ACKNOWLEGEMENT

First and foremost, I would like to convey my appreciation to Associate Professor Ir Dr Choong Kok Keong, who has devoted much time to guide to guide and mentor me. Under his supervision, I have the chance to explore more about precast industry which has become more essential nowadays in Malaysia.

Furthermore, I would like to express my gratitude to Dr Omid Hassanshahi at School of Civil of Engineering, Universiti Sains Malaysia (USM) who helped me a lot in software analysis. He taught me and guided me well in the use of finite element modeller software ANSYS. I would also like to mention Mr Hussein Alsalami, a PhD student at School of Civil Engineering for his help and guidance in modelling using ANSYS. Moreover, I would like to give my gratitude to Mr Sua Xing Yong, a Final Year Student at School of Civil Engineering who taught and guided me on another finite element software LUSAS.

Last but not least, I would like to express my thank to my family members and friends who supported so much in this final year project. They give me moral support through the project

ABSTRAK

Cerucuk kepingan adalah salah satu jenis struktur penahan bumi yang memberikan sokongan terhadap tekanan permukaan bumi. Cerucuk kepingan mempunyai aplikasi yang luas dalam perlindungan cerun dan benteng jalan. Di Malaysia, konkrit pratuang adalah komponen IBS yang paling biasa. Objektif utama kajian ini adalah untuk mengkaji kesan jarak bersih di antara liang dan garis pusat liang pada bahagian web bagi cerucuk kepingan dan membandingkan dengan struktur cerucuk kepingan tanpa berliang. Analisis elemen ini dilakukan dengan menggunakan perisian unsur terhingga ANSYS dan LUSAS. Sejumlah 26 model yang terdiri daripada 5 jenis jarak bersih di antara liang dan 5 jenis diameter untuk liang yang berbeza termasuk model kawalan. Daripada hasil analisis, dapat disimpulkan bahawa semakin besar jumlah luas liang, semakin tinggi pengurangan kapasiti struktur. Jumlah luas liang dikawal oleh dua faktor, iaitu diameter perforasi dan jarak bersih di antara perforasi. Pengurangan maksimum dalam momen lentur pada retak pertama dan pesongan yang sepadan dengan model kawalan masing-masing adalah 52.12% dan 7.702%.

ABSTRACT

Sheet piles are one type of earth retaining structures which provide support against lateral earth pressure. Sheet piles have wide application in slope protection and road embankments. In Malaysia, precast concrete is the most common IBS component. Precast reinforced concrete sheet piles are manufactured with corrugated cross section and a pile head for easy installation using vibro hammer. The main objectives of this study are to study the effect of clear spacing between perforations and diameter of the perforation on the web section of sheet piles and compare the structural capacity of sheet pile with perforated web and without perforated web. Finite element analysis was carried out using finite element software ANSYS and LUSAS. A total of 26 models consisting 5 different clear spacing between perforation and 5 different diameters of perforation together with a controlled model have been considered. From the analysis, it can be concluded that that the larger the total area of perforation at the web section, the higher the reduction of structural capacity of the concrete. The total area of perforation is governed by two factors, which are diameter of perforation and clear spacing between perforation. The maximum reduction in bending moment at first crack and the corresponding deflection relative to the control model are 52.12 % and 7.702% respectively.

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CHAPTER 1

INTRODUCTION

1.1 Background

Sheet piles are the one type of earth retaining structures which provide support against lateral earth pressure. Sheet piles have a wide application in slope protection and road embankments. Sheet piles are favourable because of the advantage of speedy construction, light weight, high driving stresses resistance, and longer lifespan above and below the water table (Holakoo et al, 2017). Sheet piles can be manufactured from steel, timber or reinforced concrete. The idea of precast concrete sheet piles is inspired by the prestressed sheet piles and precast concrete sheet piles is a new technology which is now being widely used in the modern construction due to the advancement of precast industry and IBS system. Malaysia has attempted to transform its conventional method of construction to prefabrication using industrialised building systems (IBS) and changing productivity from project based into product based (Azhari Azman et al, 2012). In Malaysia, precast concrete is the most common IBS component. Precast reinforced concrete sheet piles are manufactured with corrugated cross section and a pile head which easier to clamp it with vibro hammer during installing.

