MAKERERE UNIVERSITY

COLLEGE OF ENGINEERING ART DESIGN AND TECHNOLOGY

DEPARTMENT OF MECHANICAL ENGINEERING

DESIGN OF DEMOUNTABLE FLOOD BARRIER

Name: Nsamba Taufeeq

Student No.:214000192

Registration No: 14/U/983

Sign:..

Date:..

Lead Supervisor:

Name: Dr Norbert Mukasa

Sign:....................................

Date:....................................

Co-Supervisor:

Name: Dr Hillary Kasedde

Sign:...................................

Date:....................................

Declaration

I **NSAMBA TAUFEEQ** declare that this report is a result of my own work. It is the summation of research and ultimate design of a demountable flood barrier. The activities, the methods and the computer code are hereby free to be used for academic and commercial purpose by whosoever chooses.

The Author:

Name: Nsamba Taufeeq Sign:....................................

Date: ....

ACKNOWLEDGEMENT

The success of this project is attributed to the extensive support and great assistance from my main project supervisor Dr. Norbert Mukasa and my co-supervisor Dr. Hillary Kasedde for their helpful guidance, suggestions and encouragement throughout this project. I am also grateful to Engineer Moses Matovu for his valuable and helpful guidance. This study could not have been successfully done without his useful comments.

Special thanks go to the members of the FreeCAD forum, especially Mr Yorik for his help with the FreeCAD python scriptingmodules.

I would like to thank members of Julia community for creating and maintaining in my opinion the most revolutionary technical computing programming language to date.

I would also like to thank my teachers, friends and the staff of the Mechanical and Civil EngineeringDepartments of Makerere University for all their support.   Finally, I am extremely grateful to my family for all the support provided.

Contents

Declaration ii

ACKNOWLEDGEMENT iii

List of figures vii

List of tables: viii

ABSTRACT ix

CHAPTER ONE:INTRODUCTION 1

1.1 BACKGROUND 1

1.2 Problem Statement: 2

1.3 SCOPE OF THIS PROJECT. 2

1.4 JUSTIFICATION. 2

1.5 CASE STUDY 3

1.6 OBJECTIVES 3

1.6.1 Main objective 3

1.6.2 Specific Objectives: 3

CHAPTER TWO: LITERATURE REVIEW 4

2.1 |Introduction 4

NOTE: 4

2.2 The Thames Barrier. 4

2.3 The Eastern Scheldt Barrier. 5

2.4 The Maeslantkering 6

2.5 Passive flood barriers. 7

2.6 Flood walls and leeves. 7

2.6.0 Floodwalls 8

CHAPTER THREE : METHODOLOGY. 11

3.1 Identification of flood prone areas. 11

3.2 Identification of technologies. 11

3.3 Design of the flood barrier. 11

3.3.1 Field Investigation for the proposed flood barrier. 11

3.3.2 Flood Barrier design. 12

3.3.3 Floodwall Design (Selection and Sizing) 13

3.3 Floodwall joints and seal design 14

3.4 Floodwall span and supports. 14

3.5 Structural analysis and Testing. 14
3.6 Computer Code and data. 14
Chapter 4: Design of the barrier 15
4.1.0 Flood Risk Assessment 15
4.2.0 Floodwall Design 18
4.2.1 Floodwall Selection and Sizing 18
Sliding 18
Overturning 19
Excessive Soil Pressure 19
4.3.0 Design of anchor bolt and base plate 29
4.3.1 Design procedure of mechanical anchor bolts 29
4.4.0 Design of the Floodwall span: 34
4.5.0 Design of the supports of the wall span/plate 35
4.7.0 Design of the gaskets: 36
4.7.1 Design of seal bolts: 37
4.8.0 Site Drainage: 38
CHAPTER 5: DISCUSSION OF RESULTS 43
5.1 Results from running code: 43
5.2 Loading on base / foundation statically 44
5.2.1 Deformed Mesh 45
5.2.2 Static case solution Von misses Stress 45
5.2.3 Translational displacement Vector 46
5.3 Static loading supports. 46
5.3.1 Deformation of supports 47
5.3.2 Von Mises stress on the supports. 48
5.3.3 Translational displacement Vector of supports. 48
5.4 Cost: 49
Chapter 6: Conclusions and Recommendations. 50
6.1 Conclusions 50
6.1.1 Choice of case study. 50
6.1.2 Choice of guidelines: 50
6.1.3 Choice of floodwall: 50
6.1.4 Choice of Design Programming languages: 50
6.2 Limitations: 51

6.3 Recommendations. 51
6.3.1 Flood detection. 51
6.3.2 Channels and drainage: 51
6.3.3 Geotechnical study. 51
6.3.4 Field Tests 51
6.3.5 Ease of design program use: 51
Bibliography 52
APPENDIX 53
Appendix I:Tables used by the programs: 53
Bolt Tables: 53
Seal bolt data: 54
Wall Span data: 54
Appendix II:Computer programs: 54
Batch file(barrier.bat): 54
Main program (Barrier1.jl): 55
Module for formulae (formulas.jl) 57
Module for supports (support.jl) 58
Wall design Module (wall.jl): 59
Floodwall base module (design.jl): 60
Bolts design module: 62
Seal design module: 65
Barrier CAD design program (barrier.py): 66

List of figures

FIGURE 1-THAMES BARRIER....4
FIGURE 2-EASTERN SHELDT BARRIER....5
FIGURE 3-MAESLANTKERING....6
FIGURE 4-GRAVITY FLOODWALL....8
FIGURE 5-GRAVITY AND CANTILEVER FLOODWALL....9
FIGURE 6-FLOODWALL DESIGN FLOW CHART....13
FIGURE 7-ILLUSTRATION OF WALL FAILURE BY SLIDING....18
FIGURE 8-ILLUSTRATION OF WALL FAILURE BY OVERTURNING....19
FIGURE 9-ILLUSTRATION OF SETTLEMENT FROM EXCESS SOIL PRESSURE....19
FIGURE 10-FORCE DIAGRAM OF GENERIC FLOODWALL DESIGN....20
FIGURE 11-SUMP PUMP DESIGN PROCEDURE....40
FIGURE 12-ASSEMBLY OF STRUCTURE....42
FIGURE 13-FRONT OF ASSEMBLY....42
FIGURE 14-LOADS ON FOUNDATION....44
FIGURE 15-DEFORMED MESH....45
FIGURE 16-VON MISES STRESS ON FOUNDATION....45
FIGURE 17-TRANSLATIONAL DISPLACEMENT VECTOR OF BASE....46
FIGURE 18-LOADING SUPPORTS STATICALLY....46
FIGURE 19-DEFORMATION OF SUPPORTS....47
FIGURE 20-VON MISES STRESS ON SUPPORTS....48
FIGURE 21-TRANSLATIONAL DISPLACEMENT VECTOR ON SUPPORTS....48
FIGURE 22-BARRIER BATCH FILE....54
FIGURE 23-MAIN SCRIPT(BARRIER1.JL) I....55
FIGURE 24-MAIN SCRIPT (BARRIER.JL) PAGE 2....56
FIGURE 25-FORMULAS MODULE (FORMULAS.JL)....57
FIGURE 26-SUPPORTS MODULE (SUPPORTS.JL)....58
FIGURE 27-WALL DESIGN MODULE....59
FIGURE 28- FOUNDATION DESIGN MODULE I....60
FIGURE 29-FOUNDATION DEISGN MODULE II....61
FIGURE 30-BOLT DESIGN MODULE I....62
FIGURE 31-BOLTS DESIGN MODULE II....63
FIGURE 32-BOLTS DESIGN MODULE III....64
FIGURE 33-SEAL DESIGN MODULE....65
FIGURE 34- BARRIER CAD PROGRAM I....66
FIGURE 35-BARRIER CAD PROGRAM II....67
FIGURE 36- BARRIER CAD PROGRAM III....68

List of tables:

TABLE 1-MATERIAL PROPERTIES , BASE.....44
TABLE 2-APPLIED LOAD SET FOR BASE.....44
TABLE 3-MATERIAL PROPERTIES, SUPPORTS.....47
TABLE 4-APPLIED LOAD SET ON SUPPORTS.....47
TABLE 5-UNIT COST OF FOUNDATION.....49
TABLE 6-UNIT COST OF FLOODWALL.....49
TABLE 7-UNIT COST OF MASONRY FLOODWALL.....49
TABLE 8-GENERAL BOLT PROPERTIES.....53
TABLE 9- CONCRETE CONE RESISTANCE TABLES.....53
TABLE 10-EDGE RESISTANCE TABLES.....53
TABLE 11-CONCRETE PRY OUT RESISTANCE TABLE.....53
TABLE 12-SHEAR RESISTANCE TABLES.....53
TABLE 13-TENSION RESISTANCE TABLES.....53
TABLE 14-SEAL BOLT DATA.....54
TABLE 15-WALL SPAN DATA.....54

ABSTRACT

In recent decades due to global climate change, hundred year floods have been occurring worldwide with frightening regularity. Flooding is a natural phenomenon of the environment however floods are known to be the most common natural disaster. Extreme global flooding with increased frequency affects both the developed and the developing world with catastrophic results . (A. Mugesh, 2015).

The case study was lubigi catchment in Kampala city. The catchment suffers from flooding events occurring every year and affecting a large number of the population, mainly poor and threatening their livelihood. Flood evidences are numerous in Lubigi flood plains. Different coping strategies can be seen in every corner of habited flood plain where different structural measures were adopted by the community (Habonimana, 2014).

There have also been various attempts (Dr. Richard Sliuzus, 2013) by the government to mitigate flooding at these sites in spite of which there still exists flooding in lubigi floodplains. Consequently, Lubigi floodplains were used as the case study of this project.

A demountable movable community flood barrier system consisting of an assembly of components/pieces that are detachable to allow transportation and quick installation in flood prone area during flood season was therefore designed as a means to mitigate this flooding problem. The nature of this system is such that it allows limited access to the channel when deployed and may require disassembly to resume full access to the channel.

The structure design procedures were used to build a computer program in Julia to implement those procedures as many were iterative. The program's results were then used by a separate computer program built in python which built CAD models that were then tested with Finite Element Analysis software in CATIA.

Using a flood height of 0.909m (3ft) that is above the flood levels range 0.6m-0.8m from (Dr. Richard Sliuzus, 2013; Habonimana, 2014),the structure was designed and subsequently tested for structural integrity or strength with CATIA Finite Element Analysis tools. The flood barrier was found to retain its structural integrity.

Keywords:

Flood protection, temporary flood protection, demountable flood protection, flood barrier, failure ,operation, flood defences.

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND

Flooding may occur as an overflow of water from water bodies, such as a river, lake or ocean, in which the water overflows, resulting in some of that water escaping its usual boundaries, or it may occur due to an accumulation of rainwater on saturated ground in a real flood.

In recent decades due to global climate change, hundred year floods have been occurring worldwide with frightening regularity. Flooding is a natural phenomenon of the environment however floods are known to be the most common natural disaster. Extreme global flooding with increased frequency affects both the developed and the developing world with catastrophic results . (A. Mugesh, 2015).

As the population of this country grows, the pressure on resources such as land may lead to further wetland reclamation and increase in magnitude of flooding as several studies (Xianghu Li, 2014) have shown, the case for flood protection cannot be more urgent.

The focus of this project is on river / water channel overflow related flooding and although the extent to which this type of flooding affects this country is unclear. There exists a slew of newspaper articles reporting destruction of homes, lives and property. As of such, this project aims to seek for an engineering solution to protect the lives and homes of people at risk of river overflow flooding.

There have been various occurrences of floods resulting from rivers bursting their banks. Three particular cases stand out as they are somewhat documented better than the rest.

In one case river Nyamambwa located in Kasese, western region of the country flooded in the year 2014.The damage from this flood according to a New Vision article resulted in 1000 displaced people.

In another case on Tuesday 12 April 2016, Heavy rainfall caused river Mubuka to overflow displacing more than 1000 people in the parishes of Kanamba and Karusandara sub-county.(According to a report by Bernard Juma on floodlist.com).

In the third case a report from Daily Monitor published on 2nd October 2007 by Fred Muzaale and others says heavy rainfall during that time caused river Sezzibwa to burst its banks destroying 60 homes built close to its banks.

The traditional approach to flood protection taken by the public as well as many flood protection professionals as in the realm of civil engineering is of permanent engineered structures such as flood walls, flood embankments and large gated barriers.Although these methods have seen adoption by the developed world, this however has not been the case for developing countries particularly in as it relates to Uganda.

There are varying reasons for which this has been the case but one of the major reasons is these projects are of such high costs and yet owing to their permanent nature have very low flexibility.This results in a need for flood protection solution that is affordable and flexible specifically in as it relates to Uganda.

It is in this line of thought that the author proposes a temporary and demountable flood protections system which simply stated is a moveable flood protection system that is fully pre-installed and requires operation during flood event or one that requires part installation into pre-installed guides or sockets with a pre-constructed foundation.

The words temporary flood protection imply that the system is a removable flood protection system, wholly installed during flood event and completely removed when levels have receded.

It should however be noted that temporary and demountable flood protection systems result in risk of operational failure. To remove this risk a decision should always be made to use a permanent system if it is technically and economically viable as well as environmentally and locally acceptable.

1.2 Problem Statement:

Traditional flood defences that are of the temporary or movable type have mostly seen adoption to protect residential areas and individual homes. This leaves the complementary type(permanent flood defences) as the only solution that has seen common adoption by countries such as the United States(The Great Wall of Louisiana),United Kingdom(The Thames barrier),Netherlands(Eastern Sheldt Storm Surge Barrier).The challenge with these technologies is in their design as permanent structures that is they cannot be moved or transported to other sites.

As floods in this country, Uganda are seasonal and that Uganda is a developing country with limited financial resources, this project aims to design a demountable flood barrier system that can be detached or disassembled when not in use to resume full access to the river and can be moved to other locations.

1.3 SCOPE OF THIS PROJECT.

The project proposed herein will not cover policy and meteorological aspects pertaining to river / channel overflow flooding in this country. However this project only aims to devise a community temporary/demountable flood barrier system that will ultimately protect communities leaving in or around river flood plains in Uganda.

1.4 JUSTIFICATION.

This project recognises that there is a flooding problem in this country and that the existing community protection defences globally are such expensive solutions that is permanent flood control structures are such expensive projects to set up and maintain though reliable.

In recognition of the seasonal nature of flooding, the project aims to propose a design of a demountable system to lower cost of maintaining. The portability of the demountable flood barrier system will ensure that fewer units of this structure will be manufactured as they will be deployable to other water channels.

1.5 CASE STUDY

The study case was lubigi catchment in Kampala city.The catchment suffers from flooding events occurring every year and affecting a large number of the population, mainly poor and threatening their livelihood. Flood evidences are numerous in Lubigi flood plains.Different coping strategies can be seen in every corner of habited flood plain where different structural measures were adopted by the community.

There have also beenvarious attempts by the government to mitigate flooding at these sites despite of which there still exists flooding in lubigi floodplains. Following this,the author proposes to use Lubigi floodplains as the case study of this project.

1.6 OBJECTIVES

1.6.1 Main objective: The main objective of this project is to design and model a temporary and demountable flood barrier system using computer software to protect communities in Uganda from river overflow flooding.

1.6.2 Specific Objectives:

- To study existing flood protection technologies.
- To identify flood prone areas along the channel.
- To design the flood barrier.
- To simulate the system.

CHAPTER TWO: LITERATURE REVIEW

2.1 |Introduction

There are a variety of technologies that have been invented and used to control and prevent flooding.Some of which have been devised to protect entire comunities from flooding,others done to protect individual homes and residential areas.The following is a review of existing technologies,their strengths,their weaknesses and what this technology this project proposes to improve.

NOTE:

Although some or many of the technologies discussed in this section are used to protect coastal societies,the author sees it relevant as they could still be applied to river overflow scenarios.

First we begin this with the technologies used to protect communities.

2.2 The Thames Barrier.

The Thames Barrier is a unique flood control structure on the River Thames at Woolwich Reach in East London.It is 520 metres wide and protects London against storm surges and rainfall swelling.

Figure 1-Thames Barrier

Photo- 1-Courtesy of Cater News Agency

The barrier currently protects 125sq Km of London including an estimated 1.25 million people,250,000 GBP worth of property and infratructure,a large propotion of the London tube network and many historic bulding,power supplies,hospitals and schools.It took 8 years to build the structure,costing 535million GBP of that tme and became fully operational in 1982.

2.2.1 Operation

The barrier is a series of 10 separate movable steel gates,standing 20 metres tall and strecthing 520 metres across the river.

Each of the main gates is a hollow steel-platted structure over 20m high and weighng 3700 tonnes capable of withstanding an overall load of more than 9000 tonnes of water.

When the barrier is closed, a solid steel wall sealing the upper part of the rver from the sea is created , stopping water from flowing upstream towards the capital.The gates can also be part closed in the underspill position,allowing a controlled amount of water to pass under the gate and up the river.
Individual gates can be closed in ten minutes but the whole barrier takes around one hour and a half to close completely.
The barrier is only reopened once the water level upstream of the barrier matches water level downstream.When not in use,the gates rest out of sight in curved recessed concrete cils in the riverbed which allows river traffic to pass through.

2.3 The Eastern Scheldt Barrier.

Figure 2-Eastern Sheldt Barrier.

2.3.1 Operation

The dam is manually operated but if human control fails, an electronic security system acts as a backup. A Dutch law regulates the conditions under which the dam is allowed to close. The water levels must be at least three meters above regular sea level before the doors can be completely shut. Each sluice gate is closed once a month for testing. Emergency procedures are tested on pre-scheduled dates. Once the test is passed, the shutters are quickly opened again to create a minimum amount of effect on tidal movements

And the local marine ecosystem. It takes approximately one hour to close a door. The cost of operation is €17 million per year.

The full dam has been closed twenty-five times since 1986, due to water levels exceeding or being predicted to exceed the three meters. The last time was on 21 October 2014.

2.4 The Maeslantkering

The Maeslantkering is a storm surge barrier on the NieuweWaterweg, Netherlandswhich is controlled by a supercomputer and closes if the city of Rotterdam is threatened by floods.

Figure 3-Maeslantkering

2.4.1 Operation

The barrier is connected to a computer system which is linked to weather and sea level data. Under normal weather conditions the two doors themselves are well protected in their dry docks and a 360-metre wide gap in the waterway gives ships enough space to pass without any inconvenience. But when a storm surge of 3 metres above normal sea level is anticipated in Rotterdam, the barrier will be closed automatically. Four hours before the actual closing procedure begins, incoming and outgoing ships are warned. Two hours before closing the traffic at the NieuweWaterweg comes to a standstill. Thirty minutes before closing the dry docks that contain the gates are flooded. After this, the gates start to float and two so-called "loco mobiles" move the gates towards each other. When the gap between the gates is about 1.5 metre-wide, water is let inside the hollows of the gates, so that they submerge to the bottom of the waterway. The bottom has been elaborately dug and then laid with layers of broken stone, so that the gates are able to form a relatively watertight fit when submerged. In cases where the gates have to be shut for a prolonged period, which would cause the waters of the Rhine to rise behind them, the gate hollows are partly emptied and floated, so that excess river water runs out to sea, before they are submerged again. The decision-making algorithm that sequences storm surge-triggered events in the Maeslantkering is run entirely by computer.

2.5 Passive flood barriers.

Passive barriers will operate automatically in a flood or storm event, requiring no humanintervention or electricity. In its guidance for floodproofing non-residential buildings, FEMA recommends passive intervention whenever possible1. A passive barrier can be permanently fixed, such as a floodwall or levee, or a barrier that activates during a flood. Barriers that self-activate are generally used in tandem with permanent floodwalls or other barriers, and deploy to protect entryways or other openings behind the barrier. Typically, self-activating barriers use water pressure or action to deploy. (ABC- A Better City, 2015)

2.6 Flood walls and leeves.

A properly designed and constructed floodwall or levee can often be an effective device for repelling floodwaters. Both floodwalls and levees provide barriers against inundation, protect buildings from un-equalized hydrostatic and hydrodynamic loading situations, and in some cases may deflect floodborne debris away from buildings. However, floodwalls and levees differ in their design, construction, site characteristics, and application.

