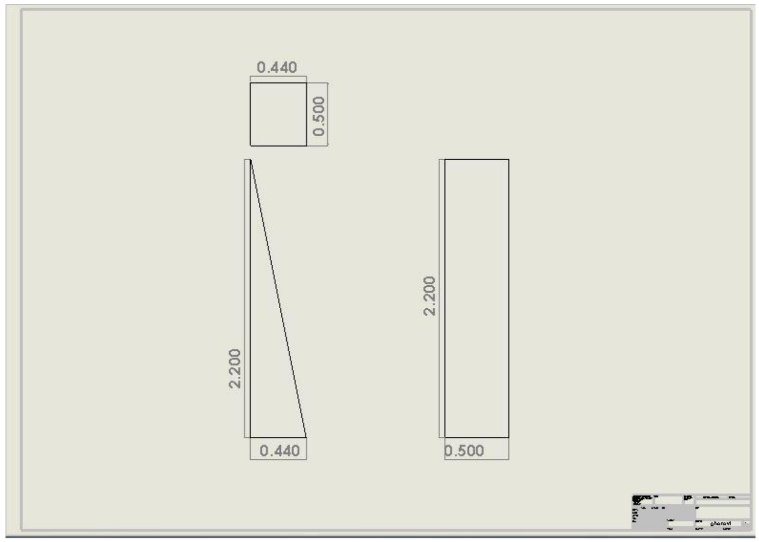


Figure 3.7: Ghazavi design

Design 1 is proposed based on the preliminary result of the flume without the support structure. It shows that the highest displacement of the flume is at the top of the sidewall. This design was extracted from Maity (2003) and undergoes modification to make it suitable for the flume Therefore Design 1 is made slightly thicker at the top compared to Ghazavi Design. Figure 3.8 shows the initial dimension of Design 1 in meter before undergoes the simulation and testing.

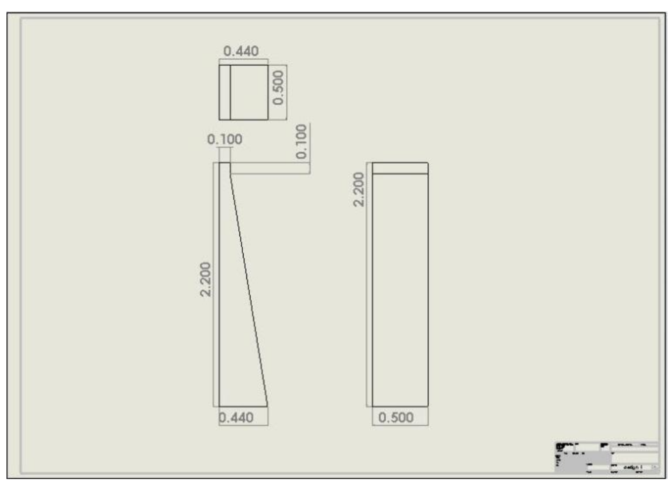


Figure 3.8: Design 1

Design 2 is proposed based on the cost of building the support structure and the flume. From the preliminary result of the flume, it shows that at the bottom of the flume there almost no displacement occurs. Therefore, the volume at the bottom of the support structure can be eliminated; hence reducing the cost of building it.. Figure 3.7 shows the initial dimension of Design 2 in meter before undergoes the simulation and testing

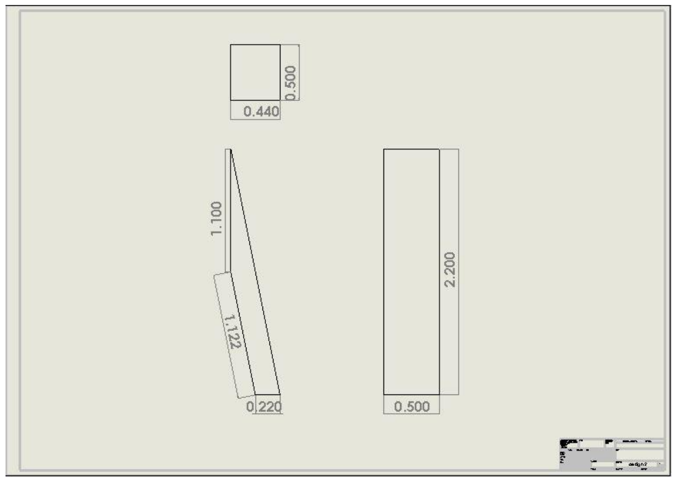


Figure 3.9: Design 2

3.6.3 CIDB Material List

Table below show the price of the material used in the simulation. Later these values will be used to determine the cost of building the flume and the support structure of each design and each parameter used.

Table 3.1: CIDB material list

Description **Ready Mix Concrete Granite**	**Unit**	**Credit Term** **(Days)**	**Del or Ex**	**Nov-2012 (RM)** **Pahang**	**Dec-2012 (RM)**
Ready Mix Concrete-Normal Mix-Grade 10 Granite	m^3	30	Delivered	175.97	175.97
Ready Mix Concrete-Normal Mix-Grade 15 Granite	m^3	30	Delivered	181.47	181.47
Ready Mix Concrete-Normal Mix-Grade 20 Granite	m^3	30	Delivered	188.60	188.60
Ready Mix Concrete-Normal Mix-Grade 25 Granite	m^3	30	Delivered	194.20	194.20
Ready Mix Concrete-Normal Mix-Grade 30 Granite	m^3	30	Delivered	206.53	206.53
Ready Mix Concrete-Normal Mix-Grade 35 Granite	m^3	30	Delivered	213.80	213.80
Ready Mix Concrete-Normal Mix-Grade 40 Granite	m^3	30	Delivered	230.17	230.17

Source: CIDB Malaysia

3.8 FLOW OF THE PROJECT

The terminology of work and planning for this research was shown in the flow chart Figure 3.1

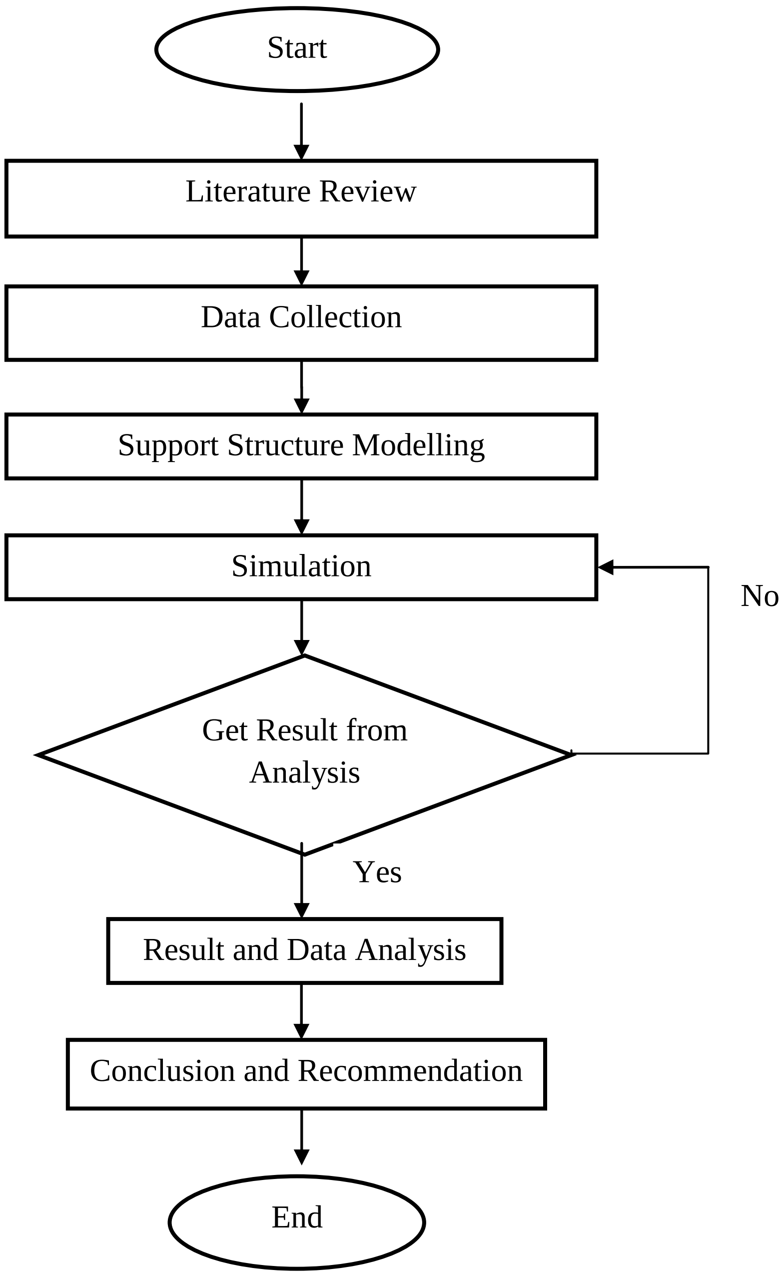


Figure 3.10: Project's flow chart

CHAPTER 4

RESULTS & DISCUSSION

4.1 INTRODUCTION

This chapter presents the results of the simulation according to the parameters. The data obtain from the result is tabulated and analyse for the design selection of support structure for an open channel flow flume.

4.2 FLOW SIMULATION

From the Solidwork Flow Simulation, the value hydrostatic and dynamic pressure exerted by the sidewall of the flume, were determined. The total pressure exerted by the sidewall of the flume is 59,680 Pa. Hence this value will be used in the Autodesk Multiphysics solver to determine the displacement of the sidewall of the flume.

4.3 BREADTH OF SUPPORT STRUCTURE

Table 4.1: Effect of breadth of the support structure

Breadth, m	Displacement, mm					
	Ghazavi Design		Design 1		Design 2	
	Grade 20	Grade30	Grade 20	Grade30	Grade 20	Grade30
0.1	3.51541	2.34361	3.24689	2.1646	3.939	2.62619
0.3	1.85437	1.23625	1.62339	1.08226	2.037	1.358
0.5	1.33223	0.888152	1.1393	0.75962	1.435	0.95649

The table above shows the effect of breadth of structure upon the displacement of the side wall of the flume by using concrete with grade 20 and grade 30. The data were obtained from the Autodesk Simulation Multiphysics solver. From the table it is shown that grade 30 concrete give the least displacement of the sidewall of the flume therefore grade 30 concrete has higher strength compared to grade 20 concrete. As the breadth of support structure increase the displacement of the sidewall of the flume decreases for each design tested. Further analysis and comparison will be made to select the best design for the support structure of the flume.

For further analysis, the effectiveness of the support structure will be determined and the volumes of the structure were obtained from the Solidwork software. Then the selected design will undergoes pricing calculation, to calculate the cost of the material to build the flume and the support structure.

4.4 AMOUNT OF SUPPORT STRUCTURE

Table 4.2: Effect of amount of the support structure

Amount of support structure, n	Displacement,mm					
	Ghazavi Design		Design 1		Design 2	
	Grade 20	Grade30	Grade 20	Grade30	Grade 20	Grade30
6	2.54189	1.69459	5.81495	3.87664	5.762	3.8413
11	2.33912	1.55942	2.27583	1.51722	2.737	1.8244
21	1.33223	0.88815	1.1393	0.75962	1.435	0.9564

The table above shows the effect of amount of structure upon the displacement of the side wall of the flume by using concrete with grade 20 and grade 30. The data were obtained from the Autodesk Simulation Multiphysics solver. From the table it is shown that grade 30 concrete give the least displacement of the sidewall of the flume therefore grade 30 concrete has higher strength compared to grade 20 concrete. As the amount of the support structure increases increase the displacement of the sidewall of the flume decreases for each design tested. Further analysis and comparison will be made to select the best design for the support structure of the flume.

For further analysis, the effectiveness of the support structure will be determined and the volumes of the structure were obtained from the Solidwork software. Then the selected design will undergoes pricing calculation, to calculate the cost of the material to build the flume and the support structure.

4.5 LENGTH OF THE SUPPORT STRUCTURE

Table 4.3: Effect of length of the support structure

Length of support structure, m	**Displacement,mm**					
	Ghazavi Design		**Design 1**		**Design 2**	
	Grade 20	**Grade30**	**Grade 20**	**Grade30**	**Grade 20**	**Grade30**
0.22	3.2287	2.15247	2.73801	1.82534	-	-
0.33	1.98788	1.32525	1.6801	1.12007	2.278	1.51859
0.44	1.33223	0.888152	1.1393	0.75962	1.435	0.95649

The table above shows the effect of the length of structure upon the displacement of the side wall of the flume by using concrete with grade 20 and grade 30. The data were obtained from the Autodesk Simulation Multiphysics solver. From the table it is shown that grade 30 concrete give the least displacement of the sidewall of the flume therefore grade 30 concrete has higher strength compared to grade 20 concrete. As the amount of the support structure increases increase the displacement of the sidewall of the flume decreases for each design tested. Further analysis and comparison will be made to select the best design for the support structure of the flume.

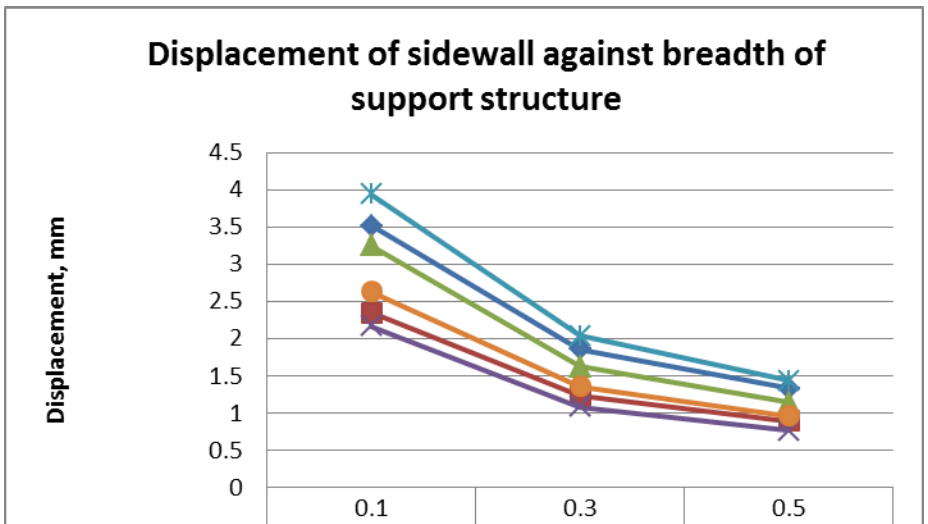
For further analysis, the effectiveness of the support structure will be determined and the volumes of the structure were obtained from the Solidwork software. Then the selected design will undergoes pricing calculation, to calculate the cost of the material to build the flume and the support structure

4.6 DISCUSSION

In this part the graph for each parameters tested will be discussed accordingly, together with the percentage of effectiveness of support structure and cost of material.

4.6.1 Breadth of support structure

Graph below was plotted by using the tabulated data from Table 4.1



	0.1	0.3	0.5
Ghazavi-G20	3.51541	1.85437	1.33223
Ghazavi-G30	2.34361	1.23625	0.888152
Design 1-G20	3.24689	1.62339	1.1393
Design 1-G30	2.1646	1.08226	0.75962
Design 2-G20	3.939	2.037	1.435
Design 2-G30	2.62619	1.358	0.95649

Figure 4.1: Graph of displacement of sidewall against breadth of support structure

Figure 4.1 shows the graph of the displacement of the sidewall against the breadth of the support structure. As the breadth was increase to 0.3 m all design shows a significant pattern and the reading shows that the displacement were reduced by half from the reading of breadth 0.1 m.When the breadth increases to 0.5 m, the decrease of displacement was not high as before. This shows, that the breadth almost reach the maximum value. The readings validate the recommendation made Ghazavi (2003) that the maximum value for breadth of the support structure is 0.5m. This shows that if the breadth is increase more than 0.5 m, the reduction of displacement of the sidewall will be small. The minimum breadth of the support structure according to Ghazavi (2003) is 0.2m. The breadth of 0.3 m and 0.5 m does not give high differences, in term of displacement reduction of sidewall but the breadth of 0.1 m give a higher compared to others. This proves the minimum value of the support structure cannot be less than 0.2m. The breadth of 0.5 m gives the least displacement compared to breadth of 0.1m and 0.3 m. Furthermore, the graph shows that Design 1 give the least displacement of the wall with the value of 1.358 mm. Meanwhile the displacement for other design with the breadth of 0.5m does not differ much with the Design 1

The graph also shows that grade 30 concrete gives the smallest displacement compared to the design that using concrete grade 20. This shows that grade 30 concrete has high strength and able to sustain the pressure of water inside the flume. Even though, the designs that uses grade 30 concrete give the smallest displacement, but the differences of reading between the two grades of concrete are small. Both grade used produce the same pattern but has difference in displacement. This shows that the only thing that differ the grade from one and another is the displacement produce and not the pattern. Further analysis will be done, to ensure which design and material are the best is in term of percentage and economically.

Design 1 was considered giving the best result compared to Ghazavi Design, this due the pressure distribution at the sidewall of the flume. Figure 3.6 shows that the displacement of the sidewall is highest at the top of the sidewall. Maity (2003) has considered the thickness at the top of the dam; therefore by applying his design, the top of the flume could sustain more pressure and gives the smallest displacement compared to other designs. Percentage of effectiveness of each design were calculated and tabulated in Table 4.4.

Table 4.4: Percentage of effectiveness of support structure

Breadth, m	Percentage of effectiveness, %					
	Ghazavi Design		Design 1		Design 2	
	Grade 20	Grade30	Grade 20	Grade30	Grade 20	Grade30
0.1	21.75	47.83	27.73	51.82	12.32	41.55
0.3	58.72	72.48	63.86	75.91	54.65	69.77
0.5	78.63	80.23	81.73	83.09	76.99	78.71

The table above, showed the percentage of effectiveness of the support structure for each design. The percentage of effectiveness will be used to determine the design that will be selected for the support structure of the flume. The designs with the percentage of effectiveness more than 80% are chosen. Therefore three designs were being selected. First is Design 1 with grade 30 concrete with 0.5 m breadth of support structure with value of 83.09%. Next is Design 1 with grade 20 concrete with 0.5 m breadth of support structure with value of 81.73% and finally is Ghazavi Design with grade 30 concrete with 0.5 m breadth of support structure with value of 80.23%. Other design give a percentage lower than 80%, therefore it was not chosen

Table 4.5: Volume of structure

Breadth, m	Volume of structure,m3					
	Ghazavi Design		Design 1		Design 2	
	Grade 20	Grade30	Grade 20	Grade30	Grade 20	Grade30
0.1	41.33	41.33	41.72	41.72	40.82	40.82
0.3	45.39	45.39	45.56	45.56	43.87	43.87
0.5	49.46	49.46	51.41	51.41	46.92	46.92

Table 4.9 shows the volume of the support structure of each design. This table also showed the volume of the three designs that being selected. From the selected design, Ghazavi Design with breadth of 0.5 m using grade 30 concrete shows the minimum volume of structure compared to the other two. Meanwhile, Design 1 with breadth of 0.5m using grade 20 & 30 concrete shows the same volume of structure. This is because the only things that change are the grade of the concrete used.

Table 4.6: Cost of material

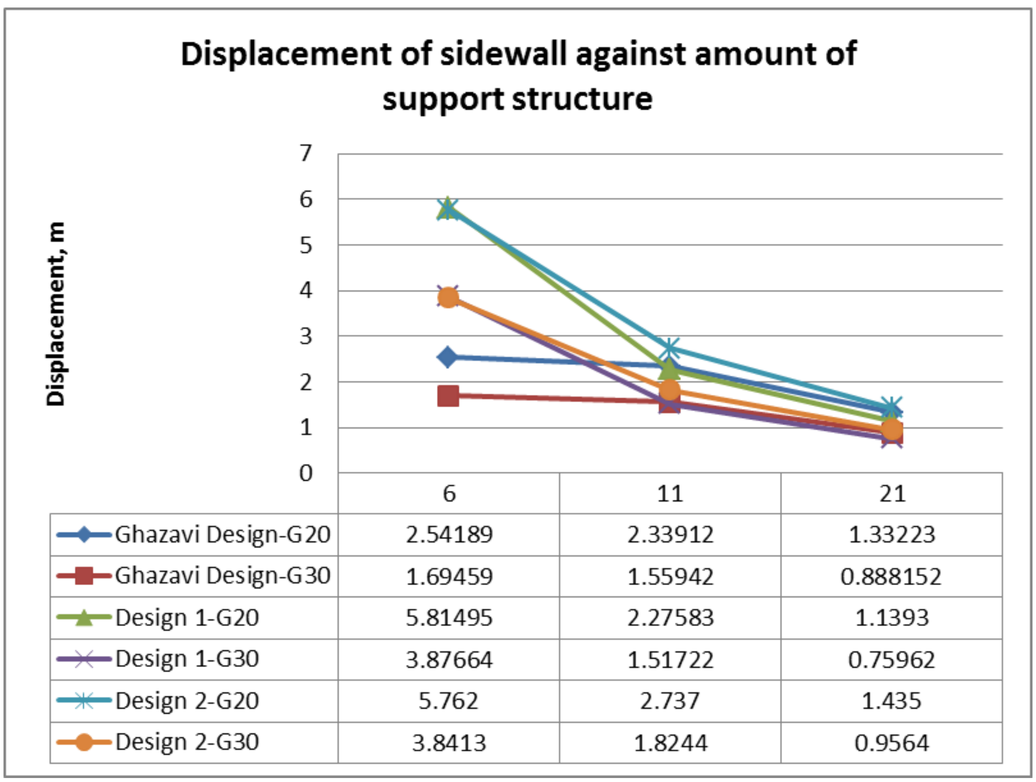
Breadth, m	Cost of material RM					
	Ghazavi Design		Design 1		Design 2	
	Grade 20	Grade30	Grade 20	Grade30	Grade 20	Grade30
0.1	7,794.83	9,512.92	7,868.39	9,602.69	7,698.65	9,395.53
0.3	8,560.55	10,447.41	8,592.61	10,486.54	8,273.88	10,097.55
0.5	9,328.16	10,214.97	9,695.92	10,617.70	8,849.112	9,690.38