Floodwalls are structures constructed of manmade materials such as concrete or masonry. The selection of a floodwall design is primarily dependent on the type of flooding expected at the building’s site. High water levels and velocities can exert hydrodynamic and hydrostatic forces and impact loads, which must be accounted for in the floodwall design. The composition of any type of floodwall must address three broad concerns:

- Overall stability of the wall as related to the external loads;
- Sufficient strength as related to the calculated internal stresses; and
- Ability to provide effective enclosures to repel floodwaters.

These internal and external forces pose a significant safety hazard if floodwalls are not properly designed and constructed, or their design level of protection is overtopped. Additionally, a tall floodwall can become very expensive to construct and maintain, and can require additional land area for grading and drainage. Therefore, in most instances, residential floodwalls are practical only up to a height of 3 to 4 feet above.

2.6.0 Floodwalls

A floodwall is a free standing,permanent engineered structured structure designed to prevent encroachment of floodwaters.Floodwalls are typically constructed of reinforced concrete or masonry,provide a barrier against inundation, protect structures from hydrostatic and hydrodynamic loads, and may deflect flood borne debris away from the structure.

Types of Floodwalls

There are two basic types of flood wall:

Those that also form part of the river frontage,such as wharf, retaining wall,or quay.

Those that are remote from the river, generally with the sole purpose of providing a flood defence.

2.6.1 Gravity Floodwall

A gravity wall consists of mass concrete generally without reinforcement. It is proportioned so that the resultant of the forces acting on any internal plane through the wall falls within, or close to the kern of the section.A small tensile stress capacity is permissible for localised stresses due to extreme and temporary loading conditions. (Engineers, 1989)

As its name implies, a gravity floodwall depends upon its weight for stability. The gravity wall's structural stability is attained by effective positioning of the mass of the wall, rather than the weight of the retained materials. The gravity wall resists overturning primarily by the dead weight of the concrete and masonry construction. It is simply too heavy to be overturned by the lateral flood load. (fema.gov; Agency, 2012)

Frictional forces between the concrete base and the soil foundation generally resist sliding of the gravity wall. Soil foundation stability is achieved by ensuring that the structure neither moves nor fails along possible failure surfaces. Gravity walls are appropriate for low walls or lightly loaded walls. They are relatively easy to design and construct. The primary disadvantage of a gravity floodwall is that a large volume of material is required. As the required height of a gravity floodwall increases, it becomes more cost-effective to use a cantilever wall. (fema.gov; Agency, 2012)

Figure 4-Gravity Floodwall

2.6.2 Cantilever Floodwall

A cantilever wall is a reinforced-concrete wall (cast-in-place or built with concrete block) that utilizes cantilever action to retain the mass behind the wall. Reinforcement of the wall is attained by steel bars embedded within the concrete or block core of the wall . Stability of this type of wall is partially achieved from the weight of the soil on the heel portion of the base, as illustrated in Figure-2.

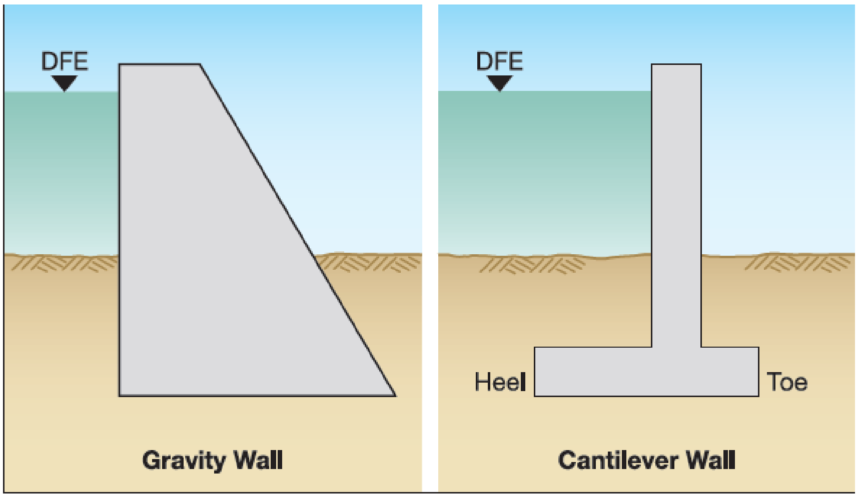

Figure 5-Gravity and Cantilever floodwall

The floodwall is designed as a cantilever retaining wall, which takes into account buoyancy effects and reduced soil bearing capacity. However, other elements of a floodproofing project (i.e., bracing effects of any slab-on-grade, the crosswalks, and possible concrete stairs) may help in its stability. This results in a slightly conservative design for the floodwall, but provides a comfortable safety factor when considering the unpredictability of the flood. Backfill can be placed along the outside face of the wall to keep water away from the wall during flooding conditions. (fema.gov)

NOTE:Reinforced concrete provides an excellent barrier in resisting water seepage, since it is monolithic in nature. The reinforcement not only gives the wall its strength, but limits cracking as well.

The concrete floodwall may be aesthetically altered with a double-faced brick application on either side of the monolithic cast-in-place reinforced concrete centre. This reinforced concrete core is the principal structural element of the wall that resists the lateral hydrostatic pressures and transfers the overturning moment to the footing. The brick-faced wall is typically used on homes with brick facades. Thus, the floodwall becomes an attractive modification to the home. In terms of the structure, the brick is considered in the overall weight and stability of the wall and in the computation of the soil pressure at the base of the footing, but is not considered to add flexural strength to the floodwall.

When the flood protection elevation requirements of a gravity or cantilever wall become excessive in terms of material and cost, alternative types of floodwalls can be examined. The use of these floodwall alternatives is generally determined by the relative costs of construction and materials, and amount of reinforcement required.

2.6.3 Buttressed Floodwall

A buttressed wall is very similar to a counterfort wall. The only difference between the two is that the transverse support walls are located on the side of the stem, opposite the retained materials. (fema.gov)

2.6.4 Counterfort Floodwall

A counterfort wall is similar to a cantilever retaining wall except that it can be used where the cantilever is long or when very high pressures are exerted behind the wall. Counterforts,or intermediate traverse support bracing, are designed and built at intervals along the wall and reduce the design forces. (fema.gov)

2.6.6 Braced Sheet Pile Flood Wall.

This wall consists of a row of vertical pre-stressed concrete sheet piles, backed by batter piles connected to the sheet piles by a cast-in-place horizontal concrete beam with shear connectors as required to resist the vertical component of load in the batter pile . This type of wall has been used for coastal flood walls. It is ideal for wet areas because no excavation or dewatering is required to construct the wall. The disadvantage is that it is more indeterminate than other wall types. (Engineers, 1989)

2.6.7 Other Flood Barrier technologies.

The following is a review of patented technologies used in flood defense.

METHOD FOR THE FABRICATION OFA DAM OR BARRIER

A water dam includes a number of loading pallets arranged side-by-side and inclined outward from the water supported by supports. Membranes are placed on loading pallets and extend a distance in front of the pallets under the water. The membranes may be held down in the front edge by Stones, sandbags, etc. initially to hold the membrane in place. The supports are triangular and made of U-shaped sheet metal beams. The one on which the pallets rest grips over the adjoining legs of two loading pallets to hold these together. To the rear the support is extended Sufficient to secure that it cannot be tilted by the water. To achieve this and achieve a good grip on the ground the inclination is preferably 45, resulting in great vertical forces on the ground, a good grip on the ground. (Sten Kullberg, 2000)

CHAPTER THREE : METHODOLOGY.

Flood barrier proposed here in will be designed in the using the following methods;

3.1 Identification of flood prone areas.

To identify flood prone areas at the channel, information about previous flooding events and history will then be obtained using a combination of site visit and the ministry of Disaster Preparedness,Kampala City Council Authority,Other government publications. A flood risk analysis will be carried out following receipt of information collected above from which various parameters such as the extent or area of the flood plain, the average height of floodwaters.

3.2 Identification of technologies.

Resources used to study existing technologies included; Corporate publications,Government data,internet,research journal et cetera.

3.3 Design of the flood barrier.

The approach to flood barrier design chosen is one of the Federal Emergency Management Authority, FEMA (Agency, 2012).

3.3.1 Field Investigation for the proposed flood barrier.

Detailed information was obtained about the site and existing structures in order to make decisions and calculations concerning the design of the flood barrier. Key information that was collected included the low point elevation areas(that was mainly Bwaise),flood history , flood levels, environmental considerations and requirements by government, flood barrier regulations and community preferences.

Once the above data was collected and established,a conceptual design of the proposed flood barrier was made.

This discussion covered the following items:

- Previous floods and which areas where affected by floods.
- A plan of action as to which areas or structures can be protected by a flood wall and flood wall closures.
- Evidence of seepage/cracking in neighbouring structures' foundation walls .
- A plan of action to use the flood wall to protect these structures from hydrostatic pressures from flood water.
- The various floodwall options and conceptual designs that would provide the necessary flood protection (obtain consensus on the favoured type, size, location, and features of the floodwalls).
- A plan of action for the design activity.

3.3.2 Flood Barrier design.

General.

Retaining walls and flood walls accommodate a difference in soil or water elevation over a typically short horizontal distance. On one side of the wall, the driving side, lateral forces exceed those on the opposite; resisting side; the force difference and resulting moment are accommodated by forces and pressures developed along the base. Lateral forces may be related to gravity, water seepage, waves, wind, and earthquakes. (Engineers, 1989).

The design of floodwalls consists of the proper selection and sizing of the actual floodwall and the specification of appurtenances such as drainage systems; waterproof materials to stop seepage and leakage; and miscellaneous details to meet site and homeowner preferences for patios, steps, wall facings, and support of other overhead structures (posts and columns). The following sections describe both a detailed design and a simplified design approach.

Limit-Equilibrium Analysis.

The forces and pressures acting on a wall are in fact highly indeterminate. Static equilibrium equations are insufficient to obtain a solution for lateral forces. Additional assumptions must be incorporated in the analysis. For nonlinear materials such as soils, this is commonly and conveniently done by assuming that a "limit" or failure state exists along some surface and that the shear force along the surface corresponds to the shear strength of the material. With these assumptions, equilibrium equations can be solved. Hence, this approach is commonly called "limit-equilibrium analysis." To assure that the assumed failure does not in fact occur, a factor (safety factor or strength mobilization factor) is applied to the material strength. It should be noted that this solution approach differs significantly from that commonly used for indeterminate structural analysis, where stress-strain properties and deformations are employed. This limit-equilibrium approach provides no direct information regarding deformations; it is implied that deformations are sufficient to induce to induce the failure condition. Deformations are indirectly limited to tolerable values by judicious choice of a safety factor, the failure condition. Deformations are indirectly limited to tolerable values by judicious choice of a safety factor.

3.3.3 Floodwall Design (Selection and Sizing)

The structural design of a floodwall to resist anticipated flood and flood-related forces followed the eight-step process outlined in

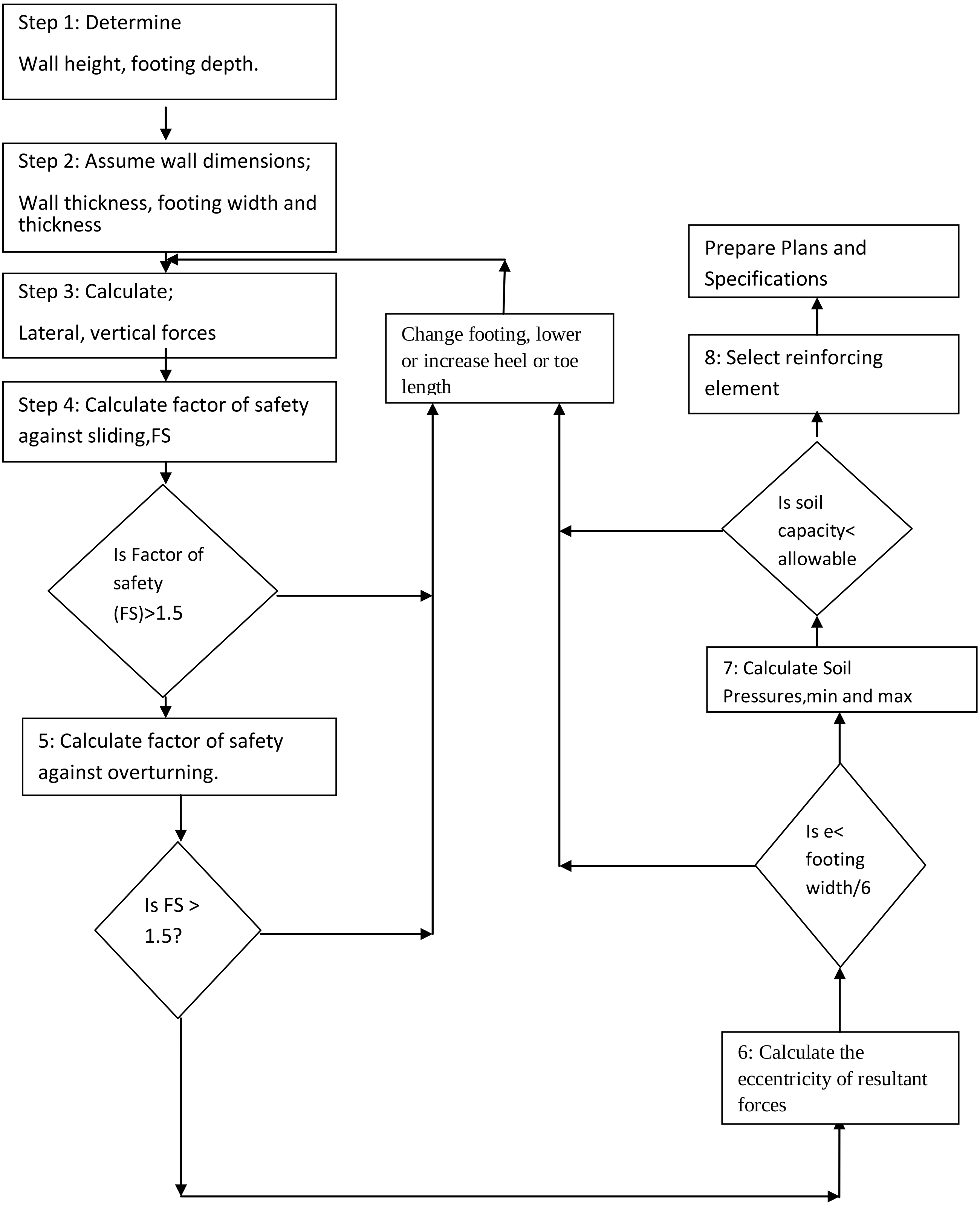

Figure 6-Floodwall design flow chart

3.3 Floodwall joints and seal design

The floodwall joints chosen were anchor bolts of the heavy expansion type and the corresponding information about how they were to be designed for was obtained from both (Chan) and (UCAN Fastening Products, 2016).

Since the procedure of bolt selection was iterative, computer programs were built in Julia to carry out the calculations and any necessary iteration.

The output of the program was the bolt selection and its parameters were written passed to the python computer program.

Seals were designed using (FSA, 2017) and (Flexitallic). The process of seal selection was not iterative but however the process of selecting the seal bolts was iterative. As of such, a computer program was built in Julia to select both the seals and the bolts necessary.

3.4 Floodwall span and supports.

The floodwall supports and span were designed using a combination of simple bending theory from (Hearn, 2000) and Roark's stress and strain Formulae (Young, 1989).

The span design was not an iterative process however it involved interpolation and multiple computations which would have raised the possibility of error if calculated by a human.

For another separate cause, since the author sought to simulate or test for multiple flood heights, it was in his best interests to automate the calculations in for these parts too.

Therefore a separate computer program was built in Julia to perform these procedures and thereby pass the resulting parameters or dimensioning to the CAD python program.

3.5 Structural analysis and Testing.

The python program was used to process the dimensioning from the Julia program upon which it built step files (An industry export format for CAD).

These files were then read by CATIA upon which finite element analysis was done.

The test case upon which the testing was done was a flood of height 3ft, the value of the height was deliberately chosen to be higher than that obtained by the research done by (Dr. Richard Sliuzus, 2013) and (Habonimana, 2014) which was between 0.6m and 0.8m in inhabited areas along the flood plain of lubigi catchment.

3.6 Computer Code and data.

All computer code that was used in the design was modularized, though the main program (barrier1.jl) has dependencies with the modules used in the design of other components of the barrier.To use the code, the author had the Julia interpreter installed as well as the necessary dependencies (the CSV Julia library and the Dataframes Library). The python program has a depency of FreeCAD that had to also be installed.The arrangement of the folders and computer code is as shown at https://github.com/TAUFEEQ1/floodwall-

Chapter 4: Design of the barrier

4.1.0 Flood Risk Assessment

The author chose to utilize the research done by Dr Richard Sliuzus et al on-Flood Risk Assessment, Strategies and Actions for Improving Flood Risk Management in Kampala (Dr. Richard Sliuzus, 2013).

The research paper details the simulation of flood scenarios and subsequent confirmations of the results obtained in two scenarios.

Scenario 0-baseline: the current baseline situation without improvement of the primary drain and a housing and road network pattern of 2010, derived from a high-resolution satellite image (0.5 m resolution). The channels are assumed to be not improved, relatively narrow and shallow, with partially blocking culverts (Dr. Richard Sliuzus, 2013).

Scenario 1-primary: the 2010 housing situation with improved primary drainage, execution of the current plan on the primary, cleaned secondary channels, wide culverts. The dimensions of the primary channel were taken as far as possible from the KDMP updated plan for Lubigi (ACE engineering, 2010). The model is tuned so that the simulated peak discharges are similar to the design discharges of this report (with channel flow resistance values and channel bed slope angle). This scenario was run a second time with non-cleaned secondary channels and partly blocked culverts, to illustrate that effect (Dr. Richard Sliuzus, 2013).

Scenario 0: baseline current situation The baseline situation (fig 3.2) shows severe flooding in many areas along the primary channel. Basically all areas west of Gayaza road are flooded on both sides of the primary channel, and a narrow area along the channel east of Gayaza road. Also North along the Gayaza road there is flooding, where secondary drains connect, but this area is not densely inhabited and poses less of a problem. The main problem areas are Bwaise III and Makerere III

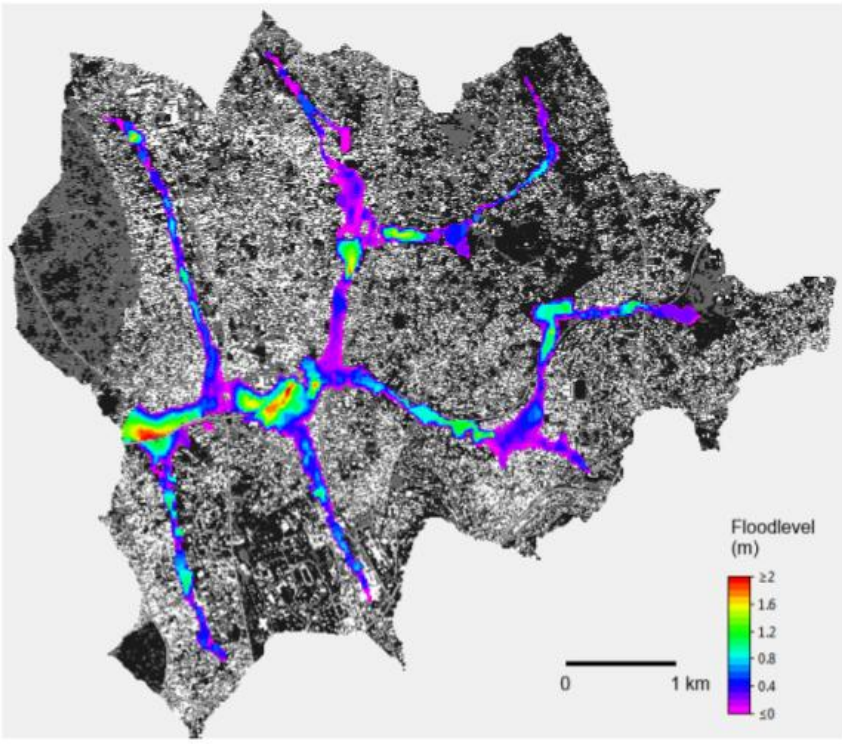

Figure 3.2. Baseline scenario results. Flood depth (in m) of the upper Lubigi catchment of a 1:10 year 100mm rainstorm without improvement of the drainage channels. The maps show areas deeper than 5 cm. The background is the 2010 1m resolution classified satellite image. The central area is shown enlarged below.