The volumes of structures obtain from Table 4.9 then were used to calculate the cost of material for each design selected. The cost of material is obtained from the CIDB material list provided by the CIDB Malaysia. The price of grade 20 concrete is

RM188.60/m^3 and for grade 30 concrete, the price is RM206.53/m$^{3.}$ In term of cost, among the three designs selected, Design 1 with 0.5 m breadth of support structure using grade 20 concrete shows the lowest cost with value of RM9,695.92. Meanwhile for the other two designs, Ghazavi Design and Design 1 with 0.5 breadth of support structure using grade 30 concrete each shows value of RM10,214.97 and RM10,617.70 Therefore, for the parameter of breadth of the support structure, Design 1 with 0.5 m breadth of support structure using grade 20 concrete is being selected in term of cost of material and percentage of effectiveness

4.6.2 Amount of support structure

Graph below was plotted by using the tabulated data from Table 4.2



	6	11	21
Ghazavi Design-G20	2.54189	2.33912	1.33223
Ghazavi Design-G30	1.69459	1.55942	0.888152
Design 1-G20	5.81495	2.27583	1.1393
Design 1-G30	3.87664	1.51722	0.75962
Design 2-G20	5.762	2.737	1.435
Design 2-G30	3.8413	1.8244	0.9564

Figure 4.2: Graph of displacement of sidewall against the amount structure

The graph above shows the displacement of the side wall decreases as the amount of support structure increase. For Design 1 and 2 it is clearly shows that the displacement decreases drastically as the amount of support structure increases. Meanwhile for Ghazavi design it does not show many changes as the amount support structure increases. But for all design, when the support structure reaches twenty-one, the displacement of each design is quite similar. According to Ghazavi (2003), the maximum spacing between the support structures is 1.54 m meanwhile the minimum value is 0.66 m. It is determined by using the formula provided which is for maximum value is 0.7H and H is the height of the flume. Meanwhile, for the minimum value is 0.3H. For the amount of twenty-one, the spacing measure between the support structures is still in the range. On the other hand, for the amount of six and eleven of support structure the spacing between the supports structures are out of the range, which is higher than 1.54m. This is the reason why the displacement for the amount of support structure of six and eleven are higher compared to the amount of twenty-one. Design 2 with the 21 support structure gives the least displacement of the side wall with value of 0.76mm.

Graph above shows the pattern of the displacement of sidewall against the amount of support structure change. It shows that, most of the design that using grade 30 concrete gives the smallest displacement compared to the design that using concrete grade 30. . This shows that grade 30 concrete has high strength and able to support the pressure of water inside the flume. Even though, the designs that uses grade 30 concrete give the smallest displacement, but the differences of reading between the two grades of concrete are small. Both grade used produce the same pattern but has difference in displacement. This shows that the only thing that differ the grade from one and another is the displacement produce and not the pattern Even though, the designs that uses grade 30 concrete give the smallest displacement, further analysis will be done, to ensure which design and material is the best in term of percentage and economically. From the graph, it also shows that as the amount of support structure increases, the displacement of the side wall decreases. This shows the amount of support structure gives and impact to the displacement of the side wall. Percentage of effectiveness of each design were calculated and tabulated in Table 4.7.

Table 4.7: Percentage of effectiveness of support structure

Amount of support structure,n	Percentage of effectiveness, %					
	Ghazavi Design		Design 1		Design 2	
	Grade 20	Grade30	Grade 20	Grade30	Grade 20	Grade30
6	43.42	62. 28	29.43	13.71	28.25	14.50
10	47.93	65.29	49.34	66.23	39.08	59.39
21	78.63	80.23	81.73	83.09	76.99	78.71

The table above showed the percentage of effectiveness of the support structure of each design. The percentage of effectiveness will be used to determine the design selection for the support structure. The designs with the percentage of effectiveness more than 80% are chosen. Therefore three designs were being selected. First is Design 1 with grade 30 concrete with twenty-one support structure with value of 83.09%. Next is Design 1 with grade 20 concrete with twenty-one support structure with value of 81.73% and finally is Ghazavi Design with grade 30 concrete also with twenty-one support structure with value of 80.23%. Other design give a percentage lower than 80%, therefore it was not chosen

Table 4.8: Volume of structure

Amount of support structure,n	Volume of structure,m^3					
	Ghazavi Design		Design 1		Design 2	
	Grade 20	Grade30	Grade 20	Grade30	Grade 20	Grade30
6	42.19	42.19	42.75	42.75	41.47	41.47
11	44.61	44.61	45.64	45.64	43.27	43.27
21	49.46	49.46	51.41	51.41	46.92	46.92

Table 4.9 shows the volume of the support structure of each design. This table also showed the volume of the three designs that being selected. From the selected design, Ghazavi Design with twenty-one support structure using grade 30 concrete shows the minimum volume of structure compared to the other two. Meanwhile, Design 1 with twenty-one support structure using grade 20 & 30 concrete shows the same volume of structure which is the highest value compared to others. This is because the only things that change are the grade of the concrete used.

Table 4.9: Cost of material

Amount of support structure,n	Cost of material, RM					
	Ghazavi Design		Design 1		Design 2	
	Grade 20	Grade30	Grade 20	Grade30	Grade 20	Grade30
6	7957.03	9710.87	8062.65	9839.76	7821.24	9545.14
11	8413.44	10267.88	8607.70	10504.95	8160.72	9959.45
21	9,328.16	10,214.97	9,695.92	10,617.70	8,849.112	9,690.38

The volumes of structures obtain from Table 4.13 then were used to calculate the cost of material for each design selected. The cost of material is obtained from the CIDB material list provided by the CIDB Malaysia. The price of grade 20 concrete is RM188.60/m^3 and for grade 30 concrete, the price is RM206.53/m^3. In term of cost, among the three designs selected, Design 1 with twenty-one support structure using grade 20 concrete shows the lowest cost with value of RM9,695.92. Meanwhile for the other two designs, Ghazavi Design and Design 1 with twenty-one support structure using grade 30 concrete each shows value of RM10,214.97 and RM10,617.70. Therefore, for the parameter of amount of the support structure, Design 1 with twenty-one support structure using grade 20 concrete is being selected.

4.6.3 Length of support structure

Graph below was plotted by using the tabulated data from Table 4.3

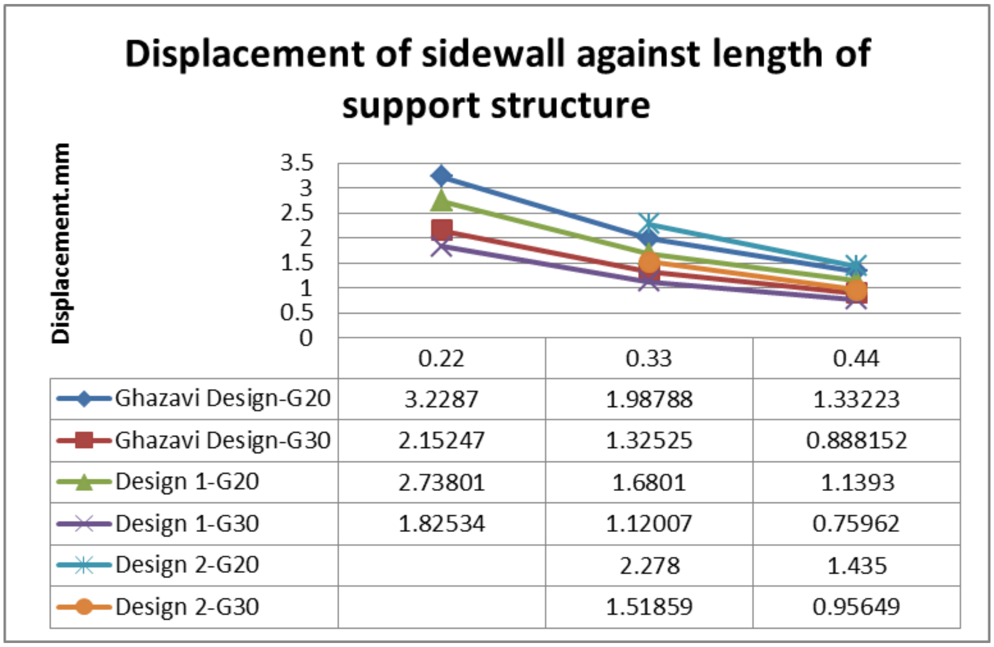


Figure 4.3: Graph of displacement of the sidewall against the length of support structure

The graph above shows the displacement of wall against the length of the support structure for material of Ready Mix Concrete-Normal Mix-Grade 20 and 30 Granite. The length of the support structure is measured from the bottom of the flume until the end of the support structure. From the guideline in designing a counterfort wall, Ghazavi (2003) stated that the minimum value for the length of the support structure must be 0.1H and H is the height of the flume. Meanwhile for the maximum value is 2.2H. Therefore for the minimum length of the support structure must be in the range of 0.22m and 4.4m. In this study, most of the lengths used are in range therefore it is applicable For Design 2; the length of 0.22 m is not applicable as it will result to zero support structure. This is because some of the volume of Design 2 was being reduced during the designing process. The displacements of the side wall for all design are decreasing as the length of the support structure increases. Design 1 with length of support structure of 0.44 m gives the smallest displacement of wall compared to other design with value of 0.76 mm.