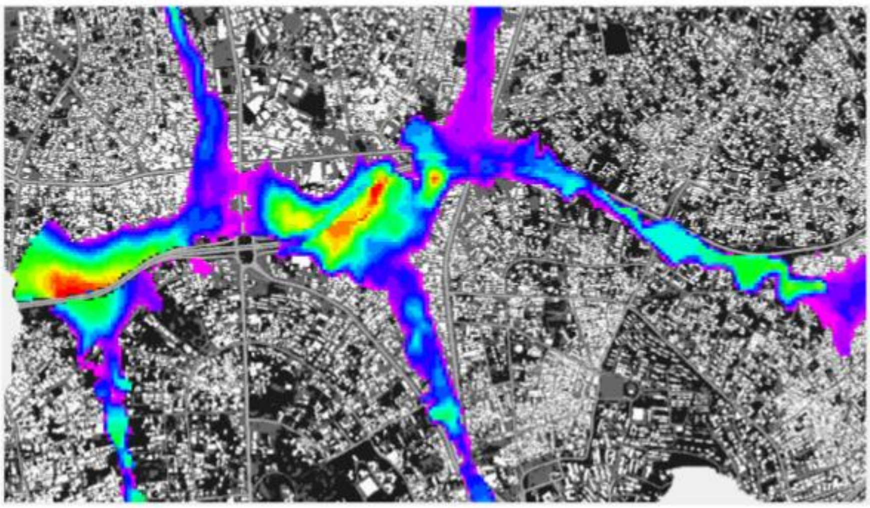

Figure 3.3 Enlargement of flood depth in the central area for enhanced detail. Legend as fig 3.2 above.

30

The most affected areas stay inundated for more than 12 hours. These are the southern half of Bwaise III, and the northern part of Kalerwe (Makerere III), as well as the area in between along the primary drain (fig 3.3). The deepest parts of the valley remain inundated for more than 20 hours (fig 3.4). Along the secondary drains the terrain is steeper and the flood duration is 4 to 5 hours. This is mainly caused by the terrain: the central valley is simply very flat and flow velocities are very low, while infiltration into the heavy clay soil is very slow. Most of the flood water has receded in less than 16 hours, bu

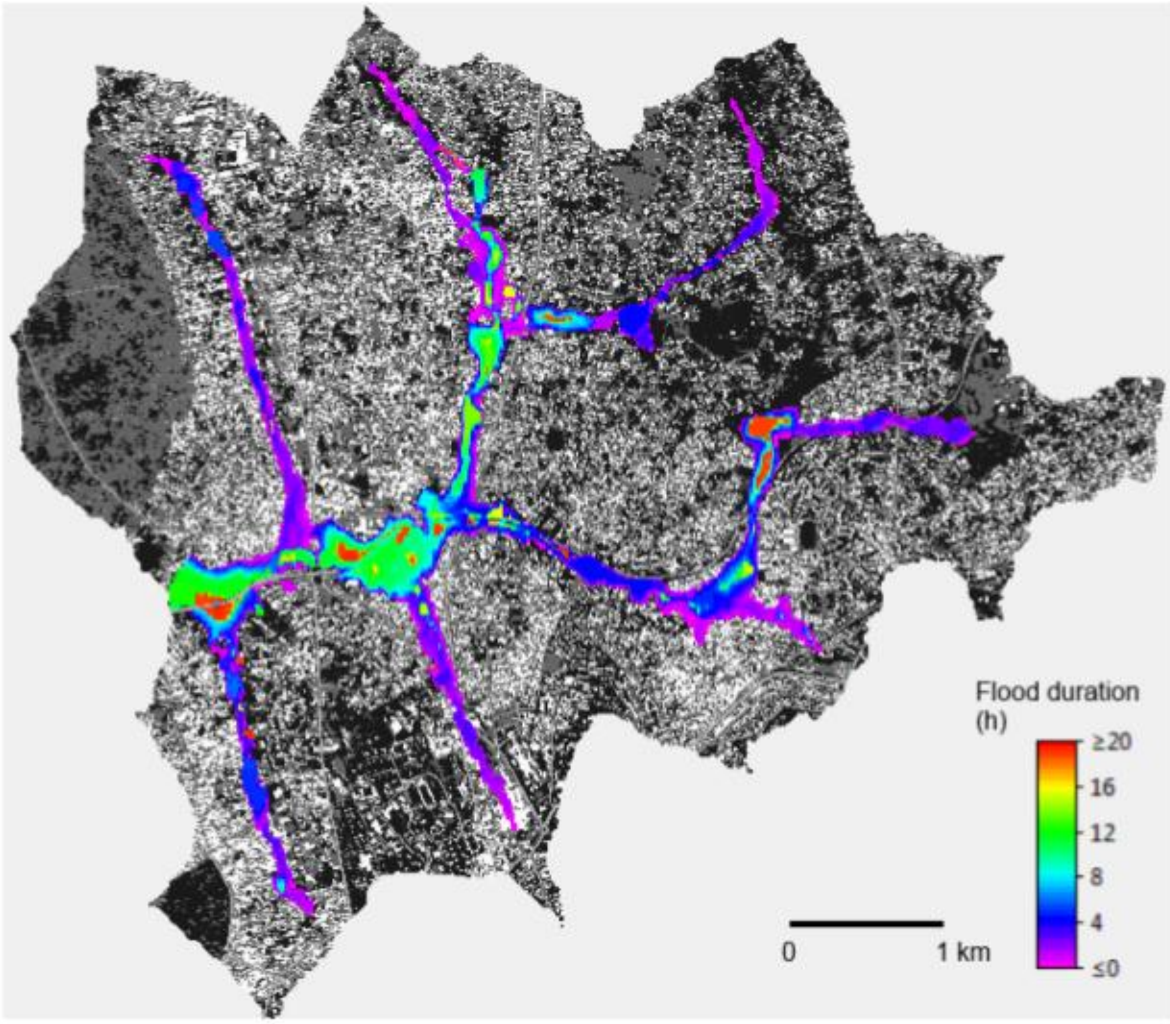

Figure 3.2. Baseline scenario results. Flood duration (in hours) of the upper Lubigi catchment "assuming relatively clean culverts". In reality the flood may last longer. The maps show areas deeper than 5 cm.

Scenario 1: Improved baseline conditions (primary improved, secondary cleaned) Improvement of the primary drainage system with its intended dimensions and large culverts, results in fewer flooded areas, certainly along the primary drain (see fig 3.5). The only really deep flooded area is south of the Northern Bypass, and a flatter area in the North East of the catchment where two secondary drains flow together. These areas are relatively uninhabited and cause fewer problems. All areas around the secondary drains remain flooded, but to a lower water depth in general because the water is evacuated from the catchment faster. The two hotspots in the unmitigated situation, Bwaise III and Kalerwe are less flooded.

Nevertheless, flooding still remains as the amount of water arriving from upstream is still large and this will not be drained rapidly because of the flat terrain. Improvement of culverts in the secondary channels has a clearly an effect, but this also delivers water more rapidly because of the flat ground.

In conclusion since scenario 0 has more floods with heights all the way to just over 2m the chosen design heights will use heights between 1m to just over 3m as the base line flood heights.

4.2.0 Floodwall Design

The design of floodwalls consists of the proper selection and sizing of the actual floodwall and the specification of appurtenances such as drainage systems; waterproof materials to stop seepage and leakage. A flood wall is a retaining wall and as of such, design considerations across the globe are very much more similar than different. As per the proposal, the author chose the guidelines set by the Federal Emergency Management Agency in the FEMA P-259 (Agency, 2012).

The following sections describe both a detailed design and a simplified design approach as derived from the above source.

4.2.1 Floodwall Selection and Sizing

The structural design of a floodwall to resist anticipated flood and flood-related forces follows the eight-step process outlined in the project proposal**Invalid source specified.**. The stability of the floodwall was investigated for different modes of failure which included the following;

Sliding: A wall, including its footing, may fail by sliding if the sum of the lateral forces acting upon it is greater than the total forces resisting the displacement. The resisting forces should always be greater than the sliding forces by a factor of safety of 1.5 (Agency, 2012).

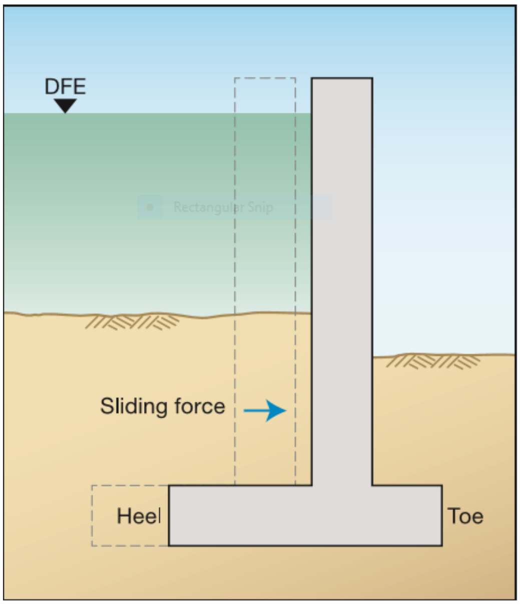

Figure 7-Illustration of wall failure by sliding

Overturning: Another mode of failure is overturning about the foundation toe. This type of failure may occur if the sum of the overturning moments is greater than the sum of the resisting moments about the toe. The sum of resisting moments should be greater than the sum of the overturning moments by a factor of safety of 1.5 (Agency, 2012).

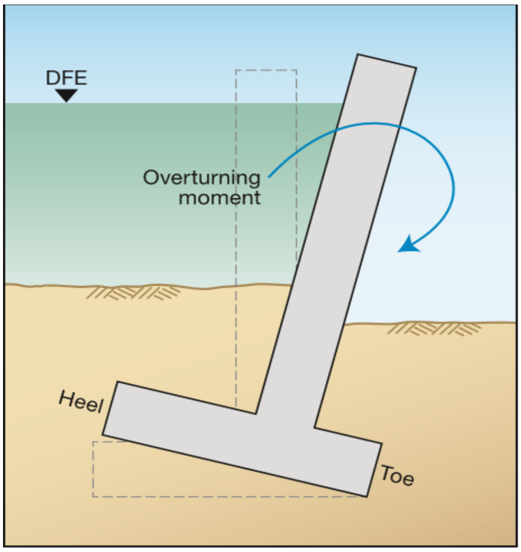

Figure 8-Illustration of wall failure by overturning

Excessive Soil Pressure: Finally, a wall may fail if the pressure under its footing exceeds the allowable soil bearing capacity as will be discussed in the following sections.

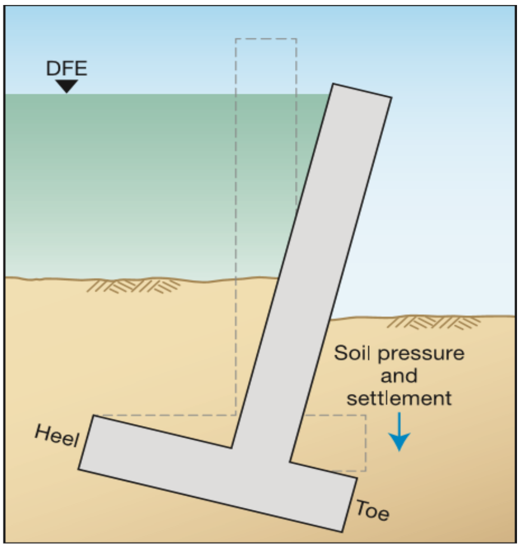

Figure 9-Illustration of settlement from excess soil pressure

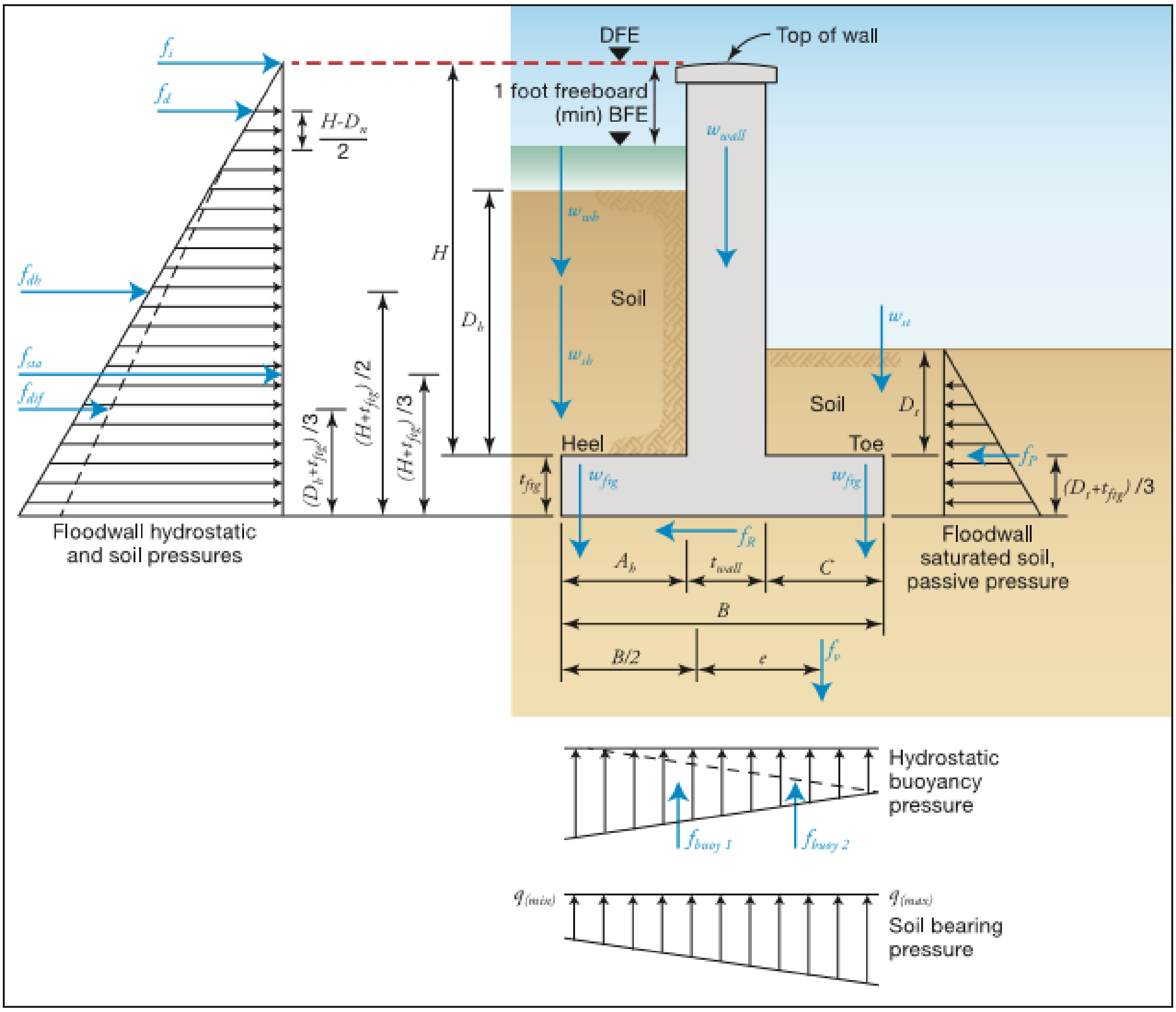

Figure 10-Force Diagram of generic floodwall design

Step 1: Determining wall height and footing depth.

- Determining wall height based on the DFE or BFE plus 1 foot of freeboard, whichever is greater was done using the studies (Habonimana, 2014) and (Dr. Richard Sliuzus, 2013) which showed that the heights were between 0.6m and 0.8m.
- Determine minimum footing depth based on the frost depth, local code requirements, and the soil conditions. The footing was to rest on suitable natural soil or on controlled and engineered backfill material.
  - Given that in Uganda we experience no frost conditions, and that the proposed structure is demountable, the author thought it best the minimum footing depth be set to zero.

Step 2: Assume dimensions.

❖ Based on the following guidelines or reference to engineering handbooks, dimensions for the wall thickness, footing width, and footing thickness were assumed.

- The choice of wall thickness depends on the wall material, the strength of the material, and the height of the wall. Typical wall thicknesses are 8, 12, and 16 inches for masonry, concrete, or masonry/ concrete walls. Wall thickness in this particular project was dependent on the design flood elevation and those design decisions were to be made by the design engineer.
- The footing width depends on the magnitude of the lateral forces, allowable soil bearing capacity, dead load, and the wall height. The typical footing width is the proposed wall height. Typically, the footing is located under the wall in such a manner that 1/3 of its width forms the toe and 2/3 of the width forms the heel. This was used by the author.

Step 3: Calculate Forces.

There are two types of forces acting on the wall and its footing: lateral and vertical.

Lateral forces: These forces are mainly the hydrostatic and differential soil/water forces on the heel side of the wall, and the saturated soil force on the toe side of the wall. Hydrostatic and soil forces.

- Hydrostatic forces: The basic equation for analyzing the lateral force due to hydrostatic pressure from standing water above the surface of the ground is illustrated in Equation 1.

  $f_{st} = \frac{1}{4}PH = \frac{1}{4}\gamma H^2$ …………………………………………… Equation 1.

  Where

  F_{st} = Lateral hydrostatic force in Ib/1ft.

  H = flood proofing design depth.

  P = hydrostatic pressure due to standing water at a depth of H (lb/ft^2), (P = ɣH).

  ɣ = specific weight of water (62.4 lb/ft^3 for fresh water and 64.0 lb/ft^3 for saltwater).

  Owing to the nature of the proposed structure, the force experienced was multiplied by the span length so as to establish the force experienced by the support in Ib.

$$F_{st} = f_{st} * len$$

  Where F_{st} is the new lateral hydrostatic force and len is the span length.

  The span length was to be determined by considering the span resistance to bending to be done separately.

  Note: The structure proposed only experiences one lateral force that is the lateral hydrostatic force since the author proposed that there be no soil depth over the foot.

Vertical forces: The vertical forces are buoyancy and the various weights of the wall, footing, soil, and water acting upward and downward on the floodwall. The buoyancy force, fbuoy, acting at the bottom of the footing is computed as follows:

$$f_{buoy} = f_{buoy\,1} + f_{buoy\,2}$$

with fbuoy1 and fbuoy2 computed as follows:

$$f_{buoy\,2} = \left(base_{lengt\,h}\right) * \text{ɣ}\left[\left(C + \frac{1}{2}t_{wall}\right)\left(t_{fg}\right)\right]$$

$f_{buoy\,1} = \gamma * H$*(0.5twall)+((Ah+(0.5twall)(tfg))

where:

fbuoy = total force due to buoyancy (lb)

fbuoy1 = buoyancy force due to hydrostatic pressure at the floodwall heel acting at an approximate distance of B/3 from the heel (lb)

fbuoy2 = buoyancy force due to hydrostatic pressure at the floodwall toe, acting at an approximate distance of B/3 from the toe (lb)

w = specific weight of water (62.4 lb/ft3 for fresh water and 64.0 lb/ft3 for saltwater)

Ah = width of the footing above the heel (ft) C = width of the footing above the toe (ft)

H = floodproofing design depth(ft)

tfg = thickness of the floodwall footing (ft)

twall = thickness of the floodwall (ft)

The gravity forces acting downward are:

The unit weight of floodwall (wwall).

$$W_{wall} = (H)t_{wall}\,S_g * (wall_{widt\,h})$$

where:

Wwall = weight of the wall (lb)

H = floodproofing design depth (ft)

twall = wall thickness (ft)

Sg = unit weight of wall material S (lb/ft3)

The unit weight of the footing (wftg)

$$W_{fg} = \left(base_{lengt\,h}\right) * Bt_{fg}S_{fg}$$

where:

wfg = weight of the footing (lb)

B = width of the footing (ft)

tfg = footing thickness (ft)

Sfg = unit weight of wall material (concrete is 150 lb/ft3)

and the unit weight of the water above the heel (wwh):-

$$w_{sh} = \left(base_{lengt\ h}\right) * A_h(H)(ɣ)$$

where:

wwh = weight of the water above the heel (lb)

Ah = width of the footing heel (ft)

H = floodproofing design depth (ft)

ɣ = specific weight of water (62.4 lb/ft3 for fresh water and 64.0 lb/ft3 for saltwater).

The total gravity forces acting downward, w_G, in pounds per linear foot can be computed as the sum of the individual gravity forces computed above.

$$w_G = w_{wall} + w_{fg} + w_{wh}$$

wG = total gravity forces acting downward (lb)

wwall = weight of wall (lb)

wftg = weight of footing (lb)

wwh = weight of water above the heel (lb).

$$f_v = w_G - fbuoy \geq 0$$

Where;

fv = net vertical force (lb)

wG = total gravity forces acting downward (lb)

fbuoy = total force due to buoyancy (lb)

The net vertical forces in Equation 5F-14 must be greater than or equal to zero. If the value is determined to be less than zero, the designer should change the footing dimensions, then go back to Step 3 and try again.

Step 4: Calculate factor of safety against sliding.

This step involves the computation of the sliding forces, the forces resisting sliding, and the factor of safety against sliding. For a stable condition, the sum of forces resisting sliding should be larger than the sum of the sliding forces.

1) Sliding Forces: The sum of the sliding (lateral hydrostatic, hydrodynamic, and impact) forces, fcomb, is computed as follows:

$$f_{comb} = f_{st} + f_{dh} + f_i$$

Fi and Fdh are assumed to be zero as the water flows parallel to the barrier.

Fst is the hydrostatic force and acts at (H + tfg)/3

Resisting Forces: The forces resistant to sliding are the frictional force, ffr, between the bottom of the footing; the cohesion force, fc, between the footing and the soil; and the soil and the saturated soil force, fp, over the toe of the footing. These resisting forces are computed as follows:

Frictional Force: The frictional force, ffr, between the bottom of the footing and the soil is a function of net vertical force, fv, times coefficient of friction, Cf. The coefficient of friction, Cf, between the base and the soil depends on the soil properties.

$$f_{fr} = C_f f_v$$

Where;

ffr = friction force between the footing and the soil (lb)

Cf = coefficient of friction between the footing and the soil

fv = net vertical force acting on the footing

Cohesion Force: The cohesion force between the base and the soil, fc, is obtained by multiplying the width of the footing, B, by the allowable cohesion value of the soil. This allowable cohesion value is usually obtained from a geotechnical analysis of the soil. The cohesion between the footing and the soil may be destroyed or considerably reduced due to contact from water. Due to potentially high variations in the allowable cohesion value of a soil, the cohesion is usually neglected in the calculations; unless the value of cohesion is ascertained by soil tests or other means, it should be taken as zero in the calculations.

$$f_c = \left(base_{lengt\,h}\right) * C_s B$$

where:

fc = cohesion force between the base and the soil (lb)

Cs = allowable cohesion force between (lb/ft2) (usually assumed to be zero) B = width of the footing (ft)

Force due to passive soil pressure at heel:

$$f_p = \frac{(base_{lengt\,h}) * 1}{2}\left[k_p(\gamma_{soil} - \gamma_{water}) + \gamma_{water}\right] * (t_{fg})^2$$

where: fp = passive saturated soil force (lb)

γ_{soil} = unit weight of the soil (lb/ft3)

t_{fg} = thickness of the floodwall footing (ft)

k_p = passive soil pressure coefficient

γ_{water} = specific weight of water (62.4 lb/ft3 for fresh water and 64.0 lb/ft3 for saltwater).

tkey= thickness of key

Force due to passive pressure from wall span:

$$f_{wallsp} = \frac{(span_{lengt\,h}) * 1}{4}\left[k_p(\gamma_{soil} - \gamma_{water}) + \gamma_{water}\right](t_{base}^2)$$

Passive soil force from key:

$$f_{key} = \frac{(base_{lengt\,h}) * 1}{2}\left[k_p(\gamma_{soil} - \gamma_{water}) + \gamma_{water}\right](t_{base}^2)$$

The sum of the resisting forces to sliding, fR, is calculated as the sum of the individual resisting forces to sliding,

$$f_R = f_{fr} + f_c + f_p + f_{wallsp} + f_{key}$$

where:

f_R = resisting force to sliding (lb)

f_{fr} = friction force between the footing and the soil (lb)

fc = cohesion force between the base and the soil (lb)

fp = passive saturated soil force over the toe (lb)

fwallsp = passive saturated soil force from wall span under soil.

Factor of Safety Against Sliding: For the stability of the wall, the sum of resisting forces to sliding, fR, should be larger than the sum of the sliding forces, fcomb. The ratio of fR over fcomb is called the Factor of Safety against sliding, FS(SL), and is calculated as:

$$FS = \frac{f_R}{f_{comb} + f_i} \geq 1.5$$

where:

FS = factor of safety against sliding (should be greater than 1.5)

f_R = sum of the forces resisting sliding in (lb)

f_{comb} = sum of the sliding forces (cumulative lateral hydrostatic force) (lb) fi = normal impact force (lb)

for the purposes of these project fi is assumed to be zero or negligible as the water flow is parallel to the barrier.

The factor of safety against sliding in Equation 5F-14 should be at least 1.5. If the factor of safety is determined to be less than 1.5, the designer should lower the footing, increase the amount of fill over the footing, and/or change the footing dimensions, then go back to Step 3 and try again.

Step 5: Calculate factor of safety against overturning. The potential for overturning should be checked about the bottom of the toe (Figure 5F-5). For a stable condition, the sum of resisting moments, MR, should be larger than the sum of the overturning moments, MO. The ratio of MR over MO is called the Factor of Safety against overturning, FS(OT).

Overturning Moments: The overturning moments are due to hydrostatic and hydrodynamic forces, impact loads, saturated soil, and the buoyancy forces acting on the footing. The sum of the overturning moments, MO, is calculated as:

Force from key=$\frac{(bas\,e_{lengt\ h})*1}{2}\left[k_p(\gamma_{soil} - \gamma_{water}) + \gamma_{water}\right] * (t_{key}^2)$

$$M_O = f_{st}\left(\frac{H + t_{fg}}{3}\right) + f_{buoy\,1}\left(\frac{2B}{3}\right) + f_{bu\,oy\,2}\left(\frac{B}{3}\right) + f_{key}\left(\frac{2}{3}tkey\right)$$

where:

MO = sum of the overturning moments (ft-lbs).

fst = lateral hydrostatic force due to standing water (lb).

fbouy1 = buoyancy force, in lb, due to hydrostatic pressure at the floodwall heel acting at an approximate distance of B/3 from the heel.

fbouy2 = buoyancy force, in lb, due to hydrostatic pressure at the floodwall toe, acting at an approximate distance of B/3 from the toe.

B = width of the footing (ft)

H = height of the wall (ft)

tfg = thickness of the floodwall footing (ft)

Resisting Moments: The resisting moments are due to all vertical downward forces and the lateral force due to soil over the toe. The sum of resisting moments, MR, is calculated as:

$$M_R = W_{wall}\left(C + \frac{t_{wall}}{2}\right) + W_{fg}\left(\frac{B}{2}\right) + W_{wh}\left(B - \frac{A_h}{2}\right) + f_p\left(\frac{t_{fg}}{3}\right) + f_{wallsp}\left(\frac{t_{fg}}{3}\right)$$

where:

M_R = sum of the resisting moments in (ft-lbs).

W_{wall} = weight of the wall (lb).

t_{wall} = wall thickness (ft).

t_{fg} = footing thickness (ft).

w_{ftg} = weight of the footing (lb/lf)

B = width of the footing (ft)

C = width of the footing toe (ft)

Ah = width of the footing heel (ft)

w_{wh} = weight of the water above the heel (lb)

f_p = passive saturated soil force over the (lb)

Factor of Safety Against Overturning: As mentioned earlier, for a stable condition, the sum of resisting moments, MR, should be larger than the sum of the overturning moments, MO, resulting in a factor of safety greater than 1.0. However, the factor of safety against overturning, FS(OT), computed in Equation 5F-17 should not be less than 1.5. If FS(OT) is found to be less than 1.5, the designer should increase the footing dimensions, then go back to Step 3 and try again.

$$FS_{OT} = \frac{M_R}{M_O} \geq 1.5$$

Step 6: Calculate eccentricity.

The final resultant of all the forces acting on the wall and its footing is a force acting at a distance, e, from the centerline of the footing. This distance, e, is known as eccentricity. The calculation of eccentricity is important to ensure that the bottom of the footing is not in tension. The eccentricity value is also needed for the calculation of soil pressures in Step 7. The eccentricity, e, is calculated as:

$$e = \left(\frac{B}{2}\right) - \left(\frac{M_R - M_O}{f_v}\right)$$

where:

e = eccentricity (ft)

B = width of the footing (ft)

fv = net vertical force acting on the footing (lb)

MO = overturning moment (ft-lbs)

MR = resisting moment (ft-lbs)

This eccentricity, e, should be less than 1/6 of the footing width. If e is found to exceed B/6, change the footing dimensions, go back to Step 3, and try again.

Step 7: Calculate soil pressures. The soil pressures, q, are determined from the following equation.

$$q = \left(\frac{f_v}{B * \left(base_{lengt\,h}\right)}\right)\left(1 \pm \left(\frac{6e}{B}\right)\right)$$

where:

q = soil pressure created by the forces acting on the wall (lb/ft2)

fv = net vertical force acting on the footing (lb) (Eq. 5F-8) B = width of the footing (ft) e = eccentricity (ft)

The maximum value of q should not exceed the allowable soil bearing capacity. The bearing capacity of soil varies with the type of soil, moisture content, temperature, and other soil properties. The allowable values should be determined by a geotechnical engineer. Some conservative allowable bearing values for a few soil types are given in Table 5F-1. If the computed value of q is more than the allowable soil bearing value, increase the footing size, then go back to Step 3 and try again.

4.3.0 Design of anchor bolt and base plate

Anchor bolts have been extensively used over the world for connecting steel structures to concrete structures. They can be either cast-in or post-installed. However, in many cases, the concrete has already been cast and set and therefore the anchor bolts are normally post-installed.

In European countries, the European Organisation of Technical Assessment (EOTA) published the Guideline for European Technical Approval of Metal Anchors for Use in Concrete (Approvals, 2010). Anchor bolts which acquire European Technical Assessments or formerly known as European Technical Approvals (ETAs) must fulfill the requirements given in (Approvals, 2010). On the other hand, the European Committee for Standardization (CEN) published Design of Fastenings for Use in Concrete (CEN/TS 1992-4) [2] which provides technical specifications on anchor bolt design which is based on the limit state approach.

The author in the case of the project chose to refer to the guidelines provided by Guide on Design of post-installed anchor bolt systems in Hong Kong by Chan specifically in as they relate to design of mechanical anchor bolt joints as opposed to chemical anchors.

It should be noted the procedure that is the (failure mechanisms, static analysis et cetera) is largely similar with that suggested by EOTA in (Approvals, 2010) except in numerical values and requirements.

4.3.1 Design procedure of mechanical anchor bolts

The design procedure of a single anchor bolt or an anchor bolt group is presented as follows.

1. Determine the design forces of the anchor bolt / bolt group. Identify design requirements, e.g. seismic, crack / non-cracked concrete, strength of concrete, corrosion and fatigue, etc.
2. Select an anchor based on design requirements. Determine the preliminary anchor bolt size, the anchor bolt layout, the dimensions of the base plate, the spacing and edge distances, etc.

3. Resolve the design forces into tension and shear of individual anchor bolt according to Section 3.2 (Chan) and 3.3 (Chan).
4. Calculate the design tension resistances of the anchor bolt according to Section 4.2 (Chan).
5. Calculate the design shear resistances of the anchor bolt according to Section 4.3 (Chan).
6. Compare the design anchor bolt forces to the design resistances according to Sections 4.1 (Chan) and 4.4 (Chan).
7. If the design resistances are larger than the design anchor bolts force, OK! If not, repeat the procedure from Step 2.

Step 1:

To determine the design forces of the anchor bolt / bolt group. Identify design requirements, e.g. seismic, crack / non-cracked concrete, strength of concrete, corrosion and fatigue, etc.

In the case of the proposed structure, the author shall as a conservative approach assume the concrete is cracked as supported by (Chan) and (Approvals, 2010) in absence of other guidance provisions.

The value of the strength of concrete, corrosion and fatigue will depend on the site conditions upon which the flood barrier base/footing is to be installed chosen in the first procedure.

Step 2:

To select an anchor based on design requirements.

The author chose to use mechanical anchor bolts as opposed to chemical anchor bolts because the structure proposed is demountable and temporary.

It can also be said that the curing time is a major disadvantage of chemical anchor bolts, whereas mechanical anchor bolts can be installed relatively immediately the same cannot be said about mechanical anchor bolts.

Determine the preliminary anchor bolt size, the anchor bolt layout, the dimensions of the base plate, the spacing and edge distances, etc.

Spacing and edge distances as well will be determined from the design of the floodwall base above and manufacturer's manual which in this case was the UCAN manual (UCAN Fastening Products, 2016).

Step 3:

Resolve the design forces into tension and shear of individual anchor bolt according to Section 3.2 (Chan) and 3.3 (Chan).

The design forces facing the anchor bolts in the proposed structure are mainly from the lateral hydrostatic force and moment.

Lateral hydrostatic force can be obtained from Equation 1 and the overturning moment can be determined from Equation 2.

The lateral force results in shear force on the anchor bolts whereas the overturning moment results in a vertical tensile load on some anchor bolts as well as a compression on the others.

$$R_1 = \frac{M_o}{s}$$

R1 = the tensile force faced by the two bolts,

Fst = Lateral hydrostatic force.

H = floodproofing height.

Mo = Overturning moment.

And since R1=-R2, R2 is compressive on the remaining two bolts.

Individual tensile force by the bolts = R1/2

Shear force = lateral hydrostatic force.

Step 4:

Calculate the design tension resistances of the anchor bolt according to Section 4.2 (Chan)

The characteristic value of bolt resistance, to tension of an anchor bolt can be calculated directly by;

$$N_{RKS} = A_s * f_{uk}$$

Where;

As is the cross-sectional area of the bolt.

F_{uk} is the ultimate tensile stress of the bolt.

And As can be determined from the preliminary selection.

Design for pull-out resistance: Unfortunately, this can only be obtained from experiments or lab tests (Approvals, 2010).

Design for concrete cone resistance:

The characteristic cone resistance in ideal conditions can be got from the formula;

$$N^{\circ}_{R_{kc}} = k_c\sqrt{f_c}h_{ef}^{1.5}$$

Where;

K_c=factor specified by the manufacturer and dependent on the condition of the concrete

f_c= concrete characteristic cube strength in N/mm^2

h_{ef}= embedment depth of the anchor in mm.

Design for splitting resistance:

Splitting failure due to installation can be avoided if the minimum requirements of edge distance , spacing s_{min} and the concrete thickness h_{min} are met. Engineers shall refer to the manufacturer design manual for the minimum requirements of edge distance, bolt spacing s_{min} and concrete thickness h_{min}

Step 5:

Calculate the design shear resistances of the anchor bolt according to Section 4.3.

Design against steel failure by shear:

The characteristic shear resistance can be calculated directly by:

$$V_{RKS} = 0.5A_S * f_{uk}$$

Where;

A_s is the bolt cross-sectional area

f_{uk} is the ultimate shear stress.

Design against concrete edge failure:

$$V_{RKC} = k_1 * d_{nom}^{\alpha} * l_f^{\beta} * \sqrt{f_{cu}} * c_1^{1.5}$$

Where

dnom is the outside diameter of the anchor bolt ≤ 60 mm

lf is the effective length of the anchor bolt = hef ≤$8.0d_{nom}$

c1 is the edge distance in the direction of the shear force.

Design against concrete pry out failure:

The characteristic value of concrete pry-out resistance can be calculated in a similar manner as:

$$V_{Rkcp} = k_3 * N_{RKC}$$

Where;

k_3 = pry-out factor given in the relevant approval documents.

$N_{R\ KC}$ = characteristic value of concrete cone failure resistance calculated for anchor bolts resisting shear forces.

By engineering experience, k3 =1. 0 for post-installed anchor with h<60mm and k3=2. 0 for post-installed anchor with h≥60mm (Approvals, 2010) and (Chan). Alternatively, the design value of concrete pry-out resistance, can be found in manufacturer design manual.

Resistance to combined tension and shear forces:

The combined effect of tension and shear will be calculated as follows:

$$\left(\frac{N_{sd}}{N_{Rd}}\right)^2 + \left(\frac{V_{sd}}{V_{Rd}}\right)^2 \leq 1.0$$

The above equation is to be used when the mode of failure is steel failure otherwise use the one below:

$$\left(\frac{N_{sd}}{N_{Rd}}\right)^{1.5} + \left(\frac{V_{sd}}{V_{Rd}}\right)^{1.5} \leq 1.0$$

Step 7:

If the design resistances are larger than the design anchor bolts force, OK! If not, repeat the procedure from Step 2.

Design resistance are estimated using partial factors of safety

γ_{MC} covers concrete break-out failure modes (i.e. cone failure, edge failure and pry-out failure).

γ_{MS} covers steel failure by tension and shear.

$\gamma_{MS} = 1.2 \frac{f_{uk}}{f_{yk}} \geq 1.4$…… for tension;

$\gamma_{MS} = 1.0 \frac{f_{uk}}{f_{yk}}$for $\frac{f_{uk}}{f_{yk}} \leq 0.8$…. for shear; and the value of this factor is greater than or equal to 1.25

γ_{MS} = 1.5 for $\frac{f_{uk}}{f_{yk}} > 0.8$

$$\gamma_{MC} = \gamma_c \gamma_2$$

where

γ_c partial factor for concrete under compression = 1.5

γ_2 partial factor taking into account the installation safety of the fastening system

As of the scope of this project γ_2 will be set to 1.00 for high installation safety in tension and γ_2 is set to 1.0 for all scenarios.

The author has chosen to use bolt data obtained from tables provided by UCAN. As of this writing, UCAN Fastening Products is a wholly Canadian owned company specialized in concrete anchoring systems.

Bolts type chosen were heavy load expansion anchors (carbon steel) and tension data used is included in Table 2B-SZ (UCAN Fastening Products, 2016).

Shear design data chosen was from Table 3A-SZ (UCAN Fastening Products, 2016).