Graph above shows that, most of the design that using grade 30 concrete gives the smallest displacement compared to the design that using concrete grade 30. This shows that grade 30 concrete has high strength and able to support the pressure of water inside the flume. Even though, the designs that uses grade 30 concrete give the smallest displacement, but the differences of reading between the two grades of concrete are small. Both grade used produce the same pattern but has difference in displacement. This shows that the only thing that differ the grade from one and another is the displacement produce and not the pattern. Even though, the designs that uses grade 30 concrete give the smallest displacement, further analysis will be done, to ensure which design and material is the best in term of percentage and economically. For Design 2, the length of support structure for 0.22 m is not applicable as this will result to zero support structure. Therefore the reading of displacement for Design 2 is started at length of 0.33 m. From the graph, it also shows that as the amount of support structure increases, the displacement of the side wall decreases. This shows the amount of support structure gives and impact to the displacement of the side wall. Percentage of effectiveness of each design were calculated and tabulated in Table 4.10

Table 4.10: Percentage of effectiveness of support structure

Length of support structure,m	Percentage of effectiveness, %					
	Ghazavi Design		Design 1		Design 2	
	Grade 20	Grade30	Grade 20	Grade30	Grade 20	Grade30
0.22	48.22	52.09	56.09	59.37	-	-
0.33	68.12	70.50	73.05	75.07	63.47	66.19
0.44	78.63	80.23	81.73	83.09	76.99	78.71

The table above showed the percentage of effectiveness of the support structure of each design. The percentage of effectiveness will be used to determine the design selection for the support structure. The designs with the percentage of effectiveness more than 80% are chosen. Therefore three designs were being selected. First is Design 1 with grade 30 concrete with 0.44 m length of support structure with value of 83.09%. Next is Design 1 with grade 20 concrete with 0.44 m length support structure with value of 81.73% and finally is Ghazavi Design with grade 30 concrete also with 0.44 m length support structure with value of 80.23%. Other design give a percentage lower than 80%, therefore it was not chosen

Table 4.11: Volume of structure

Length of support structure, m	Volume of structure,m^3					
	Ghazavi Design		Design 1		Design 2	
	Grade 20	Grade30	Grade 20	Grade30	Grade 20	Grade30
0.22	44.38	44.38	46.56	46.56	-	-
0.33	46.92	46.92	48.99	48.99	44.38	44.38
0.44	49.46	49.46	51.41	51.41	46.92	46.92

Table 4.11 shows the volume of the support structure of each design. This table also showed the volume of the three designs that being selected. From the selected design, Ghazavi Design with 0.44 m length of support structure using grade 30 concrete shows the minimum volume of structure compared to the other two. Meanwhile, Design 1 with 0.44 m length of support structure using grade 20 & 30 concrete shows the same volume of structure which is the highest value compared to others. This is because the only things that change are the grade of the concrete used.

Table 4.12: Cost of material

Length of support structure, m	**Cost of material, RM**					
	Ghazavi Design		**Design 1**		**Design 2**	
	Grade 20	**Grade30**	**Grade 20**	**Grade30**	**Grade 20**	**Grade30**
0.22	8,370.07	9,165.80	8,781.21	9,616.03	-	-
0.33	8,849.11	9,690.38	9,239.51	10,117.90	8,370.068	9,165.80
0.44	9,328.16	10,214.97	9,695.92	10,617.70	8,849.112	9,690.38

The volumes of structures obtain from Table 4.17 then were used to calculate the cost of material for each design selected. The cost of material is obtained from the CIDB material list provided by the CIDB Malaysia. The price of grade 20 concrete is RM188.60/m^3 and for grade 30 concrete, the price is RM206.53/m^3 In term of cost, among the three designs selected, Design 1 with 0.44 m length of support structure using grade 20 concrete shows the lowest cost with value of RM9,695.92. Meanwhile for the other two designs, Ghazavi Design and Design 1 with 0.44m length of support structure using grade 30 concrete each shows value of RM10,214.97 and RM10,617.70. Therefore, for the parameter of length of the support structure, Design 1 with 0.44m length of support structure using grade 20 concrete is being selected.

4.6.4 Design Selection

For the design selection for each parameter stated, Design 1 with 0.5m breadth of support structure, twenty-one support structure and 0.44 m length of support structure using Ready Mix Concrete-Normal Mix-Grade 20 Granite is the design selected. Therefore it is selected as the design of a support structure for the open channel flow flume. This design had met the requirement for percentage of effectiveness of the support structure and has the minimum value for cost.

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

5.1 INTRODUCTION

Generally, this chapter conclude the study. Besides that, the objective of the study is also being reviewed in this chapter either it is achieved. The recommendation of this study, limitation are also been discussed in this chapter.

5.2 CONCLUSION

Based on the study, the following remarks are drawn:

1. The pressure at the sidewall of the flume are:
   i) Theoretical value : 55,215 Pa
   ii) Simulation value : 59,680 Pa

2. Three design for the support structure of the flume are proposed, there are;
   i) Ghazavi Design
   ii) Design 1
   iii) Design 2

3. The highest displacement of the flume occur at the top of the sidewall for displacement for Ready Mix Concrete-Normal Mix-Grade 20 Granite is 6.23483 mm and for Ready Mix Concrete-Normal Mix-Grade 30 Granite is 4.49268 mm

As a conclusion Design 1 with the breadth of 0.5 m, length of 0.44 m with twenty-one amount of the support structure by using Ready Mix Concrete-Normal Mix-Grade 20 Granite was selected as it gave desirable result with the acceptable cost involves, effectiveness of the support structure and economically.

5.3 RECOMMENDATIONS

For the improvement of study, there are several matter can be done:

i) Using variety of material in the simulation such as fiberglass, and acrylic that are light and easy to handle

ii) The scale of the flume should be scale down for a lab scale test, then using the lab scale flume, the result of experiment and simulation could be compared.

iii) Other shape of support structure could be proposed to determine better support structure for the flume.

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APPENDIX A

FORMULA AND CALCULATION

Volume of water, m^3 = l x h x w

= length x height x width

= 30m x 1.5m x 2m

=$90m^3$

Static Pressure,Pa (at bottom of the channel) =ρgh

= density x gravity x height

= $1000kg/m^3$ x $9.81m/s^2$ x 1.5m

= 14.715 KPa

Dynamic Pressure,Pa = ½ ρv^2

= ½ x density x $velocity^2$

= ½ x $1000kg/m^3$ x $(9m/s^2)^2$

= 40,500 Pa

= 40.5 kPa

Area (sidewall) m^2 = l x w

= length x width

= 30m x 1.5m

= $45m^2$

Total Pressure = Static Pressure + Dynamic Pressure

= 14.715 kPa + 40.5k Pa

= 55.215 kPa

Percentage of effectiveness = $\frac{\text{(old value-new value)}}{\text{old value}}\ X\ 100\%$

These theoretical value, will be used in the simulation and to compare the result with the simulation value that will be obtain through the flow simulation