4.4.0 Design of the Floodwall span:

For the design of the span, the author chose to use method proposed in the FEMA guidelines for floodwall closures and appurtenances.

Whatever material is used(in this case alpha alumina corundum was used properties obtained from www.matweb.com), it must be of sufficient strength and thickness to resist bending and deflection failures. The ability of a specific material to withstand bending stresses may be substantially different from its ability to withstand deflection stresses. Therefore, to provide for an adequate factor of safety, the required closure thickness should be calculated twice: first taking into account bending stresses, and second taking into account deflection stresses. The resulting thicknesses should be compared and the larger value specified in the final wall span design.

One method of determining the thickness of the closure for steel and aluminum is presented in Roark's formulas for stress and strain (Young, 1989). For a flat plate supported on three sides, the plate thickness required due to bending stresses may be determined by the following equation:

$$t = \sqrt{\frac{P_h * W_c^2 * \beta}{Max\sigma}}$$

Where

t = plate thickness (in.)

P_h = hydrostatic pressure due to standing water (psi).

Wc = width of closure (in.)

Max σ = allowable stress for the plate material (from material handbooks) (lb/in.2)

β = moment coefficient from Table 15 from (Agency, 2012).

Similarly, for a steel or aluminum flat plate supported on three sides, the plate thickness required due to deflection stresses may be determined by the following Equation:

$$t = \frac{\sqrt{360 * \alpha * P * W_c^3}}{E}$$

Where;

α = deflection coefficient from Table 15 from (Agency, 2012).

E = modulus of elasticity for the plate material (from material handbooks) (lb/in.2)

P_h = hydrostatic pressure due to standing water (psi).

Allowable values for α and E may be found for steel plates in the Steel Construction Manual (AISC, 2005), and for aluminum plates in the Aluminum Construction Manual (AA, 1959).

4.5.0 Design of the supports of the wall span/plate

The design of the support was done following simple bending theory detailed in the book Mechanics of Materials 1 by EJ Hearn (Hearn, 2000).

Step 1:

Establish bending moment on the cantilever support:

Accordingly, the bending moment of a uniformly varying load of the nature in which the load decreases uniformly towards the free end as in the case being discussed is given by the formula,

$$M = \frac{w * l^2}{6}$$

Where

W = load per unit height

L = height of the barrier.

W is also given by:

$$w = \frac{2 * fsta}{barrier\_height}$$

Where fsta is the hydrostatic force given earlier.

Step 2:

Establish material elastic limit or yield stress

Step 3:

Determine section modulus:

$$Z = \frac{M}{yield\_stress}$$

Step 4:

Choose any I section that meets the required value above, using trial and error.

The I section must be able to house the wall span and have an allowance for the seals/gaskets.

Step 5:

Update the values of the wall thickness and repeat the entire procedure of the structure design (floodwall foundation et cetera).

4.7.0 Design of the gaskets:

A gasket/seal is to be placed between wall span and the support, and between the support and foundation.

The author used methods and considerations in the (FSA, 2017) and (Flexitallic).

Operating Conditions

Condition one requires a minimum load be determined in accordance with the following equation:

$$W_{m1} = \frac{3.14G^2P}{4} + 2b3.14GmP$$

This equation states the minimum required bolt load for operating conditions and is the sum of the hydrostatic end force, plus a residual gasket load on the contact area of the gasket times a factor times internal pressure. Stated another way, this equation requires the minimum bolt load be such that it will maintain a residual unit compressive load on the gasket area that is greater than internal pressure when the total load is reduced by the hydrostatic end force.

In the case of this structure, there exists no hydrostatic end force,

$$W_{m1} = 2b3.14GmP$$

Since the seal is of rectangular section the formula becomes,

$$W_{m1} = 2 * b * j * m * P$$

Where

b is the gasket width

j is the length

m is the maintenance factor.

P is the internal pressure which in this case is the hydrostatic pressure.

Gasket Seating: (condition two)

Requires a minimum bolt load be determined to seat the gasket regardless of internal pressure and utilises a formula:

$$W_{m2} = 3.14bGy$$

The "b" in these formulae is defined as the effective gasket width and "y" is defined as the minimum seating stress in psi.

Modifying formula for rectangular section, where j is the length of the seal.

$$W_{m2} = b * j * y$$

b = b_o when $b_o \leq 1/4$"… b = 0.5 $\sqrt{b_o}$ when $b_o > 1/14$"

After Wm1, and Wm2 are determined, the minimum required bolt area Am is determined as follows:

$A_{m1} = \frac{W_{m1}}{S_b}$ where Sb is the allowable bolt stress at operating temperature, and

$A_{m2} = \frac{W_{m1}}{S_a}$ where Sa is the allowable bolt stress at atmospheric temperature

Then Am is equal to the greater of Am1 or Am2. Bolts are then selected so the actual bolt area, Ab, is equal to or greater than Am.

Since there is a risk of chemical attack as the pH of the water is variable, the designer saw it fit that Sigma products were chosen to be used as they have outstanding chemical resistance suitable across the whole pH range (0-14).

4.7.1 Design of seal bolts:

Fasteners are also made of aluminum (the most commonly used alloys being 2024-T4, 2111-T3, and 6061-T6), brass, copper, nickel, Monel, Inconel, stainless steel, titanium, beryllium, and various plastics. For any application the fastener material must be considered in connection with potential corrosion problems associated with the anticipated environment and the other metals involved (Section 9.2 of (Robert C.)). In addition, appropriate coatings should be considered for corrosion protection and to reduce thread friction and wear.In this case the designer chose to use alpha alumina corundum alloy.

For most applications, screws and nut-bolt assemblies should ideally be tightened to produce an initial tensile force Fi nearly equal to the full "proof load," which is defined as the maximum tensile force that does not produce a normally measurable permanent set. (This is a little less than the tensile force producing a 0.2 percent offset elongation associated with standard tests to determine Sy.) On this basis initial tensions are commonly specified in accordance with the equation:

$$F_i = K_i * A_t * S_p$$

Where:

F_i = Initial tensile force;

K_i = a constant in ordinary static loading cases is 0.9 (Robert C.)

A_t = tensile area of the thread Tables10.1 and 10.2 of (Robert C.)

S_p = Proof stress in Tables 10.4and 10.5 (Robert C.)

From Table 14(Robert C.) Proof strength for SAE Class 4.6 is 225MPa for diameters 5mm to 36mm.

The official American National Standard from which the information in Table 10.1 (Robert C.) was taken is ANSI (American National Standards Institute) B1.1 (1974), which is published by the American Society of Mechanical Engineers and sponsored jointly by the ASME and the Society of Automotive Engineer

For the design of these bolts, it is assumed that their performance at operating temperature and atmospheric temperature doesn't vary. As of such Wm1 and Wm2 will be compared in magnitude and the greater of the two will be chosen or selected.

4.8.0 Site Drainage:

The drainage system for the area enclosed by a floodwall or levee must accommodate the precipitation runoff from this interior area (and any contributing areas such as roofs and higher ground parcels) and the anticipated seepage through or under the floodwall or levee during flooding conditions. There are two general methods for removing interior drainage. The first is a gravity flow system, which provides a means for interior drainage of the protected area when there is no floodwater against the floodwall or levee. This is accomplished by placing a pipe(s) through the floodwall or levee with a flap gate attachment. The flap gate prevents flow from entering the interior area through the drainpipe when floodwater rises above the elevation of the pipe. The second method, a pump system, removes accumulation of water when the elevation of the floodwater exceeds the elevation of the gravity drain system. A collection system composed of pervious trenches, underground tiles, or sloped surface areas transports the accumulating water to a sump area. In the levee application, these drains should be incorporated into the collection system. The anticipated seepage from under and through floodwalls and levees must also be taken into consideration by combining it with flow from precipitation (see Figure 4-14) (Agency, 2012). It is important to verify that the pump system has a reliable power source that can handle the flooding in the area enclosed by the floodwall or levee. This is essential to the performance of the floodwall or levee system. To determine the amount of precipitation that can collect in the contained area, the rainfall intensity, given in inches per hour, must be determined for a particular location. This value is multiplied by the enclosed area, Ad, in square feet, a residential terrain runoff coefficient (c) of 0.7, and a conversion factor of 0.01. The answer is given in gallons per minute (gpm). See

RUNOFF QUANTITY IN AN ENCLOSED AREA

The rational equation is used to compute the amount of precipitation runoff from small areas. It is generally not applicable to drainage areas greater than 10 acres in size.

$$Q = 0.01 * c * ir * Ad$$

Where:

Q = run off of the enclosed area

0.01 = factor for converting answer to gpm

C = residential terrain run off coefficient of 0.7

Ir = Intensity of rainfall (inch/hr)

Ad = Area Enclosed by the floodwall

Seepage flow rates from the levee or floodwall, Qc, must also be estimated. In general, unless the seepage rate is calculated by a qualified soils engineer, a value of 2 gpm for every 300 feet of levee or 1 gpm for every 300 feet of floodwall should be assumed during base 100-year-flood conditions.

The estimated flow rate from seepage is given by:

$$Q = sr * l$$

Sr is the seepage rate per foot of barrier

L is the length of the barrier wall

If the floodwall is in such a way that it partially encloses a protected area and that there exists high ground that is draining into the protected area, the flow rate or drainage rate for that too must be established.

$$Q = 0.01 * c * ir * Ab$$

Where c,ir are as decribed in the above equation and Ab is the area of the high ground.

The minimum discharge for pump installation is therefore:

$$Q_{min} = Q_{high\_ground} + Q_{seepage} + Q_{protected\_area}$$

4.8.1 Design of sump pump applications.

The design of sump pump applications follows the procedure outlined in the flow chart

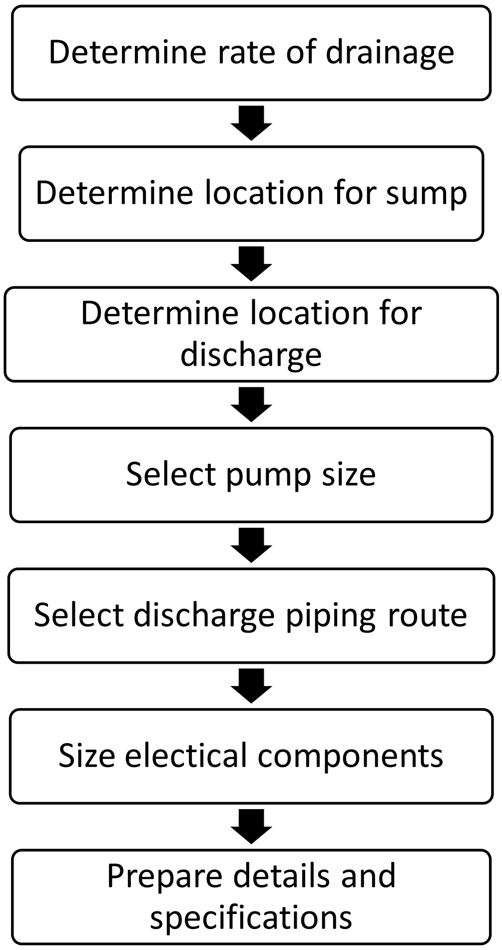

Figure 11-Sump pump design procedure

Step 1:
From the previous section, Drainage rates were obtained.

Step 2:
Determine the location for sump. This entails establishing wether there are subfloor considerations that would interefere with pump installations. It also entails finding out wether submerged pump is tolerable or acceptable.

Step 3:
Determine location for discharge.
It is not permissible to discharge into sanitary systems as this may raise health risks and risks of operational failure as a result of blockage.
Therefore as a result of this consideration, the discharge will be made into the water body or channel.

Step 4:
Selecting pump size:
In selecting a pump, the designer needs the following information:

- Estimate of the quantity of floodwater that will infiltrate into the space per unit of time
- The total dynamic head for the sump discharge. This equals the vertical distance from the pump to the point of discharge plus the frictional resistance to flow through the piping, the fittings, and the transitions. Use the preliminary sketch and field investigation information developed earlier to determine these parameters.
- The head loss due to pipe friction can be obtained from hydraulic engineering data books and is dependent on the pipe material and pipe length.

TOTAL DISCHARGE HEAD

$$TDH = Z + h_{fpipe} + h_{ffittings} + h_{ftrans}$$

Where;
TDH is the Total Discharge head in ft
Z is the elevation difference between the bottom of the sump and the point of discharge.
H_{fpipe} is the head loss due to pipe friction.
$H_{ffittings}$ is the head loss through the fittings.
H_{ftrans} is the head loss through the transitions.

Head losses due to pipe transitions and fittings.

$$h_{ffittings} + h_{ftrans} = (K_b + K_c + K_e)(\frac{V^2}{2g})$$

Where:
hf-fittings = head loss through pipe fittings (ft)
hf-trans = head loss through the transitions (ft)
Kb = loss coefficient of the pipe fitting(s), taken from hydraulic engineering data books
Ke = loss coefficient of the pipe entrance, assumed to be 0.5
Ko = loss coefficient of the pipe exit/outlet, assumed to be 1.0 V = velocity of flow through the pipe , taken from hydraulic engineering data books (ft/sec) g = acceleration of gravity, 32.2 (ft/sec2)

Step 5: Select pump size.
The capacity and size of the sump depends on two factors: physical size of the sump pump; and recommendations of the sump pump manufacturer regarding pump cycling or other constraints. The designer should take these considerations into account in locating the sump and configuring the sump pump discharge.
Step 6:

- Select discharge piping route:

- measure minimize length of pipe between sump and discharge point;
- avoid utility and structural components along route;
- attach discharge pipe to structure as required by code; and
- protect discharge point against erosion.

Steps 6 to 8:

These steps are to be done according to specifications from Geotechnical and Electrical personnel and are beyond the scope of the project.

ASSEMBLY OF STRUCTURE:

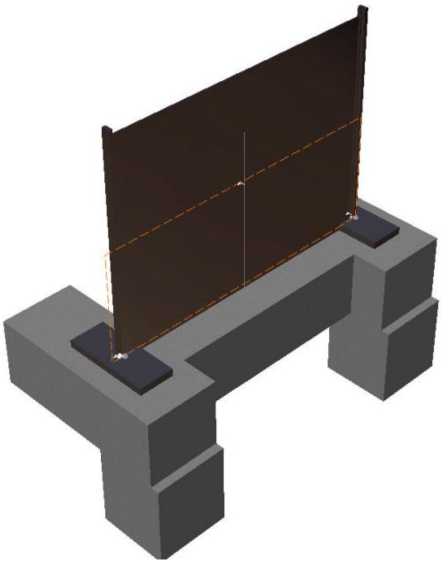

Figure 12-Assembly of structure

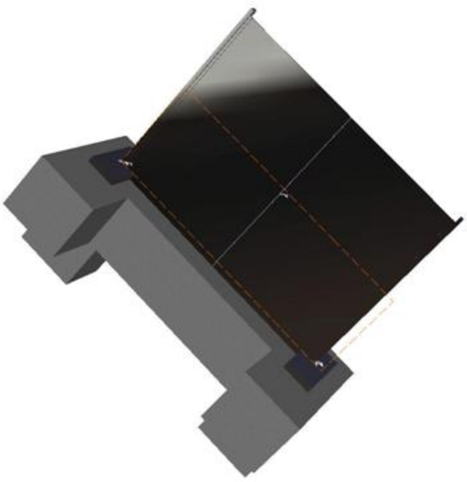

Figure 13-front of assembly

CHAPTER 5: DISCUSSION OF RESULTS

Testing for height of 3ft:

5.1 Results from running code:

```
support height: 3 , support thickness: 0.11511619113706724 , support length: 0.053130549755569495
barrier_thickness : 35.052880201236974 mm
sliding check finished
overturning check finished
settlement check finished
Area of top reinforcement in inch2 : 0.05192325088384525
Area of bottom reinforcement in inch2 : 0.13404036259554
barrier height: 3 , base width: 2.580000000000001 , base length: 1.0320000000000005
base thickness: 0.9450000000000003
Designing steel-concrete anchor bolt
Against tensile failure: M8
Against concrete cone failure: M8
establish pull out resistance
steel shear resistance : M8
Against edge failure : M8
Against concrete pry-out : M8
Seal screw: M14.0 X 2.0
```

The output of the program states the dimensions of the structure and the anchor bolt selection which is M8 and the seal screw diameter(M14) and pitch(2mm).

The computer program then passes the dimensions to the python scripts which build the models in step files as shown.

```
Writing STEP file......
Face...

*******************************************************************
******        Statistics on Transfer (Write)                 ******

*******************************************************************
******        Transfer Mode = 0  I.E.  As Is       ******
******        Transferring Shape, ShapeType = 0                      ******
** WorkSession : Sending all data
 Step File Name : ./simulations/3/barrier_base.stp(1286 ents)  Write  Done

...
Writing STEP file......
Face...

*******************************************************************
******        Statistics on Transfer (Write)                 ******

*******************************************************************
******        Transfer Mode = 0  I.E.  As Is       ******
******        Transferring Shape, ShapeType = 0                      ******
** WorkSession : Sending all data
 Step File Name : ./simulations/3/barrier_foundation.stp(2038 ents)  Write  Done

...
Writing STEP file......
Face...

*******************************************************************
******        Statistics on Transfer (Write)                 ******

*******************************************************************
******        Transfer Mode = 0  I.E.  As Is       ******
******        Transferring Shape, ShapeType = 0                      ******
** WorkSession : Sending all data
 Step File Name : ./simulations/3/flange.stp(1038 ents)  Write  Done
```

5.2 Loading on base / foundation statically

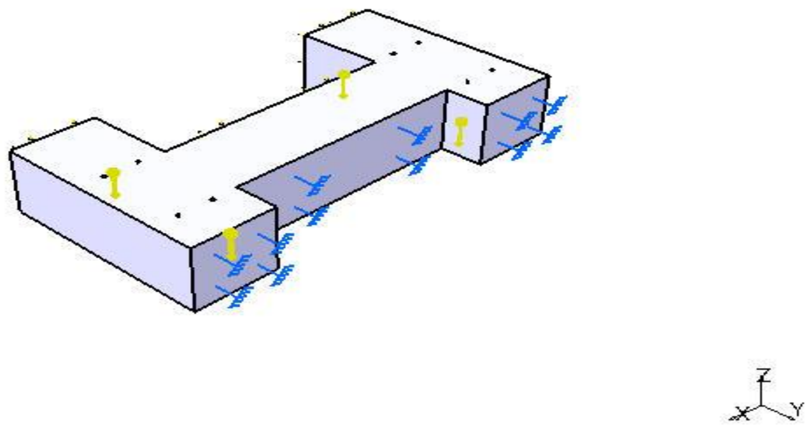

Figure 14-Loads on foundation

The foundation of the structure was loaded with its own weight, the horizontal load in the y-axis from the hydrostatic force, a couple from the overturning moment caused by the hydrostatic force.

The material properties are listed in Table-1:

Table 1-Material properties , base

Material	Concrete
Young's modulus	2.5e+010N_m2
Poisson's ratio	0.3
Density	2320kg_m3
Coefficient of thermal expansion	1e-005_Kdeg
Yield strength	0N_m2

Applied loads sets are shown in Table-2:

Table 2-Applied load set for base

Components	Reactions	Residual	Relative Magnitude Error
Fx (N)	0.00E+00	-4.67E-09	-4.67E-09
Fy (N)	1.32E+03	-1.32E+03	-5.95E-09
Fz (N)	-5.03E+06	5.03E+06	-2.79E-08
Mx (Nxm)	2.59E+05	-2.59E+05	5.94E-09
My (Nxm)	-1.53E-07	1.38E-07	-1.43E-08
Mz (Nxm)	5.45E-10	-1.48E-08	-1.42E-08

5.2.1 Deformed Mesh

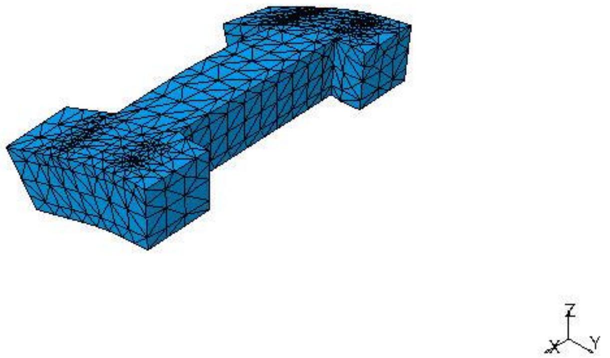

Figure 15-Deformed Mesh

Figure 15 shows the resultant deformed mesh after applying the load set in Table 2.The resulting bending moments from the load set deform the foundation of the barrier in the shape shown in Figure 15. The deformation shown here does not affect the functioning of the barrier since it does not reduce its effective height which would result in a risk of operational failure.