APPENDIX B

RESULT FOR SIMULATION AUTODESK SIMULATION MULTIPHYSCS

Breadth,m

Ghazavi Design

Grade 20	Grade 30

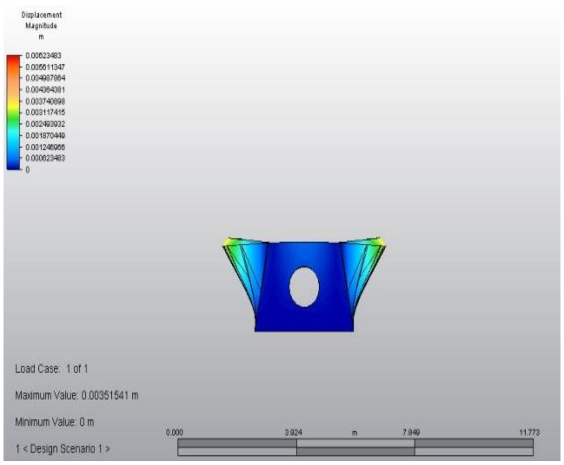

Figure A-1: 0.1m

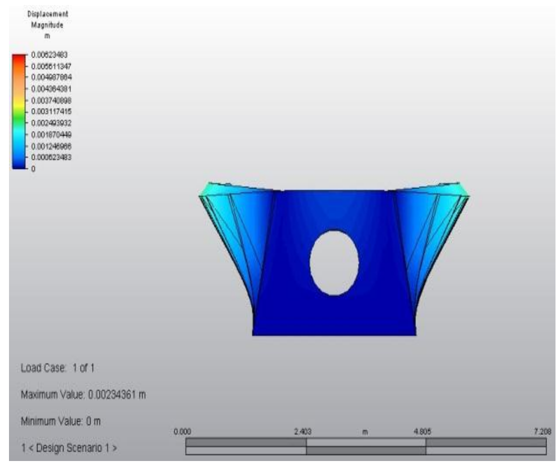

Figure A-2: 0.1m

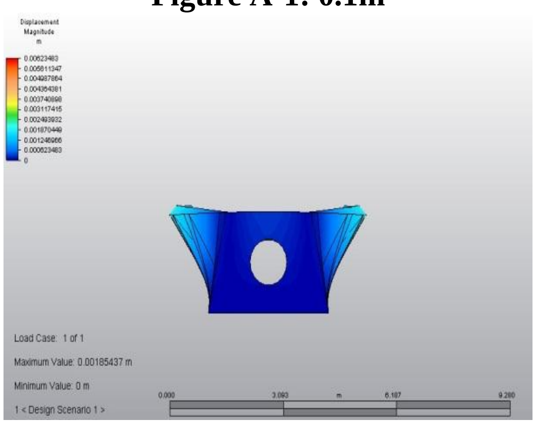

Figure A-3: 0.5m

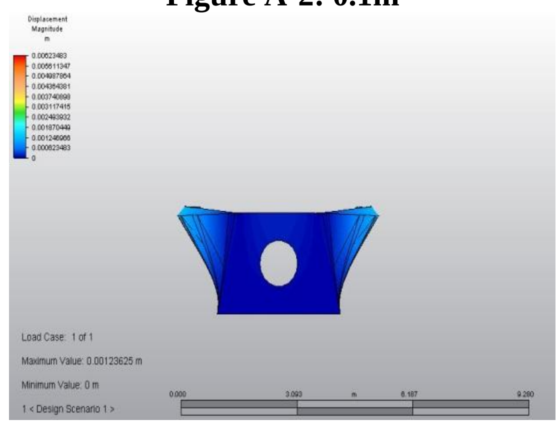

Figure A-4: 0.3m

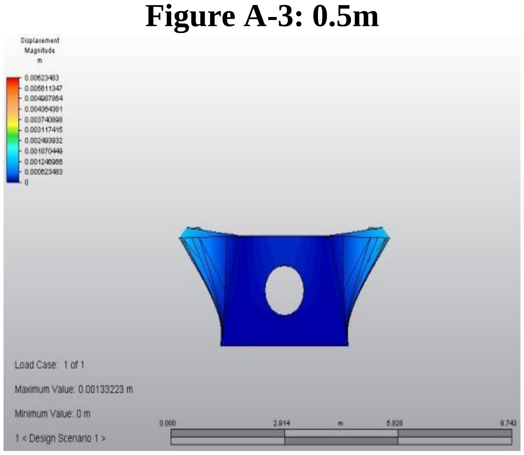

Figure A-5: 0.5m

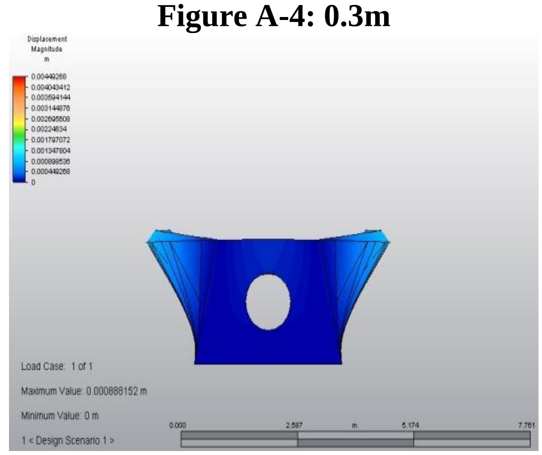

Figure A-6: 0.5m

RESULT FOR SIMULATION AUTODESK SIMULATION MULTIPHYSCS

Breadth,m	
Design 1	
Grade 20	Grade 30

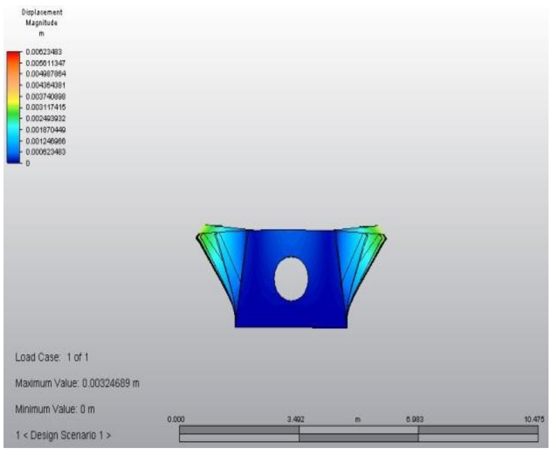

Figure A-7: 0.1m

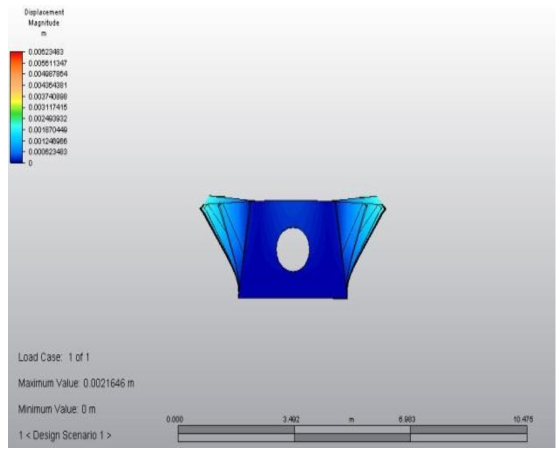

Figure A-8: 0.1m

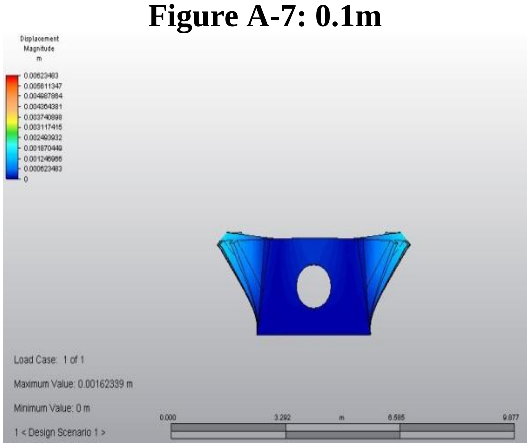

Figure A-9: 0.5m

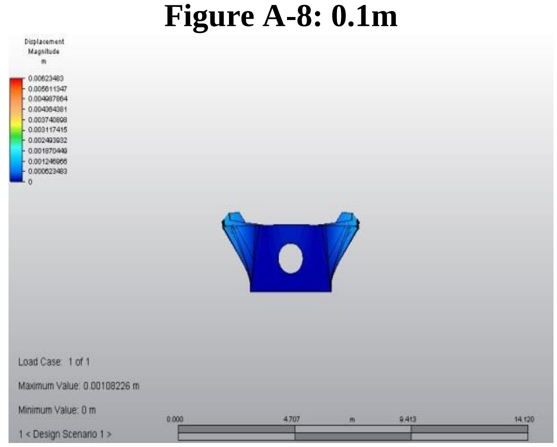

Figure A-10: 0.3m

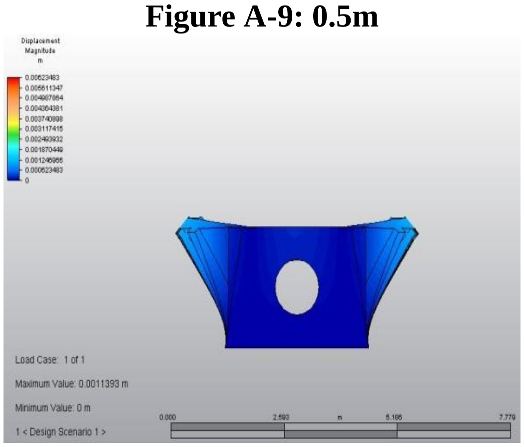

Figure A-11: 0.5m

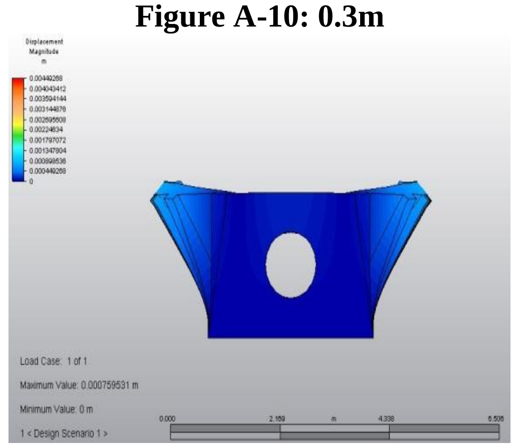

Figure A-12: 0.5m

RESULT FOR SIMULATION AUTODESK SIMULATION MULTIPHYSCS

Breadth,m

Design 2

Grade 20	Grade 30

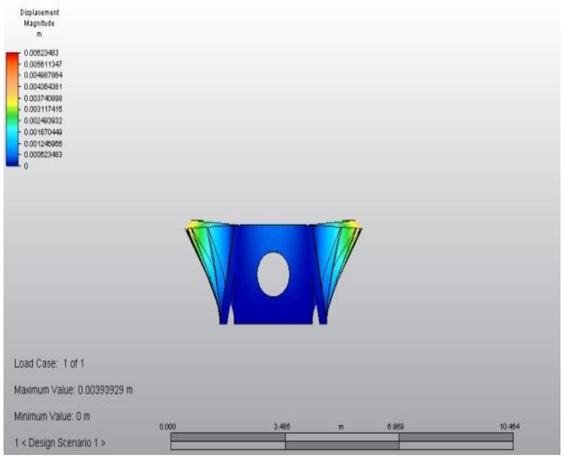

Figure A-13: 0.1m

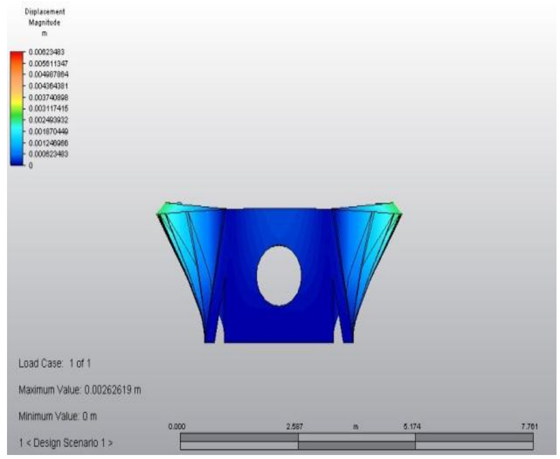

Figure A-14: 0.1m

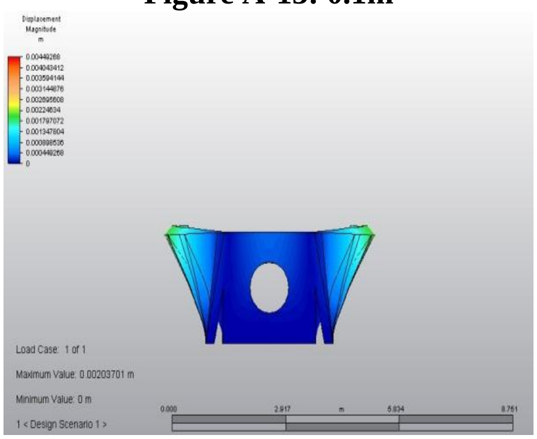

Figure A-15: 0.5m

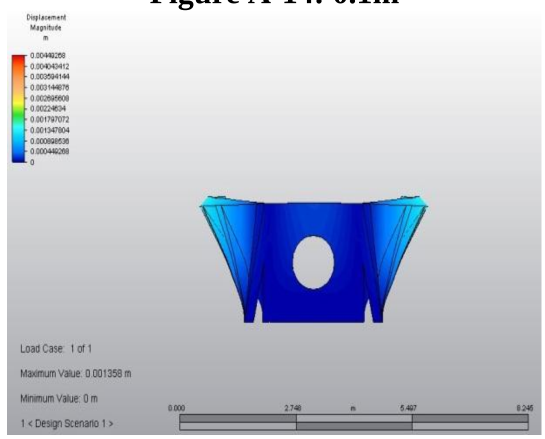

Figure A-16: 0.3m

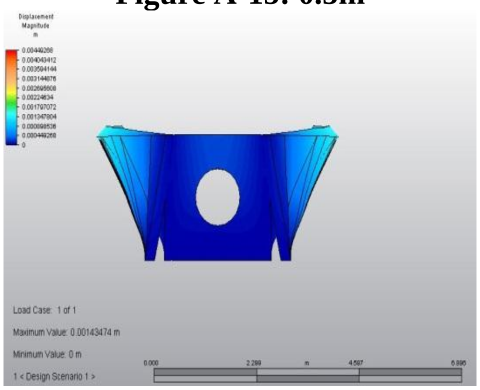

Figure A-17: 0.5m

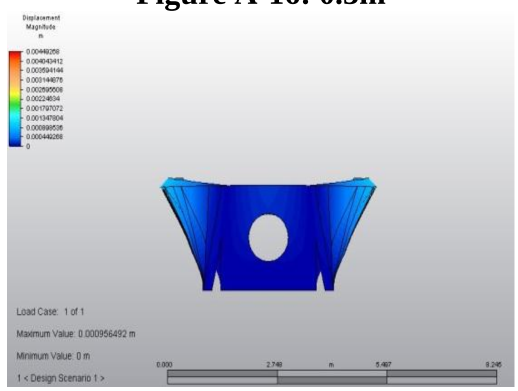

Figure A-18: 0.5m

RESULT FOR SIMULATION AUTODESK SIMULATION MULTIPHYSCS

Amount of support structure, n

Ghazavi Design

Grade 20 | Grade 30

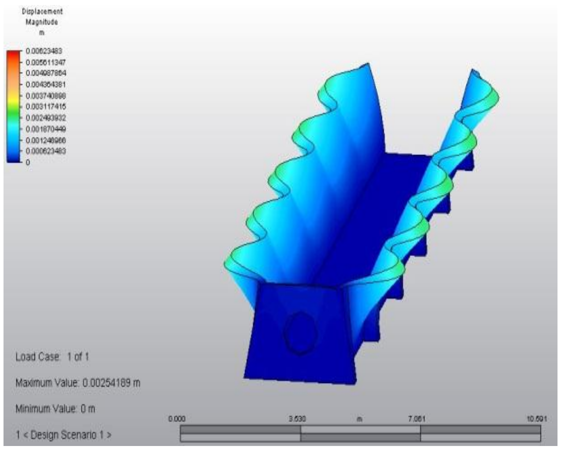

Figure A-19: 6

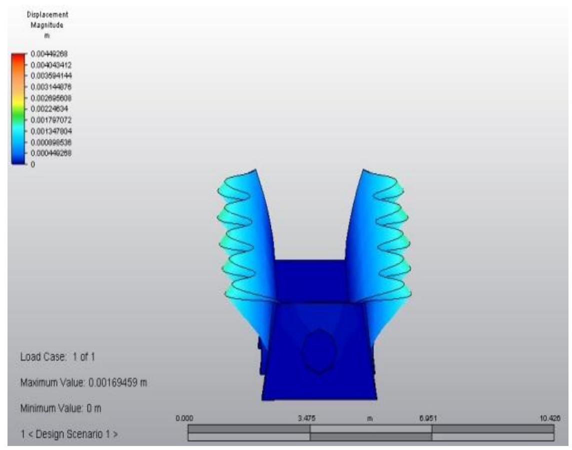

Figure A-20: 6

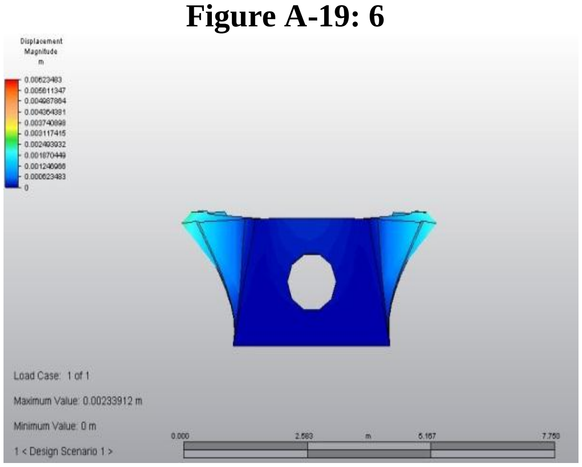

Figure A-21: 11

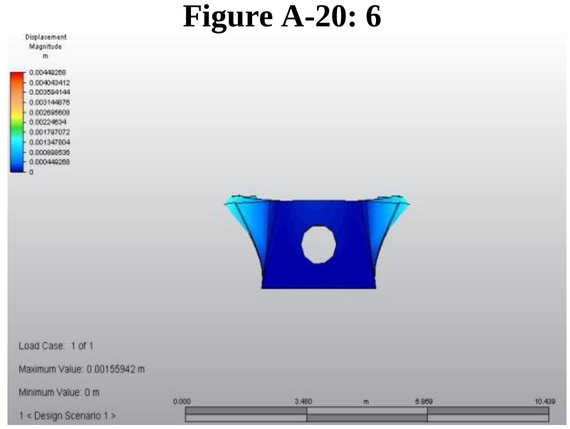

Figure A-22: 11

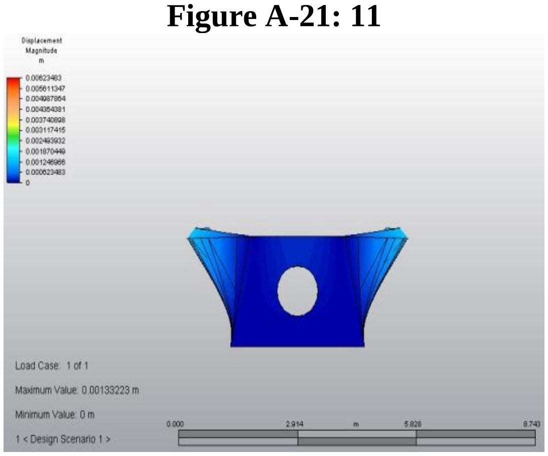

Figure A-23: 21

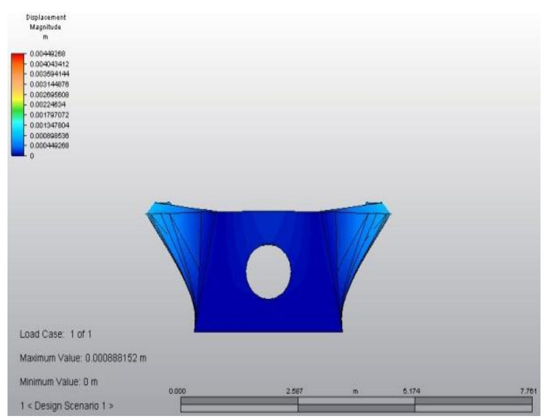

Figure A-24: 21

RESULT FOR SIMULATION AUTODESK SIMULATION MULTIPHYSCS

Amount of support structure, n

Design 1

Grade 20 | Grade 30

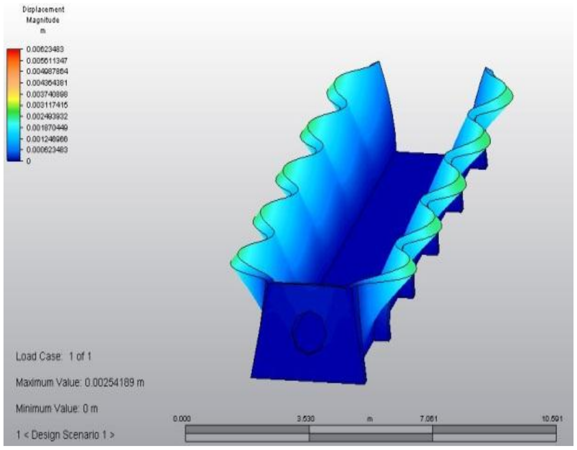

Figure A-25: 6

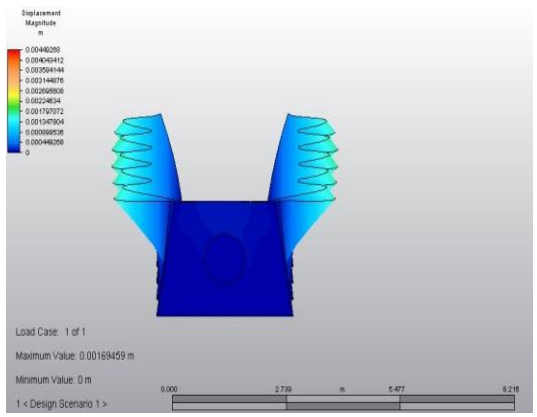