5.2.2 Static case solution Von misses Stress

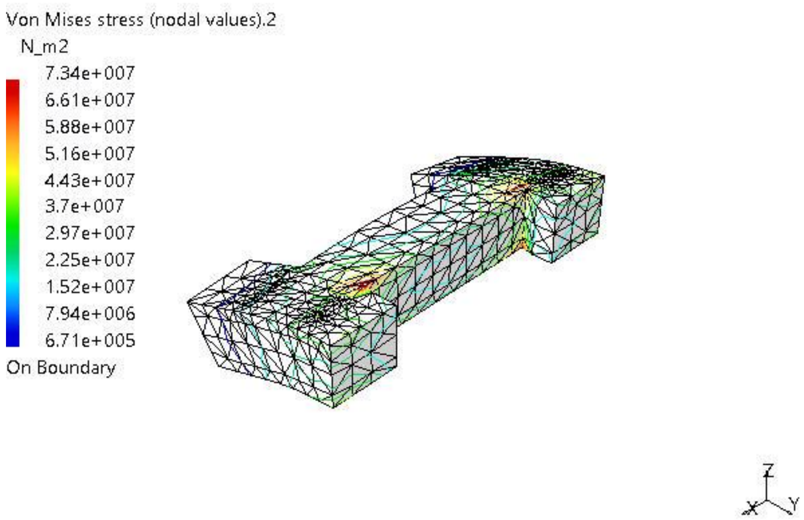

Figure 16-Von Mises Stress on foundation

Figure 16shows that the stress distribution on the foundation from the loads and moments on the base/foundation.

5.2.3 Translational displacement Vector

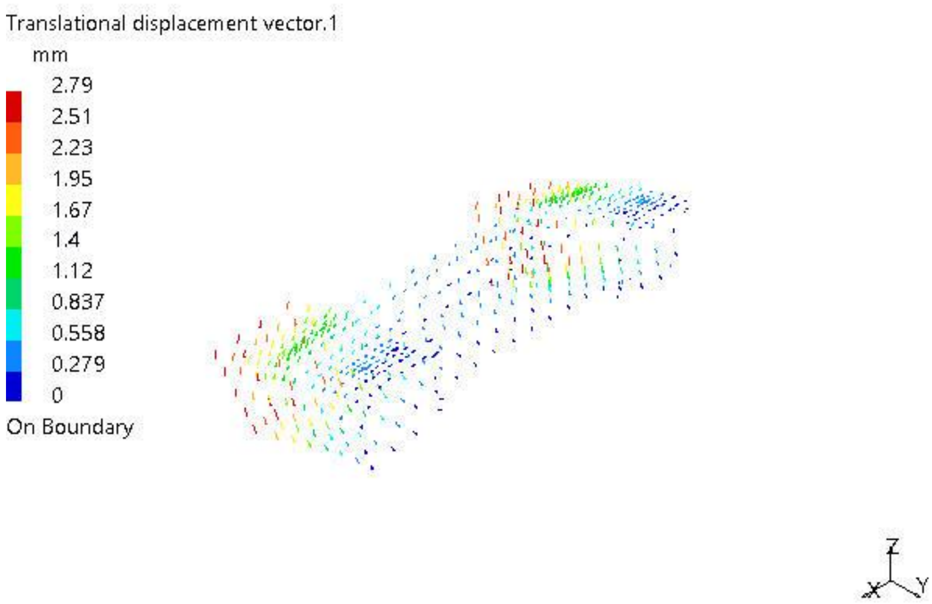

Figure 17-Translational displacement Vector of base

Figure 17 shows the translational displacement vector which shows the maximum displacement less than 3mm which still shows structural integrity. Since a displacement of this magnitude is not likely to affect the functioning of the structure and the concrete retains its elasticity, the result shows that flood barrier design is viable.

5.3 Static loading supports.

Figure 18-Loading supports statically

Figure 18 shows the metal frames that form the supports in the structure, their material properties are as shown in Table 3 , below:

Table 3-Material properties, supports

Material	Aluminium
Young's modulus	7e+010N_m2
Poisson's ratio	0.346
Density	2710kg_m3
Coefficient of thermal expansion	2.36e-005_Kdeg
Yield strength	9.5e+007N_m2

Figure 18 also shows the loads, and restraints on the supports that are numerically described in Table-4 below:

Table 4-Applied loadset on supports

Components	Applied Forces	Reactions Residual	Relative Magnitude Error
Fx (N)	9.18E-15	9.45E-09	9.45E-09
Fy (N)	1.32E+03	-1.32E+03	-5.01E-08
Fz (N)	-2.39E-14	-1.71E-09	-1.71E-09
Mx (Nxm)	-1.02E+03	1.02E+03	5.34E-08
My (Nxm)	-1.36E-13	9.78E-09	9.78E-09
Mz (Nxm)	-9.42E-07	9.31E-07	-1.17E-08

5.3.1 Deformation of supports

Figure 19-Deformation of supports

Figure 19, shows the deformation of the supports under hydrostatic load in Table 4.

5.3.2 Von Mises stress on the supports.

Figure 20-Von Mises Stress on supports

Figure 20 shows the stress distribution and it is as expected greater at the top than bottom as in any cantilever system. Load set used here is in Table 4.

5.3.3 Translational displacement Vector of supports.

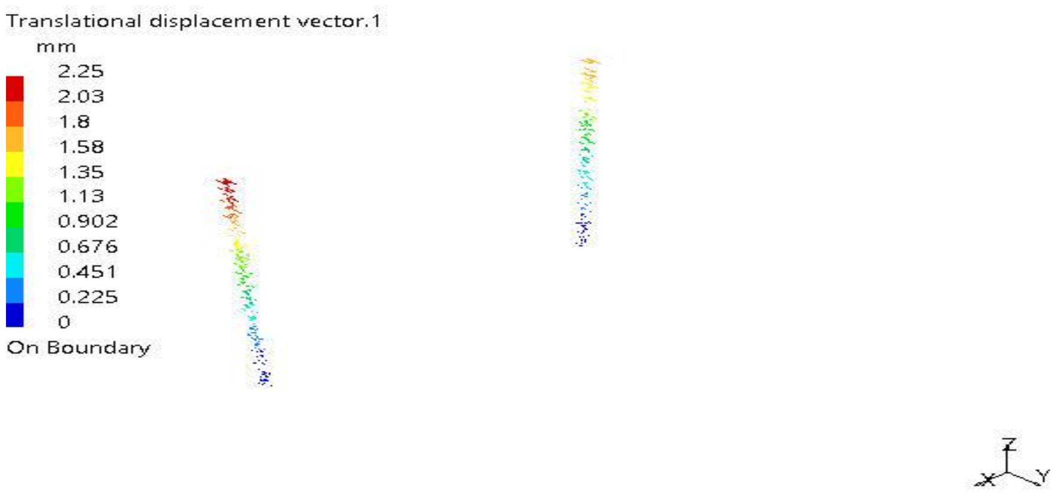

Figure 21-Translational displacement vector on supports.

Figure 21 shows the translational displacement vector which shows that the maximum translation is 2.25 mm upon testing. The displacement obtained under these conditions would cause some version of overtopping of the supports but however since the hydrostatic loads applied on these structures has been amplified(that is assumed to be uniformly distributed), the supports would experience minimal to no deflection under the actual loading that is in reality not uniformly distributed.

5.4 Cost:

The actual cost of the floodwall or structure includes variable costs such as the length of the area in the flood plain to be protected, to fix those costs it was decided that the barrier protect a length of 67m.

Table 5-Unit Cost of foundation

Dimension	Value
Area	9.32512ft^2
Footing depth	0.945ft
Volume	8.8122ft^3
Unit cost @ \$3.98 per ft^3	\$35.07

Table 6-Unit cost of floodwall

Component	Value(@$2 unit cost per kg of Aluminium)
Supports	$5.59
Wall span	$210
Total cost	$291.79

Table 7-Unit cost of masonry floodwall

Component	Value(@ \$4 unit cost per ft^3 of masonry)
Wall span @12inch wall thickness	\$48
Reinforcement	\$50
Total	\$98

As shown on material cost basis the designed floodwall is more expensive than the alternate masonry floodwall. However when costs for finishing, transportation and workman ship are added to the masonry the differences between the costs reduces significantly.

The main advantage of this structure is not in the cost but in convenience with which it can be removed and transported as it weighs less than the masonry(105 kg as opposed to 820kg).

Chapter 6: Conclusions and Recommendations.

6.1 Conclusions

6.1.1 Choice of case study.

The design of the flood barrier was originally aimed to stop flooding from river Nyamwamba in Kasese; however there was inadequate data as well as inadequate financial resources to fund the project. Consequently it was decided that the design of the flood barrier will proceed with Water channels which have been studied extensively in Kampala.

Nakivubo water channel was originally chosen however the flood risk from this channel was found to be low as the widening of the channel by the government (Kampala City Council Authority) rendered this almost impossible. Subsequently Lubigi water channel and its tributaries were chosen as the case study for the project.Lubigi water channel, its tributaries Kiyanja, et cetera still experience flooding from water channel overflow as of the dayof writing this report that is May 2018, and to the authors knowledge.

6.1.2 Choice of guidelines:

While designing the floodwall, author chose guidelines of a governmental body or authority called Federal Emergency Management Authority in the United States. Consequently the section for designing the floodwall, wall span and pump headutilize an American Metric system hence flood design heights were set in feet.

While designing the anchorage, the guide on design of post installed anchor bolt systems in Hong Kong (Chan) was used in conjunction with (Approvals, 2010).

Sealing guidelines were obtained from the Fluid Sealing Association.

6.1.3 Choice of floodwall:

According to literature (Engineers, 1989), types other than the cantilever type of floodwall are chosen when the design is in excess of8ft, consequently it was decided that use of a cantilever wall was chosen as the type of floodwall.

6.1.4 Choice of Design Programming languages:

A programming language (Julia) for technical computing was chosen over the legacy software which is MATLAB for the major reason that MATLAB is commercial software. Since the project was designed to be freely accessible to everyone, MATLAB was dropped. However Scilab an open source alternative to MATALAB was also dropped mainly because unclear insufficient documentation and install storage space requirements are massive in comparison with a programming language.

It was also decided that a programming language is much more dynamic in comparison with software in general since all software is built from programming languages.Julia in particular was chosen over other languages for its relative friendliness with mathematics.

Dynamic languages (Julia and Python) were chosen over statically compiled languages(C++,C# and Java) because of simplicity of use and rapid testing ability.

Python (with FreeCAD modules) was used to design the CAD models in step files CAD format because both python and FreeCAD are free. Although there are FreeCAD modules that carry out finite Element Analysis on structures, they don’t yet generate detailed result sets as well as the commercial alternative which is CATIA. For this reason Finite Element Analysis on the CAD results was done with CATIA. This is however not to say FreeCAD Finite Element Analysis cannot be done on the structure.

6.2 Limitations:

The major limitation of this design process is that environmental conditions are erratic and inreality the loading of the structure may not follow a static manner or form. Under such conditions the performance of the structure might be drastically different from that expected from the design process.

Other limitations may include:

- External stability of the flood barrier was designed for but never tested by the software mainly because during the time frame of the project, software designed to do just that was never found.
- Soil mechanical properties in the sites were never established as they required an independent geotechnical study, the time and resources for which was limited. Also the available soil data from (Habonimana, 2014; Dr. Richard Sliuzus, 2013) did not include the necessary soil mechanical properties such as soil specific weight and passive pressure coefficient. Consequently the soil properties used in the design were from one soil type that is GW of the United Soil Classification System that was obtained from (Agency, 2012).
- The financial cost of this project retains uncertainties particularly in as it relates to installation and processing cost for the material and structure.
- There remains uncertainty as to how long it will take to install the flood barrier when required.

6.3 Recommendations.

6.3.1 Flood detection.

Research into flood detection systems and meteorological aspects(rainfall-flood patterns) should be done prior to using the designs from this project.

Since the design of the flood barrier may require some lead time for installation, it is recommended that the design be modified be of a flap gate design instead. The modification would allow the structure to respond more instantly to flood detection or warning systems.

6.3.2 Channels and drainage:

For this structure to be fully operational, existing tributaries to main water channels should utilize underground piping or plumbing that is the network of minor open tributaries should be made closed and fitted underground.

6.3.3 Geotechnical study.

A study of the soil mechanics and properties should be done by fully qualified personnel. Subsequently the results should be fed into the Julia program in order to update the design.

6.3.4 Field Tests

The flood barrier should be tested in the laboratory and field for structural integrity, external stability and operational capacity.

6.3.5 Ease of design program use:

The designed program is a console application which is not user friendly therefore it should be modified to include a Graphical User Interface.

Bibliography

A. Mugesh, L. K. (2015). Self-Closing Flood Barrier a Preventive System to Defense Extreme High Flood Events. *International of Engineering Research and Technology* .

AA. (1959). *Aluminum Construction Manual.* Aluminum Association.

ABC- A Better City. (2015). *Passive Flood Barrier Publication.*

Agency, F. E. (2012). *Engineering Principles and Practices for Retrofitting Flood-Prone Residential Structures (Third Edition).*

AISC. (2005). Steel Construction Manual. In A. I. Construction, *Steel Construction Manual* (pp. 325-05).

Approvals, E. O. (2010). *Guideline for European Technical Approval of Metal Anchors for use in concrete.* Brussels: European Organisation for Technical Approvals.

Chan, D. S. *Guide on Design of post-installed anchor bolt systems in Hong Kong* . Hong kong: The Hong Kong Institute of Steel Construction .

Dr. Richard Sliuzus, D. S. (2013). *Flood Risk Assessment, Strategies and Actions for Improving Flood Risk Management in Kampala* . Kampala: UN HABITAT.

Engineers, U. A. (1989). *Retaining and Flood walls Engineer Manual.*

fema.gov. *ENGINEERING PRINCIPLES AND PRACTICES for Retrofitting Flood-Prone Residential Structures.*

Flexitallic. *Gasket Design Criteria.*

FSA. (2017). *Gasket Design Handbook.* Wayne: Fluid Sealing Association.

Habonimana. (2014). *Intergrated flood modelling in Lubigi Catchment.* Enschede.

Hearn, E. (2000). *Mechanics of Materials 1.* Oxford, United Kingdom: Butterworth-Heinemann .

Robert C., K. M. *Fundamentals of Machine Component Design.* John Wiley & Sons Inc.

Sten Kullberg, V. (2000). *METHOD FORTHE FABRICATION OF A DAM OR BARRIER.* US PATENT Number 6,132,140 .

The Town Clerk KCC. (1999). *The Nakivubo Channel Rehabilitation Project,Environmental Impact Assessment.* Kampala: Kampala City Council.

UCAN Fastening Products. (2016). Section 2.1. In *Technical Manual.*

Xianghu Li, Q. Z.-Y. (2014). The changing patterns of floods in Poyang Lake, China: characteristics and explanations.

Young, R. a. (1989). In R. a. Young, *Roark's Formulas for Stress and Strain.* McGraw-Hill.

APPENDIX

Appendix I:Tables used by the programs:

Bolt Tables:

Table 8-General bolt properties

Properties	M8	M10	M12	M16	M20
clearance hole diameter	14	17	20	26	31
embedment depth	69	82.5	94.5	118	148
minimum hole depth	80	95	105	130	160
minimum edge distance	60	70	90	120	180
minimum spacing	125	175	200	320	540
plate thickness	30	30	25	20	30

Table 9- Concrete cone resistance tables.

Properties	M8	M10	M12	M16	M20
h_{ef}	60	71	80	100	125
C_{ed}	132	178	160	230	288
k_{cr}	7.1	7.1	8.8	8.8	8.8

Table 10-Edge resistance tables

Properties	M8	M10	M12	M16	M20
d_{nom}	12	14.5	17.5	23.5	27.5
l_e	23	29	35	47	55

Table 11-Concrete Pry out resistance table

Properties	M8	M10	M12	M16	M20
k_{cp}	1	2	2	2	2

Table 12-Shear Resistance tables

Properties	M8	M10	M12	M16	M20
Sr	24	39.1	58	96	123

Table 13-Tension resistance tables

Properties	M8	M10	M12	M16	M20
f_{yk}	640	640	640	640	640
f_{ut}	800	800	800	800	800
s_{min}	125	175	200	320	540
A_e	37	58	84.3	157	245

Seal bolt data:

Table 14-Seal bolt data

norminal diameter	M5	M6	M7	M8	M10	M12	M14	M16	M18	M20	M22	M24	M27
ndiameter	5	6	7	8	10	12	14	16	18	20	22	24	27
pitch diameter	0.8	1	1	1.25	1.5	1.75	2	2	2.5	2.5	2.5	3	3
minor diameter	4.02	4.77	5.77	6.47	8.16	9.85	11.6	13.6	14.9	16.9	18.9	20.3	23.3
stress area	14.2	20.1	28.9	36.6	58	84.3	115	157	192	245	303	353	459

Wall Span data:

Table 15-Wall span data

Properties	p1	p2	p3	p4	p5	p6	p7	p8	p9
H/W	0.05	0.67	1	1.5	2	2.5	3	3.5	4
alpha	0.11	0.16	0.2	0.28	0.32	0.35	0.36	0.37	0.37
beta	0.03	0.03	0.04	0.05	0.06	0.06	0.07	0.07	0.07

Appendix II:Computer programs:

Batch file(barrier.bat):

```
@echo off
echo ---------Welcome-----
rem %julia% "F:\usb\barrier1.jl" --bheight="5" --splen="4" --spec_soil="120" ^
rem --cb="0" --kp="3.7" --cf="0.55" --sb=2000 --cube_stren=30 --concrete_cracked="true" ^
rem --bstress="35286" --young="49300" --flange_coeff="13"
rem %freecadcmd% "F:\usb\barrier.py"
rem echo ---Finish---
rem Comment out the statements below and uncomment those above if you desire to run the program against one height.
for /l %%i in (3,1,4) do (
echo ----Starting test-----
%julia% "F:\usb\barrier1.jl" --bheight=%%i --splen="4" --spec_soil="120" ^
--cb="0" --kp="3.7" --cf="0.55" --sb=2000 --cube_stren=30 --concrete_cracked="true" ^
--bstress="35286" --young="49300" --flange_coeff="7"
%freecadcmd% -l "F:\usb\barrier.py"
echo ---Finish test---
)
echo ----Simulation done---
```

Figure 22-Barrier batch file.