Figure A-26: 6

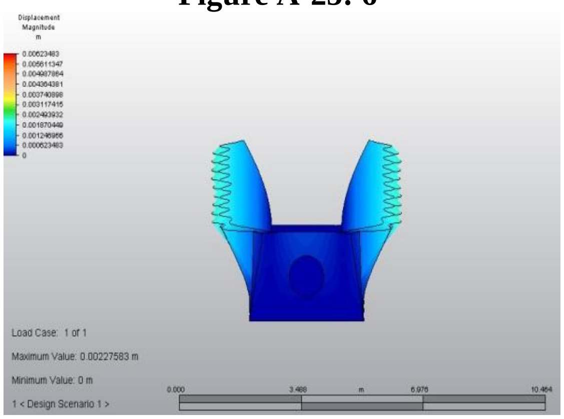

Figure A-27: 11

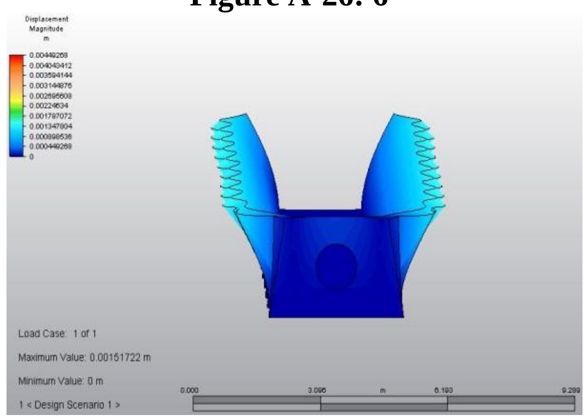

Figure A-28: 11

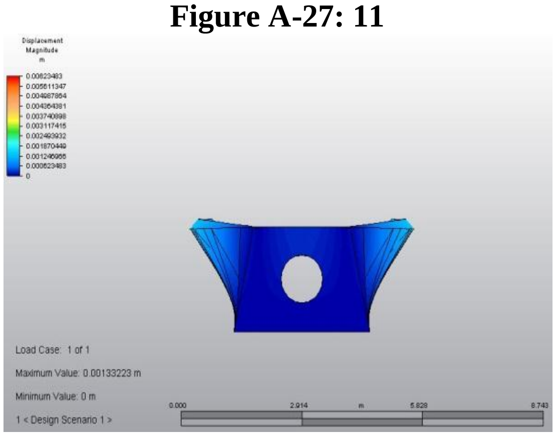

Figure A-29: 21

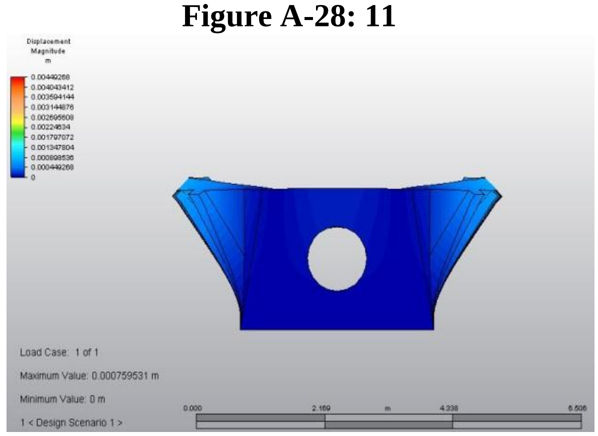

Figure A-30: 21

RESULT FOR SIMULATION AUTODESK SIMULATION MULTIPHYSCS

Amount of support structure, n

Design 2

Grade 20	Grade 30

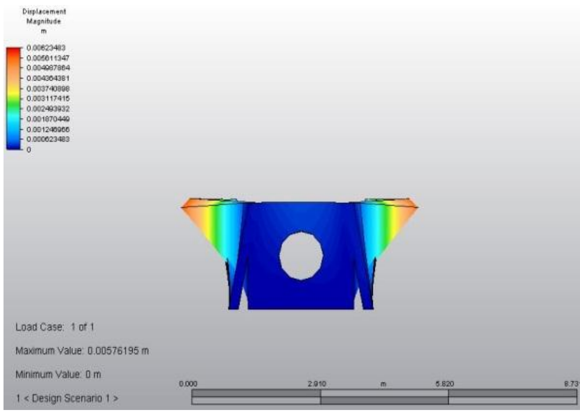

Figure A-31: 6

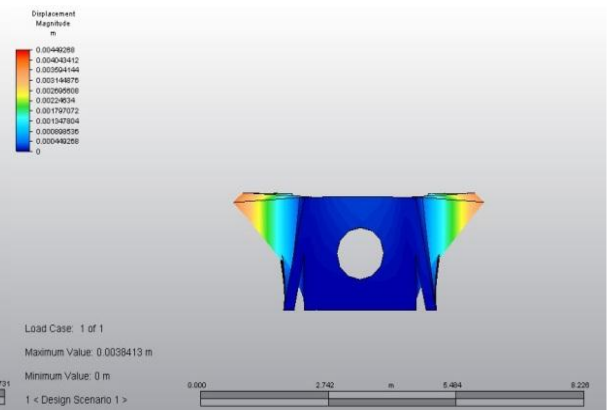

Figure A-32: 6

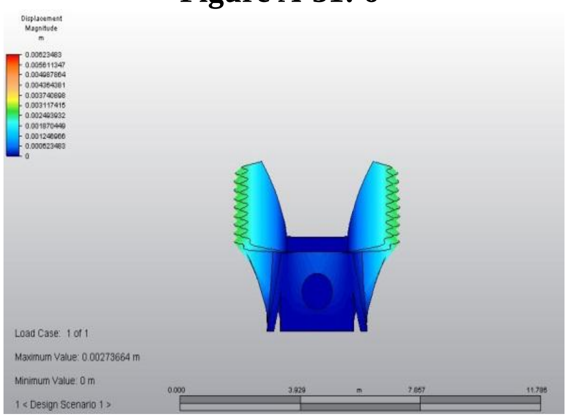

Figure A-33: 11

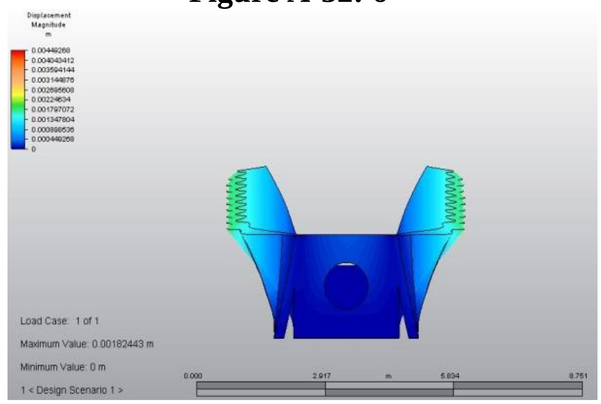

Figure A-34: 11

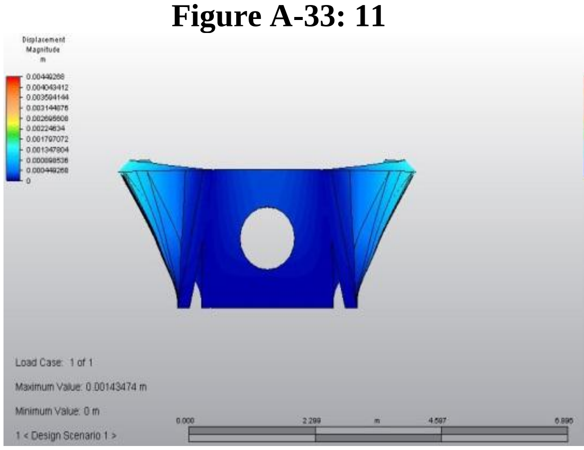

Figure A-35: 21

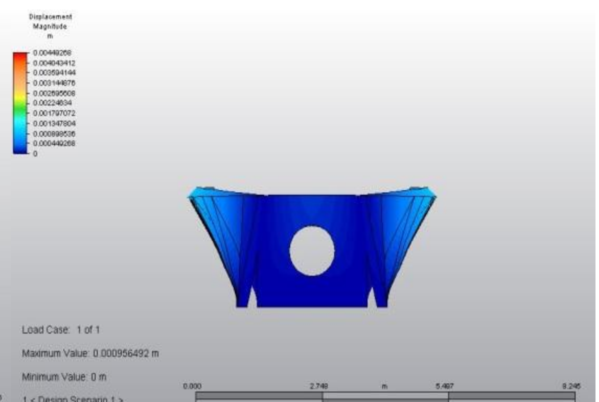

Figure A-36: 21

RESULT FOR SIMULATION AUTODESK SIMULATION MULTIPHYSCS

Length of support structure, m

Ghazavi Design

Grade 20 | Grade 30

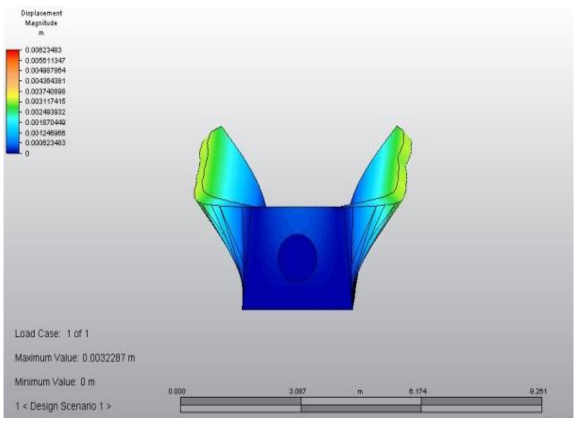

Figure A-37: 0.22m

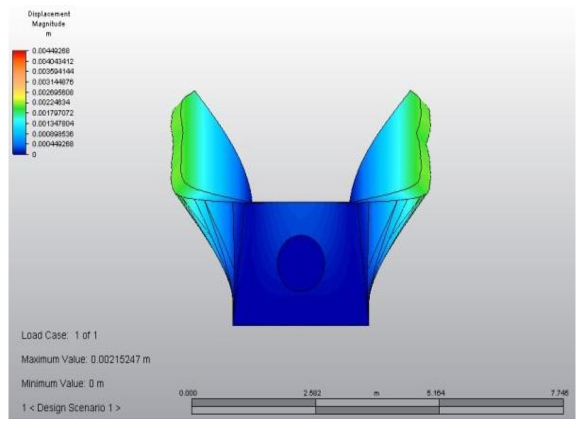

Figure A-38: 0.22m

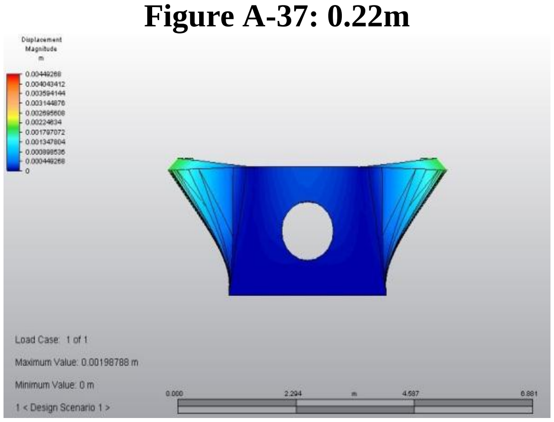

Figure A-39: 0.33m