Main program (Barrier1.jl):

05/31/18 05:20:56 /media/nsamba/W7_AIOX86X6/usb/barrier1.jl

```
using ArgParse,CSV
include("formulas.jl") #formulas to be used
include("design.jl") #functions that design against sliding, overturning and settlement
include("bolts.jl") #functions that design bolts
include("wall.jl") #functions that design wall
include("support.jl") #functions that design wall supports
include("seal.jl") #functions that design seal.
function main(support,constants,barrier,args)
    #set main props
    s = ArgParseSettings(description ="Arguments passed by cli")
    @add_arg_table s begin
        "--bheight"
            default = "5"
            help = "This flag sets the barrier height in ft"
        "--splen"
            default = "4"
            help ="This option sets the span length in ft"
        "--spec_soil"
            default = "120"
            help = "This option sets the specific soil weight in Ib/ft"
        "--spec_mat"
            default = "175"
            help ="sets the wall specific weight in Ib/ft"
        "--spec_base"
            default = "150"
            help = "This option sets the specific concrete base weight in Ib/ft"
        "--cube_stren"
            default = "30"
            help ="Expected concrete cube strength in N/mm2"
        "--cb"
            default = "0"
            help = "This option sets the cohesion coefficient"
        "--kp"
            default = "3.7"
            help = "This option sets the passive soil pressure"
        "--cf"
            default = "0.55"
            help = "This option sets the friction coefficient"
        "--sb"
            default = "2000"
            help ="This sets the allowable bearing stress"
        "--bstress"
            default="50800"
            help ="This sets the allowable bending stress of wall span material in Ib/in2"
        "--young"
            default="49300"
            help="modulus of elasticity for the plate material in kIb/in2"
        "--flange_coeff"
            default = "19"
            help ="Flange coefficient is the multiple of wall thickness used to obtain flange length."
        "--seal_selection"
            default ="2"
            help="2 - glass microspheres\n 3 - silica\n 4 - Barium sulphate\n 5- PTFE588\n 6 - PTFE600"
        "--concrete_cracked"
            default = true
            help ="Nature of concrete that is cracked / uncracked"
        "--mat_shear"
            default = "330"
            help="shear strength of material in bolts, state in MPa"
    end
    data = parse_args(s)
    barrier.height = parse(Int8,data["bheight"])
    barrier.span_length = parse(Int8,data["splen"])
    constants.spec_soil=parse(Int16,data["spec_soil"])
    constants.spec_base=parse(Int16,data["spec_base"])
    constants.Cb = parse(Int16,data["cb"])
    constants.Kp = parse(Float16,data["kp"])
    constants.Cf = parse(Float16,data["cf"])
    constants.Sb = parse(Int32,data["sb"])
    constants.cube_stren= parse(Int16,data["cube_stren"])
    constants.con_stats = data["concrete_cracked"]
    constants.young = parse(Int32,data["young"])
    constants.bstress = parse(Int32,data["bstress"])
    constants.young = parse(Int32,data["young"])
    constants.spec_mat = parse(Int32,data["spec_mat"])
    constants.flange_coeff = parse(Int16,data["flange_coeff"])
    constants.seal_select = parse(Int8,data["seal_selection"])
    constants.mat_shear = parse(Int16,data["mat_shear"])
    coeff = 0.5
    barrier.base_width = coeff * barrier.height
    barrier.span_t = 2*(1/12) * design_wall(constants,barrier,wconst,wall)
    println(304.5*barrier.span_t)
    support_data = design_support(support,constants,barrier)
    barrier.wall_t = support_data.height
    b = 304.5 * barrier.wall_t
```


Figure 23-Main Script(barrier1.jl) I

```
    println("barrier_thickness : $b mm")
    j=design(constants,barrier)
    while j < 1.5
        coeff = coeff + 0.05
        barrier.base_width =coeff * barrier.height
        j = design(constants,barrier)
    end
    println("sliding check finished")
    infor=overturning(constants,barrier)
    i = infor[1]
    while i < 1.5
        coeff = coeff+0.02
        barrier.base_width = coeff * barrier.height
        dat = overturning(constants,barrier)
        i = dat[1]
    end
    println("overturning check finished")
    k = Ecentricity(constants,barrier)
    while k > (barrier.base_width)/6
        coeff = coeff+0.1
        barrier.base_width = coeff * barrier.height
        k = Ecentricity(constants,barrier)
    end
    o=soil_pressure(constants,barrier,k)
    p = o[1]
     while p > constants.Sb
        coeff =coeff+0.05
        barrier.base_width= coeff * barrier.height
        o = soil_pressure(constants,barrier,k)
        p = o[1]
     end
     println("settlement check finished")
    reinforcement(constants,barrier,k)
    output_dimensions(barrier)
    println("Designing steel-concrete anchor bolt")
    design_bolts(constants,barrier,bolt,bconsts)
    des_seal(seal,constants,barrier)
end
main(support,constants,barrier,ARGS)
```

Figure 24-Main script (barrier.jl) page 2

Module for formulae (formulas.jl)

```
#Assumptions for dimensions
base_len(x)=0.40*x #formula for base length
base_thick(x)=0.45*x #formula for base width
heel(x,z)=(2/3)*(x-z)
toe(x,z)=(1/3)*(x-z)
ecentricity(B,Mr,Mo,fv)=(B/2) - ((Mr-Mo)/fv)
tst(blen,wlt)=blen+(2*wlt)

#Vertical Forces
weight(spec_wt,leng,width,height)=spec_wt*leng*width*height
fboy1(a,H,twall,ah,t,len)= a*((H)*(0.5*twall)+(ah*(twall/2)*(t)))*len
fboy2(gm,c,twall,tf,lent)= lent*gm*((c+(twall/2)*tf))
Fbuoy(spec_wt,leng,width,height)=spec_wt*leng*width*height
Fv(wall,basew,Wwat,fb)=basew+wall+Wwat-fb

#sliding Forces
F_sta(sp,H,len)=len*0.5*0.5*sp*(H^2)

#Resisting Forces(horizontal)
Fr(Cf,fv)=Cf*fv
Fc(Cb,B)=Cb*B
Fp(kp,spec_soil,spec_water,t,len)=len*0.5*(kp*(spec_soil-spec_water)+spec_water)*(t^2)
Fkey(kp,spec_soil,spec_water,tkey,len)=len*0.5*(kp*(spec_soil-spec_water)+spec_water)*(tkey^2)
Fwall(kp,spec_soil,spec_water,tbase,len,t)=0.5*0.5*(len-t)*(kp*(spec_soil-spec_water)+spec_water)*(tbase^2)

#moments
M_sta(fst,H,t)= fst*((H+t)/3)
M_fp(fpee,t)= fpee*(t/3)
M_bouy(fb1,fb2,B) = (fb1*(B/3)) + (fb2*(2/3)*B)
Mbse(bw,B)=bw*(B/2)
Mwallwt(Fwt,C,twall)= Fwt*(C+(twall/2))
Mwh(waterw,B,Ah)=waterw*(B-(Ah/2))
Mfwall(fwall,t)=fwall*(t/3)
Mfkey(fkey,t)=fkey*((2/3)*t)

#soil pressure
soil_p(fv,blen,bwidth,ece)=(fv/(bwidth*blen))*(1+((6*ece)/bwidth))
soil_p1(fv,blen,bwidth,ece) =(fv/(bwidth*blen))*(1-((6*ece)/bwidth))
#forces on bolt
Tensr(Ae,fuk)=Ae*fuk
des_t(movert,bwallt,coeff)=movert/(coeff*bwallt*304.5)
Yms(fuk,fyk) = 1.2*(fuk/fyk)

#force on concrete
cconr(kc,he,fc)=kc*(sqrt(fc))*((he)^1.5)

#shear forces on concrete
edge_res(k1,dnom,alph,le,bet,fc,c1)=k1*(dnom^alph)*(le^bet)*sqrt(fc)*(c1^1.5)

#design wall span
Ph(Y,H)=Y*H
thickness(ph,wc,bet,stress)=sqrt((ph*(wc^2)*bet)/stress)
thicknes(alph,P,wc,E)=sqrt(360*alph*P*(wc^3))/E

#reinforcement
Are_a(Mb,df)=(Mb/1000)/(1.76*df)

#supports
ismall(coef,h) = 2*((coef*(h^4))/12)
ibig(coef,h) = (coef*(h^3))/12

#seals
Wm1(b,j,m,p)=2*b*j*m*p
Wm2(b,j,y)=b*j*y
Fi(Sp,At) = 0.9*At*Sp
```

Figure 25-Formulas module (formulas.jl)

Module for supports (support.jl)

```
type Support
    height
    width
    coef
end
support = Support(0,0,3)
function sec_modulus(Ismall,support,fx_height)
    support.height = (support.coef)*(fx_height)
    y = 0.5*(support.height)
    Ibig = ibig(support.width,support.height)
    Ibal = Ibig - Ismall
    Z = Ibal/y
    return Z
end
function ch_base(support)
    support.coef = support.coef+1
end
function design_support(support,constants,barrier)
    Fsta = F_sta(constants.spec_water,barrier.height,barrier.span_length)
    w = (2*Fsta)/(barrier.height)
    l = barrier.height
    Mst = (w*(l^2))/6
    stress_yield = constants.bstress*(12*12) #Alumina
    Z= (Mst/stress_yield)
    h = barrier.span_t
    #assume b = coef * h
    coef = 2
    h1 = 3/304.5
    Ismall = ismall(coef,h+h1)
    support.width = 3*(coef*h)
    Z1 = sec_modulus(Ismall,support,barrier.span_t)
    println(Z)
    println(Z1)
    while Z1 < Z
        ch_base(support)
        Z1 = sec_modulus(Ismall,support,barrier.span_t)
    end
    output_dimensioning(support,barrier)
    return support
end
function output_dimensioning(support,barrier)
    height = barrier.height
    sptick = support.height
    spwid = support.width
    println("support height: $height , support thickness: $sptick , support length: $spwid")
    x=[height sptick spwid barrier.span_t]
    filepath ="./wall_span/supports.csv"
    fid1 = open(filepath,"w")
    writecsv(fid1,x)
    close(fid1)
    filepath= "./wall_span/support_data.csv"
    fid2 = open(filepath,"a")
    writecsv(fid2,x)
    close(fid2)
end
```

Figure 26-Supports module (supports.jl).

Wall design Module (wall.jl):

```
type wallsp
    thickness
    height
    width
end
wall = wallsp(0,0,0)
type wcontsts
    #allowable stress
    bstress
    young
    bet
    alpha
end
wconst =wcontsts(0,0,0,0)
function bending_stress(wconst,wall,spec_water)
    #design against bending stresses
    #alpha alumina corundum,aluminium oxide
    wall_data=CSV.read("./wall_span/wall.csv")
    r=(wall.height)/(wall.width)
    coln = names(wall_data)
    col =[]
    for q = 1:9
        temp=wall_data[coln[q]]
        push!(col,temp)
    end
    for i = 2:9
        if r < col[i][1]
            y2=col[i][1]
            x2=col[i][3]
            y1=col[i-1][1]
            x1=col[i-1][3]
            y0 = r
            wconst.bet =(((x2-x1)/(y2-y1))*(y0-y1))+x1
            break;
        end
    end
    p=Ph(spec_water,wall.height)
    t = thickness(p,wall.width,wconst.bet,wconst.bstress)
    return t
end
function deflection(wconst,wall,spec_water)
    wall_data = CSV.read("./wall_span/wall.csv")
    r = (wall.height)/(wall.width)
    coln = names(wall_data)
    col = []
    for q =1:9
        temp = wall_data[coln[q]]
        push!(col,temp)
    end
    for i = 2:9
        if r <col[i][1]
            y2 = col[i][1]
            x2 = col[i][2]
            y1 = col[i-1][1]
            x1 = col[i-1][2]
            y0 = r
            wconst.alpha = (((x2-x1)/(y2-y1))*(y0-y1))+x1
            break;
        end
    end
    P = Ph(spec_water,wall.height)
    t = thicknes(wconst.alpha,P,wall.width,wconst.young)
    return t
end
function design_wall(constants,barrier,wconst,wall)
    wall.height = 12*(barrier.height)
    wall.width = 12*(barrier.span_length)
    wconst.bstress = constants.bstress
    wconst.young = constants.young
    wconst.young = 1000*(wconst.young)
    bending_thickness = bending_stress(wconst,wall,constants.spec_water/(12*12*12))
    bending_tick = deflection(wconst,wall,constants.spec_water/(12*12*12))
    if bending_thickness < bending_tick
        return bending_tick
    else
        return bending_thickness
    end
end
```

Figure 27-Wall design module

Floodwall base module (design.jl):

```
type Barrier
    height
    base_width
    base_thickness
    base_length
    span_length
    key_depth
    wall_t
    span_t
end
barrier=Barrier(0,0,0,0,0,0,0,0)
type Constants
    spec_water
    spec_base
    spec_soil
    mat_shear
    spec_mat
    Cb
    Cf
    Kp
    Sb
    cube_stren
    con_stats
    young
    bstress
    flange_coeff
    seal_select
end
constants=Constants(64,0,0,0,0,0,0,0,0,0,true,0,0,0,2)
function fvertical(constants,barrier)
    #wall_con= weight(constants.spec_mat,barrier.wall_t,barrier.height,barrier.span_length)
    wall_con = 0
    basew=weight(constants.spec_base,barrier.base_length,barrier.base_width,barrier.base_thickness)
Wwat=weight(constants.spec_water,heel(barrier.base_width,barrier.wall_t),barrier.base_length,barrier.height)
    fb=Fbuoy(constants.spec_water,barrier.base_width,barrier.base_length,barrier.base_thickness)
    fv=Fv(basew,Wwat,wall_con,fb)
    return fv
end
function Fres(constants,barrier)
    friction=Fr(constants.Cf,fvertical(constants,barrier))
    fc=Fc(constants.Cb,barrier.base_width)
fp=Fp(constants.Kp,constants.spec_soil,constants.spec_water,barrier.base_thickness,barrier.base_length)
    barrier.key_depth = 1.2 * barrier.base_thickness
    tkey = barrier.key_depth + barrier.base_thickness
    fkey= Fkey(constants.Kp,constants.spec_soil,constants.spec_water,tkey,barrier.base_length)
    fwall =
Fwall(constants.Kp,constants.spec_soil,constants.spec_water,barrier.base_thickness,barrier.span_length,barrier.base_length)
    resf=friction+fc+fp+fkey+fwall
    return resf
end
function design(constants,barrier)
    #for redesign of barrier
    barrier.base_length=base_len(barrier.base_width)
    barrier.base_thickness=base_thick(barrier.base_width)
    Fst=F_sta(constants.spec_water,barrier.height,tst(barrier.span_length,barrier.wall_t))
    Fresist=Fres(constants,barrier)
    ans=Fresist/Fst
    return ans
end
function output_dimensions(barrier)
    height=barrier.height
    bwd=barrier.base_width
    blen=barrier.base_length
    bthick=barrier.base_thickness
    wallt = barrier.wall_t
    wallh = barrier.height
    println("barrier height: $height , base width: $bwd , base length: $blen")
    println("base thickness: $bthick")
    x=[barrier.height barrier.wall_t barrier.base_width barrier.base_thickness barrier.base_length
barrier.span_length barrier.key_depth barrier.span_t]
    filepath ="./barrier/barrier.csv"
    fid1 = open(filepath,"w")
    writecsv(fid1,x)
    close(fid1)
end
function Mres(constants,barrier)
    Mbase =
Mbse(weight(constants.spec_base,barrier.base_width,barrier.base_length,barrier.base_thickness),barrier.base_width)
    wallwt=0.5*weight(constants.spec_mat,barrier.wall_t,barrier.span_length,barrier.height)
    Mwwt = Mwallwt(wallwt,toe(barrier.base_width,barrier.wall_t),barrier.wall_t)
```

Figure 28- Foundation design module I

```
    wh =weight(constants.spec_water,heel(barrier.base_width,barrier.wall_t),barrier.base_length,barrier.height)
    Mwheel=Mwh(wh,barrier.base_width,heel(barrier.base_width,barrier.wall_t))
    fp=Fp(constants.Kp,constants.spec_soil,constants.spec_water,barrier.base_thickness,barrier.base_length)
    Mfp = M_fp(fp,barrier.base_thickness)
    fwall = Fwall(constants.Kp,constants.spec_soil,constants.spec_water,barrier.base_thickness,barrier.span_length,barrier.base_length)
    Mwall =Mfwall(fwall,barrier.base_thickness)
    fkey = Fkey(constants.Kp,constants.spec_soil,constants.spec_water,barrier.key_depth,barrier.base_length)
    Mkey =Mfkey(fkey,barrier.key_depth)
    Mresisting=Mfp+Mwwt+Mbase+Mwheel+Mwall+Mkey
    return Mresisting
end
function overturning(constants,barrier)
    #barrier.base_thickness = base_thick(barrier.base_width)
    barrier.base_length = base_len(barrier.base_width)
    fst=F_sta(constants.spec_water,barrier.height,tst(barrier.span_length,barrier.wall_t))
    Mst=M_sta(fst,barrier.height,barrier.base_thickness)
    hel=heel(barrier.base_width,barrier.wall_t)
    toy=toe(barrier.base_width,barrier.wall_t)
    fbuoy1=fboy1(constants.spec_water,barrier.height,barrier.wall_t,hel,barrier.base_thickness,barrier.base_length)
    fbuoy2=fboy2(constants.spec_water,toy,barrier.wall_t,barrier.base_thickness,barrier.base_length)
    Mbouy=M_bouy(fbuoy1,fbuoy2,barrier.base_width)
    Mov=Mst+Mbouy
    Mresist=Mres(constants,barrier)
    ans=Mresist/Mov
    return [ans,Mov]
end
function Ecentricity(constants,barrier)
    Mr=Mres(constants,barrier)
    Mover=overturning(constants,barrier)
    fv =fvertical(constants,barrier)
    ece = ecentricity(barrier.base_width,Mr,Mover[2],fv)
    return ece
end
function soil_pressure(constants,barrier,k)
    o = []
    fv = fvertical(constants,barrier)
    o1 = soil_p(fv,barrier.base_length,barrier.base_width,k)
    o2 = soil_p1(fv,barrier.base_length,barrier.base_width,k)
    o = [o1,o2]
    return o
end
function reinforcement(constants,barrier,k)
    l = soil_pressure(constants,barrier,k)
    qmin = l[2]
    qmax = l[1]
    x = heel(barrier.base_width,barrier.wall_t)+ barrier.wall_t
    q =(((qmin-qmax)/barrier.base_width)*x)+qmax
    C = toe(barrier.base_width,barrier.wall_t)
    Mb = (q+(2*qmax))*((C^2)/6)
    df = 12*0.10*(barrier.base_thickness)
    A1 = Are_a(Mb,df)
    println("Area in inch2 : $A1")
    water_w = weight(constants.spec_water,heel(barrier.base_width,barrier.wall_t),barrier.base_length,barrier.height)
    Ah = 0.5*heel(barrier.base_width,barrier.wall_t)
    Mb = water_w*Ah
    A2 = Are_a(Mb,df)
    println("Area in inch2 : $A2")
end
```

Figure 29-Foundation deisgn module II

Bolts design module:

```
type bolts
    area
    hef
    cedge
    embeddment_depth
    min_hole_depth
    hole_diameter
    spacing
    fixture_thickness
end
bolt = bolts(0,0,0,0,0,0,0,0)
type bolts_consts
    fut
    fyk
    kcr
end
bconsts=bolts_consts(0,0,0)
function tension_design(bolt,bconsts,tdata,dest,n)
    #define tensr
    coln = names(tdata)
    bolt_data = tdata[coln[n]]
    bolt.area = bolt_data[4]
    bconsts.fut = bolt_data[2]
    bconsts.fyk = bolt_data[1]
    tensr = Tensr(bolt.area,bconsts.fut)
    yms = Yms(bconsts.fut,bconsts.fyk)
    m = tensr/yms
    if m < dest
        if n==6
            println("bolts size required is beyond M20,changing flange_length")
            constants.flange_coeff = constants.flange_coeff + 1
            design_bolts(constants,barrier,bolt,bconsts)
        else
            n = n+1
            tension_design(bolt,bconsts,tdata,dest,n)
        end
    else
        return [n,coln[n]]
    end
end
function concrete_con(constants,bolt,bconsts,cdata,n,dest)
    coln = names(cdata)
    bolt_data = cdata[coln[n]]
    bolt.hef = bolt_data[1]
    bolt.cedge = bolt_data[2]
    bconsts.kcr = bolt_data[3]
    ccres = cconr(bconsts.kcr,bolt.hef,constants.cube_stren)
    m = ccres/1.5
    if m < dest
        if n==6
            println("bolts size required is beyond M20,changing flange_length")
            constants.flange_coeff = constants.flange_coeff + 1
            design_bolts(constants,barrier,bolt,bconsts)
        else
            n = n+1
            concrete_con(constants,bolt,bconsts,cdata,n,dest)
        end
    else
        return [n,coln[n],ccres]
    end
end
function shear_resistance(sdata,fst,n)
    coln =names(sdata)
    bolt_data = sdata[coln[n]]
    stren = bolt_data[1]
    stren =1000*stren
    m = stren/1.25
    if m < fst
        if n==6
            println("bolts size required is beyond M20,changing flange_length")
            constants.flange_coeff = constants.flange_coeff + 1
            design_bolts(constants,barrier,bolt,bconsts)
        else
            n= n+1
            shear_resistance(sdata,fst,n)
        end
    else
        return [n,coln[n]]
    end
end
function concrete_edge(constants,edge_data,fst,c1,n)
    coln = names(edge_data)
    bolt_data = edge_data[coln[n]]
    dnom = bolt_data[1]
    c1 = c1*304.5
```

Figure 30-Bolt design module I

```julia
    le = bolt_data[2]
    alph = 0.1*((le/c1)^0.5)
    fc = constants.cube_stren
    bet = 0.1*((dnom/c1)^0.2)
    k1 = 1.35
    Vedge = edge_res(k1,dnom,alph,le,bet,fc,c1)
    m = Vedge/1.5
    if m < fst
        if n==6
            println("bolts size required is beyond M20,changing flange_length")
            constants.flange_coeff = constants.flange_coeff + 1
            design_bolts(constants,barrier,bolt,bconsts)
        else
            n = n+1
            concrete_edge(constants,edge_data,fst,c1,n)
        end
    else
        return [n,coln[n]]
    end
end
function pry_out_resistance(pry_data,nrc,n,fst)
    coln = names(pry_data)
    bolt_data = pry_data[coln[n]]
    k = bolt_data[1]
    pry_res = k*nrc
    if pry_res < fst
        if n==6
            println("bolts size required is beyond M20,changing flange_length")
            constants.flange_coeff = constants.flange_coeff + 1
            design_bolts(constants,barrier,bolt,bconsts)
        else
            n = n+1
            pry_out_resistance(pry_data,nrc,n,fst)
        end
    else
        return [n,coln[n]]
    end
end
function design_bolts(constants,barrier,bolt,bconsts)
    tdata = CSV.read("./bolts/tension.csv")
    l = overturning(constants,barrier)
    movert = l[2]
    movert = 0.5*1355.75*movert
    bwallt = barrier.wall_t
    dest = des_t(movert,bwallt,constants.flange_coeff)
    n=2
    answer=tension_design(bolt,bconsts,tdata,dest,n)
    boltr= answer[2]
    println("Against tensile failure: $boltr")
    n=answer[1]
    cdata = CSV.read("./bolts/concrete_cone_resistance.csv")
    answer2 = concrete_con(constants,bolt,bconsts,cdata,n,dest)
    concr= answer2[2]
    println("Against concrete cone failure: $concr")
    n = answer2[1]
    if(n == 2)
        println("establish pull out resistance")
    end
    fst=F_sta(constants.spec_water,barrier.height,barrier.span_length)
    fst = 0.25*4.45*fst
    sdata = CSV.read("./bolts/shear_resistance.csv")
    ans = shear_resistance(sdata,fst,n)
    tans = ans[2]
    n = ans[1]
    println("steel shear resistance : $tans")
    c1 = toe(barrier.base_width,barrier.wall_t)
    c1 = c1 - (0.5*constants.flange_coeff*(barrier.wall_t))
    if c1 < 0
        constants.flange_coeff = constants.flange_coeff - 1
        design_bolts(constants,barrier,bolt,bconsts)
    end
    edge_data =CSV.read("./bolts/edge.csv")
    answ = concrete_edge(constants,edge_data,fst,c1,n)
    rans = answ[2]
    n = answ[1]
    println("Against edge failure : $rans")
    pry_data = CSV.read("./bolts/pry.csv")
    ansr = pry_out_resistance(pry_data,answer2[3],n,fst)
    xans = ansr[2]
    println("Against concrete pry-out : $xans")
    r = ansr[1]
    output_bolt_data(r,bolt)
    return 0
end
function output_bolt_data(n,bolt)
    temp_data = CSV.read("./bolts/base.csv")
    coln = names(temp_data)
    bolt_data = temp_data[coln[n]]
```


Figure 31-Bolts design module II

```
    bolt.hole_diameter = bolt_data[1]
    bolt.embeddment_depth = bolt_data[2]
    bolt.min_hole_depth = bolt_data[3]
    bolt.cedge = bolt_data[4]
    bolt.spacing = bolt_data[5]
    bolt.fixture_thickness = bolt_data[6]
    x=[bolt.hole_diameter bolt.embeddment_depth bolt.min_hole_depth bolt.cedge bolt.spacing bolt.fixture_thickness]
    filepath ="./bolts/hole_params.csv"
    fid1 = open(filepath,"w")
    writecsv(fid1,x)
    close(fid1)
end
```

Figure 32-Bolts design module III

Seal design module:

5/31/2018 seal.jl

05/31/18 05:32:48 /media/nsamba/W7_AIOX86X6/usb/seal.jl

```
type Seal
    thickness
    seating_pressure
    width
    len
end
seal = Seal(0,0,0,0)
function des_bolts(wm,fst,nbolts,shear,n)
    Sp = 225*0.14503773*1000
    bolt_data = CSV.read("./seal/bolts/bolts.csv")
    cols = names(bolt_data)
    bolt_props = bolt_data[cols[n]]
    Area1 = 0.00155*bolt_props[4]
    fi = Fi(Sp,Area1)
    if fi < wm
        n = n+1
        des_bolts(wm,fst,nbolts,shear,n)
    else
        shear = shear*0.14503773*1000
        fst1 = (fst/nbolts)/144
        Area2 = fst1/shear
        if Area1 < Area2
            n = n+1
            des_bolts(wm,fst,nbolts,shear,n)
        else
            return [n,bolt_data]
        end
    end
end
function output_screw_dimensions(m)
    bolt_data = m[2]
    n = m[1]
    cols = names(bolt_data)
    bolt_props = bolt_data[cols[n]]
    pitch = bolt_props[2]
    bolt_diameter = bolt_props[1]
    minor_diameter = bolt_props[3]
    println("Seal screw: M$bolt_diameter X $pitch")
    x = [bolt_diameter pitch minor_diameter]
    filepath ="./seal/bolts/screw_data.csv"
    fid = open(filepath,"w")
    writecsv(fid,x)
    close(fid)
    filepath ="./seal/bolts/test_screw_data.csv"
    fid = open(filepath,"a")
    writecsv(fid,x)
    close(fid)
end
function des_seal(seal,constants,barrier)
    P = Ph(constants.spec_water,barrier.height)
    P = P/(144) #convert pft to psi
    seal.width = 2*(barrier.span_t)*12 #width of seal
    seal.len = barrier.height
    n = constants.seal_select
    seal_data = CSV.read("./seal/seal_data.csv")
    cols = names(seal_data)
    seal_props = seal_data[cols[n]]
    seal.seating_pressure = seal_props[3]
    m = seal_props[2]
    seal.thickness = seal_props[1]
    if seal.width < 1/4
        b = seal.width
    else
        b = 0.5 * sqrt(seal.width)
    end
    seal.len = 12*barrier.height
    wm1 = Wm1(b,seal.len,m,P)
    wm2 = Wm2(b,12,seal.seating_pressure)
    fst = F_sta(constants.spec_water,barrier.height,barrier.span_length)
    nbolts = 2*(barrier.height)
    if wm1<wm2
        m = des_bolts(wm2,fst,nbolts,constants.mat_shear,2)
    else
        m = des_bolts(wm1,fst,nbolts,constants.mat_shear,2)
    end
    output_screw_dimensions(m)
    x = [seal.len seal.width seal.thickness]
    filepath ="./seal/ seal_data.csv"
    fid = open(filepath,"w")
    writecsv(fid,x)
    close(fid)
    filepath ="./seal/test_seal_data.csv"
    fid = open(filepath,"a")
    writecsv(fid,x)
    close(fid)
```

file:///tmp/tmp4kww8z.html 1/2

Figure 33-Seal Design module

Barrier CAD design program (barrier.py):


```python
import os,csv
import Part,Arch,Draft
from FreeCAD import Base

def design_base(wall_t,wall_width,base_width,base_thickness,base_length,span_length,key_depth,folder_path):
    x=span_length/2 + base_length
    s =base_width-wall_width
    y=s/3
    y=y+(wall_width/2)
    point=[]
    point.append(Base.Vector(-x,y,0))
    point.append(Base.Vector(-x+base_length,y,0))
    point.append(Base.Vector(-x+base_length,wall_width/2,0))
    point.append(Base.Vector(-x+base_length+span_length,wall_width/2,0))
    point.append(Base.Vector(-x+base_length+span_length,y,0))
    point.append(Base.Vector(x,y,0))
    point.append(Base.Vector(x,y-base_width,0))
    point.append(Base.Vector(x-base_length,y-base_width,0))
    point.append(Base.Vector(x-base_length,-wall_width/2,0))
    point.append(Base.Vector(x-base_length-span_length,-wall_width/2,0))
    point.append(Base.Vector(x-base_length-span_length,y-base_width,0))
    point.append(Base.Vector(x-base_length-span_length-base_length,y-base_width,0))
    edg = list()
    for i in range(0,11):
        edg.append(Part.makeLine(point[i],point[i+1]))
    edg.append(Part.makeLine(point[11],point[0]))
    w=Part.Wire(edg)
    f=Part.Face(w)
    P=f.extrude(FreeCAD.Vector(0,0,base_thickness))
    nsolid=P
    cylinders = bolt_holes(wall_t,span_length,base_length,base_width,base_thickness)
    for i in cylinders:
        nsolid = nsolid.cut(i)
    filepath = folder_path + "/barrier_base.stp"
    nsolid.exportStep(filepath)
    keys = design_key(span_length,base_length,base_width,key_depth,wall_width,wall_t)
    compound = Part.makeCompound([keys[0],nsolid])
    compound  = Part.makeCompound([compound,keys[1]])
    compound.exportStep(folder_path+"/barrier_foundation.stp")

def design_key(span_length,base_length,base_width,key_depth,wall_width,wall_t):
    x = span_length/2
    y2 = (base_width - wall_t)
    y2 = y2/3.8
    y = (wall_width/2) + y2
    points = []
    points.append(Base.Vector(x,y,0))
    points.append(Base.Vector(x+(base_length),y,0))
    points.append(Base.Vector(x+(base_length),y-wall_width,0))
    points.append(Base.Vector(x,y-wall_width,0))
    edges = []
    for i in range(0,3):
        edges.append(Part.makeLine(points[i],points[i+1]))
    edges.append(Part.makeLine(points[3],points[0]))
    w = Part.Wire(edges)
    f = Part.Face(w)
    key = f.extrude(FreeCAD.Vector(0,0,-key_depth))
    keys = []
    keys.append(key)
    key = key.mirror(Base.Vector(0,0,0),Base.Vector(1,0,0))
    keys.append(key)
    return keys

def bolt_holes(wall_t,span_length,base_length,base_width,base_thickness):
    bolt_d = file("./bolts/hole_params.csv","r")
    bolt_data = csv.reader(bolt_d)
    cylinders = []
    for row in bolt_data:
        bolt_diam = float(row[0])
        bolt_depth = float(row[2])
        bolt_spacing = float(row[4])
    x = (span_length/2)+(base_length/2)-(bolt_spacing/2)
    y = (0.5*wall_t)+(4*wall_t)
    pos  = Base.Vector(x,y,base_thickness)
    des_cyl(bolt_diam,bolt_depth,pos,cylinders)
    x = (span_length/2)+(base_length/2)+(bolt_spacing/2)
    pos = Base.Vector(x,y,base_thickness)
    des_cyl(bolt_diam,bolt_depth,pos,cylinders)
    pos = Base.Vector(x,-y,base_thickness)
    des_cyl(bolt_diam,bolt_depth,pos,cylinders)
    x = x - (bolt_spacing)
    pos = Base.Vector(x,-y,base_thickness)
    des_cyl(bolt_diam,bolt_depth,pos,cylinders)
    return cylinders
```


Figure 34- Barrier CAD program I

```python

def design_shield(span_length,span_t,swidth,bheight,folder_path,bthick):
    points = []
    x = 0
    y = 0.5*span_t
    z = bthick
    points.append(Base.Vector(0,y,z))
    x = (0.5*span_length) -(swidth+5)
    points.append(Base.Vector(x,y,z))
    y = y+(3*span_t)
    points.append(Base.Vector(x,y,z))
    x = x+5
    points.append(Base.Vector(x,y,z))
    y = y-(3*span_t)
    points.append(Base.Vector(x,y,z))
    x = x+swidth
    points.append(Base.Vector(x,y,z))
    points.append(Base.Vector(x,-y,z))
    x = x - swidth
    points.append(Base.Vector(x,-y,z))
    y = -(y+(3*span_t))
    points.append(Base.Vector(x,y,z))
    x = x - 5
    points.append(Base.Vector(x,y,z))
    y = y+(2*span_t)
    points.append(Base.Vector(x,y,z))
    x = 0
    points.append(Base.Vector(x,y,z))
    edges = []
    for i in range(0,11):
        edges.append(Part.makeLine(points[i],points[i+1]))
    edges.append(Part.makeLine(points[11],points[0]))
    w = Part.Wire(edges)
    f = Part.Face(w)
    height = 304.5*bheight
    P = f.extrude(Base.Vector(0,0,height))
    P1 = P.mirror(Base.Vector(0,0,0),Base.Vector(1,0,0))
    cpd = Part.makeCompound([P,P1])
    cpd.exportStep(folder_path+"/wall_span.stp")
    screw_dat = file("./seal/bolts/screw_data.csv")
    screw_data = csv.reader(screw_dat)
    for row in screw_data:
        diameter = float(row[0])
        pitch = float(row[1])
        minor_diam = float(row[2])
    #to be finished.

def design_plate(span_length,base_length,base_width,wall_t,base_thickness,folder_path):
    bolt_d = file("./bolts/hole_params.csv","r")
    bolt_data = csv.reader(bolt_d)
    for row in bolt_data:
        bolt_diam = float(row[0])
        bolt_spacing = float(row[4])
        bolt_fixture = float(row[5])
    x = (span_length/2)+(base_length/2)
    y = (0.5*wall_t)+(4.8*wall_t)
    x2 = 0.6*bolt_spacing
    z = base_thickness
    points = []
    points.append(Base.Vector(x-x2,y,z))
    points.append(Base.Vector(x+x2,y,z))
    points.append(Base.Vector(x+x2,-y,z))
    points.append(Base.Vector(x-x2,-y,z))
    edges = []
    for i in range(0,3):
        edges.append(Part.makeLine(points[i],points[i+1]))
    edges.append(Part.makeLine(points[3],points[0]))
    w = Part.Wire(edges)
    f = Part.Face(w)
    P = f.extrude(Base.Vector(0,0,bolt_fixture))
    plate = Part.makeSolid(P)
    cylinders = bolt_holes(wall_t,span_length,base_length,base_width,base_thickness+bolt_fixture)
    for i in cylinders:
        plate = plate.cut(i)
    plate1 = plate.mirror(Base.Vector(0,0,0),Base.Vector(1,0,0))
    cpd = Part.makeCompound([plate1,plate])
    cpd.exportStep(folder_path+"/flange.stp")
    return bolt_fixture

def des_cyl(bolt_diam,bolt_depth,pos,cylinders):
    cylinda = Part.makeCylinder(bolt_diam/2,bolt_depth,pos,Base.Vector(0,0,1),360)
    cylinda = Part.makeSolid(cylinda)
    cylinders.append(cylinda)
    cylinda = cylinda.mirror(Base.Vector(0,0,0),Base.Vector(1,0,0))
    cylinders.append(cylinda)

def design_frame(span_length,base_length,folder_path,bthick):
    pos = Base.Vector(0,0,0)
```


Figure 35-Barrier CAD program II

```
    support_data = file("./wall_span/supports.csv")
    support_data = csv.reader(support_data)
    for row in support_data:
        sheight = 304.5*int(row[0])
        sthick = 304.5*float(row[1])
        swidth = 304.5*float(row[2])
        hthick = 304.5*float(row[3])
    hwidth = 2*hthick
    points = []
    x = (0.5*span_length)+(0.5*base_length) - (0.5*swidth)
    y = (0.5*sthick)
    z = bthick
    points.append(Base.Vector(x,y,z))
    points.append(Base.Vector(x+swidth,y,z))
    points.append(Base.Vector(x+swidth,-y,z))
    points.append(Base.Vector(x,-y,z))
    locs = []
    y = (0.5*hthick)
    locs.append(Base.Vector(x,y,z))
    locs.append(Base.Vector(x+hwidth,y,z))
    locs.append(Base.Vector(x+hwidth,-y,z))
    locs.append(Base.Vector(x,-y,z))
    edges = []
    for i in range(0,3):
        edges.append(Part.makeLine(points[i],points[i+1]))
    edges.append(Part.makeLine(points[3],points[0]))
    w = Part.Wire(edges)
    f = Part.Face(w)
    P = f.extrude(Base.Vector(0,0,sheight))
    edges = []
    for i in range(0,3):
        edges.append(Part.makeLine(locs[i],locs[i+1]))
    edges.append(Part.makeLine(locs[3],locs[0]))
    c = Part.Wire(edges)
    cf = Part.Face(c)
    cd = cf.extrude(Base.Vector(0,0,sheight))
    x = (0.5*span_length)+(0.5*base_length)
    cd1 = cd.mirror(Base.Vector(x,0,0),Base.Vector(1,0,0))
    P = P.cut(cd)
    P = P.cut(cd1)
    P1 = P.mirror(Base.Vector(0,0,0),Base.Vector(1,0,0))
    cpd = Part.makeCompound([P1,P])
    cpd.exportStep(folder_path+"/frames.stp")
    return swidth
    # to be finished

def main():
    barrier_data = file("F:/usb/barrier/barrier.csv","r")
    des_data = csv.reader(barrier_data)
    for row in des_data:
        wall_height = int(row[0])
        wall_t = float(row[1])
        wall_t = 304.5*wall_t
        wall_width= 304.5*1
        base_width = float(row[2])
        base_width = 304.5*base_width
        base_thickness = float(row[3])
        base_thickness = 304.5*base_thickness
        base_length = float(row[4])
        base_length = 304.5*base_length
        span_length = float(row[5])
        span_length = (304.5*span_length) - base_length
        key_depth = float(row[6])
        key_depth = 304.5*key_depth
        span_thickness = 304.5*(float(row[7]))
    folder_path = "F:/usb/simulations/"+ str(wall_height)
    if not os.path.exists(folder_path):
        os.mkdir(folder_path)

design_base(wall_t,wall_width,base_width,base_thickness,base_length,span_length,key_depth,folder_path)
    plate_thickness=design_plate(span_length,base_length,base_width,wall_t,base_thickness,folder_path)
    swidth = design_frame(span_length,base_length,folder_path,base_thickness+plate_thickness)
    design_shield(span_length+base_length,span_thickness,swidth,wall_height,folder_path,base_thickness)
main()
```


Figure 36- Barrier CAD program III