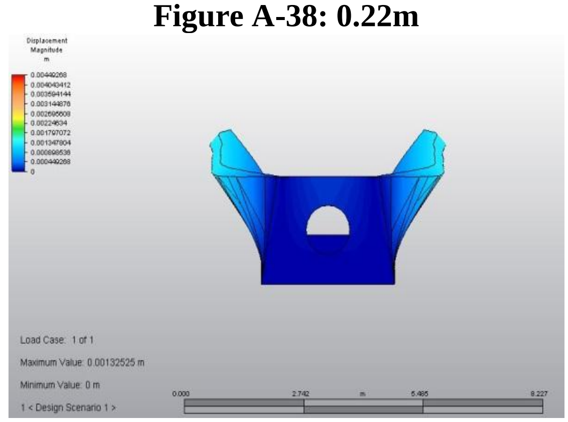

Figure A-40: 0.33m

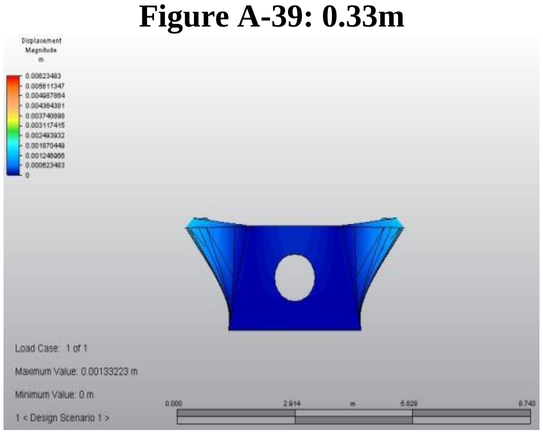

Figure A-41: 0.44m

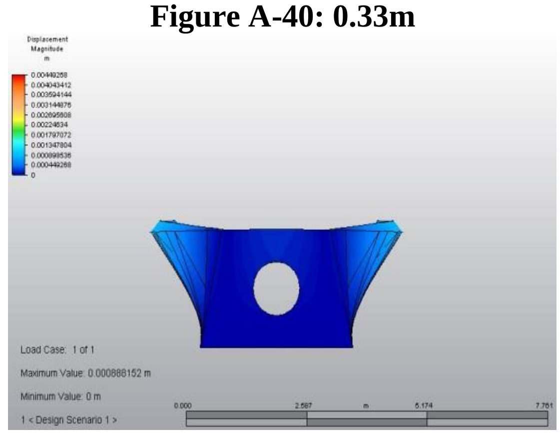

Figure A-42: 0.44m

RESULT FOR SIMULATION AUTODESK SIMULATION MULTIPHYSCS

Length of support structure, m	
Design 1	
Grade 20	Grade 30

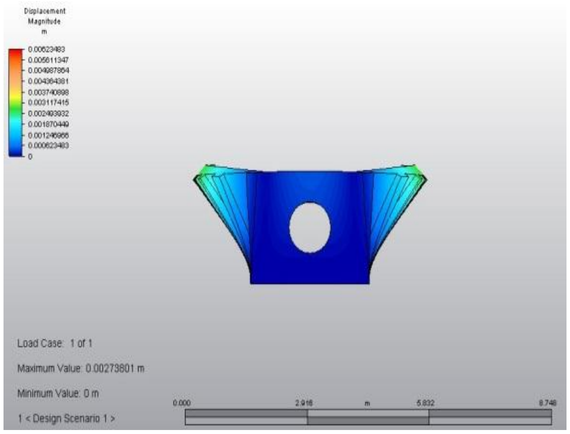

Figure A-43: 0.22m

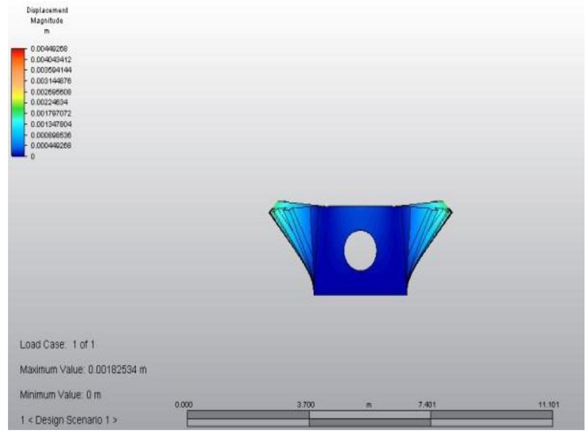

Figure A-44: 0.22m

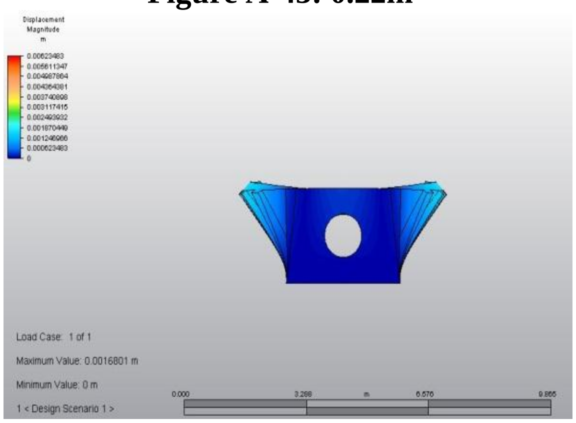

Figure A-45: 0.33m

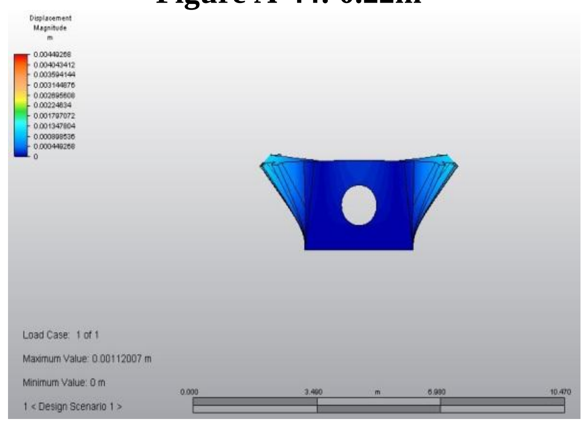

Figure A-46: 0.33m

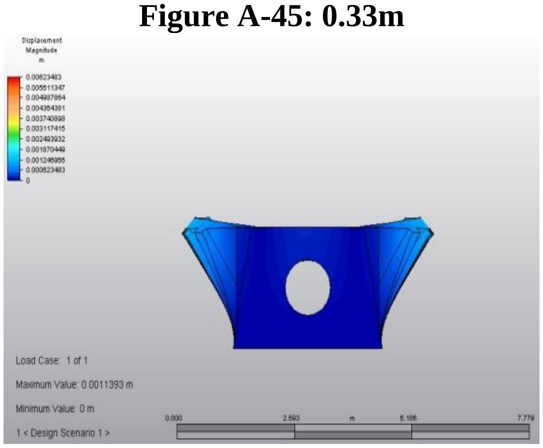

Figure A-47: 0.44m

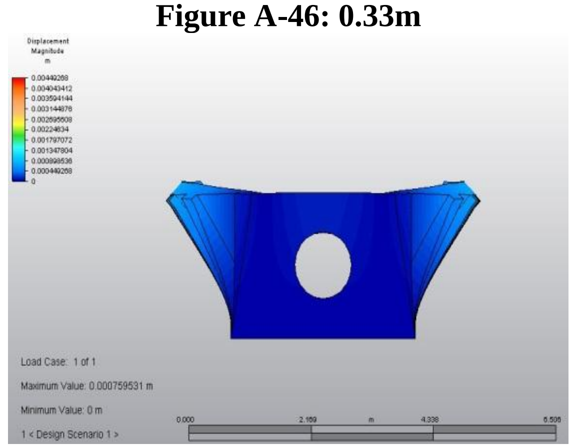

Figure A-48: 0.44m

RESULT FOR SIMULATION AUTODESK SIMULATION MULTIPHYSCS

Length of support structure, m

Design 2

Grade 20	Grade 30

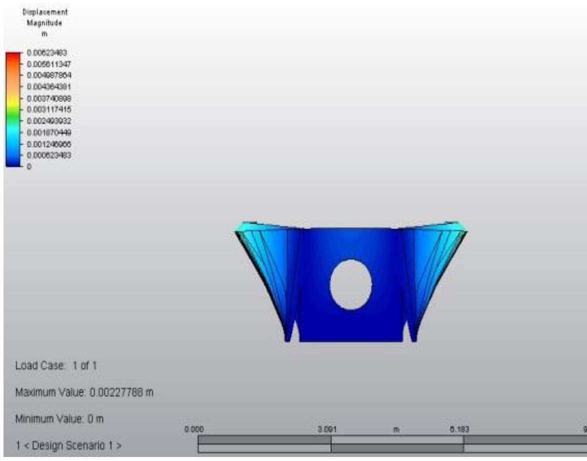

Figure A-49: 0.33m

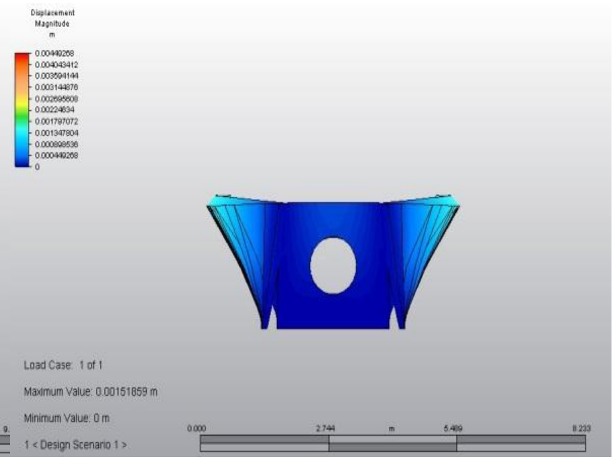

Figure A-50: 0.33m

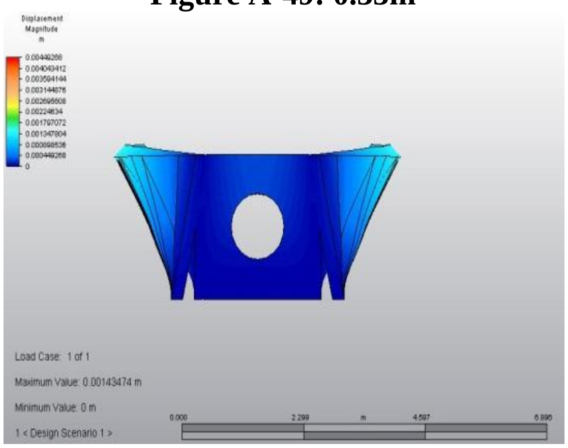

Figure A-51: 0.44m

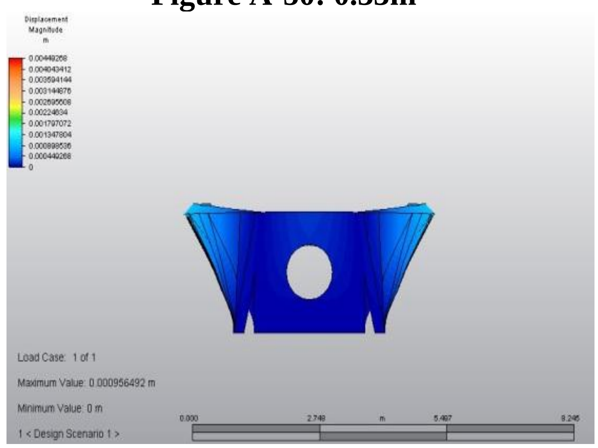

Figure A-52: 0.44m