Figure 1.1 Tongue and Groove (T&G) joints

Precast sheet piles are connected through series of Tongue and Groove (T&G) joints along the side of sheet piles as shown in Figure 1.1. The T&G joints reduce or prevent washing out of soil though the gap between sheet piles unit. The interlocking sheet piles system form a wall which acts as permanent or temporary support with reduce inflow of groundwater.

Figure 1.1 Installation of Precast Concrete Sheet Piles
(Source: Product Brochure Rivo Sheetpile)

Figure 1.2 shows the actual situation of installation of precast concrete sheet piles at site. Installation of sheet piles required vibro hammer or hydraulic hammer depend on the site condition. Pile head as shown in Figure 1.4 is introduced so it is easier for the vibro hammer to clamp firmly on it thus increasing the speed and efficiency of the installation process. On harder soil layer, a pile toe as shown in Figure 1.3 is introduced for smoother penetration into the soil. On softer soil where it is adjacent to the river, precast concrete sheet piles can be used for stabilization of road embankment (Falidah at el, 2014).

Figure 1.2 Pile Head

Figure 1.3 Pile Toe

Malaysia's local precast companies has been using precast reinforced concrete sheet pile technology for years. Many contractors prefer concrete sheet piles over steel sheet piles because concrete sheet piles are durable, maintenance free and corrosion free. In river banks stabilization project, steel sheet piles is much more expensive compared to concrete and vinyl sheet piles. Steel materials also require post-construction maintenance to protect against corrosion (Istijono and Hakam, 2015). Concrete mix will depend on the site condition. Special mix is required for embankment of soil at seaside. Additional supports such as anchors, ties, struts can be placed at a higher level behind the wall for extra stability.

Figure 1.4 Flexural testing of a Precast Concrete Sheet Pile
(Source: Product Brochure Rivo Sheetpile)

A flexural test is conducted on a precast concrete sheet pile (Tan et al, 2014). Figure 1.5 shows the sample of precast concrete sheet pile tested at the lab with concentrated loading at the mid-span and simply supported condition. The capacity of precast concrete sheet piles have 1.49 and 1.48 times higher than the estimated capacity at ULS of 175kNm. The structure behaves like a beam as the lateral earth force will induce bending moment. Flange to web thickness ratio will also affects the structural behaviour of corrugated RC section (Ong et al, 2015). Similar study was conducted on steel beam to determine the efficiency of structural steel section with perforated-corrugated web profile subjected to shear loading condition (De'nan et al, 2017). For bending strength of steel beams with corrugated webs, the contribution of the web to the ultimate moment capacity of a beam with corrugated web is negligible, thus Perforation in web is expected to cause less effect on ultimate moment capacity (Elgaaly et al, 1997).

1.2 Problem Statement

Nowadays, precast industry is growing and concrete sheet piles have been widely used in construction projects. However, typical concrete sheet piles are heavy compared to steel sheet piles. This creates challenge during transportation and installation process. Concrete sheet piles also consumes large amount of material. Heavy structure increases the cost of transportation whereas high materials consumption is also not economical. One possible solution to the above mentioned problem is the introduction of perforations in suitable parts of the concrete sheets piles. As concrete sheet piles are mainly used as retaining structure, its bending capacity is important. Since bending capacity is mainly contributed by the top and bottom flange of the section, one suitable part to introduce the perforation is the web. However, it is expected that introduction of perforation in web will lead to reduction in capacity. There are different parameters such as shape of perforation, size of perforation and spacing of perforation which are expected to have different degree of influence on the structural capacity of concrete sheet piles. It is necessary to carry out study to investigate the behaviour of concrete sheet piles with perforated web under different combination of parameter of perforation.

1.3 Objectives

This study is carried out with the following objectives:

i. To study the effect of clear spacing between perforations and diameter of the perforation on the web section of sheet piles on structural capacity.
ii. To compare the structural capacity of sheet pile with perforated web and without perforated web.

1.4 Layout of Thesis

Chapter One describes the overview and provides explanation of the problem statement and objectives of the research.

The type of sheet pile commonly used in construction industry is explained in Chapter Two. Past research studies on analysis of the flexural strength of concrete sheet pile with corrugated section and effect of perforation on the structural capacity are also presented.

Chapter Three describes the procedure of modelling the concrete sheet pile by using finite element software ANSYS and LUSAS. The specification and method are explained in order to determine the effect of perforation in the web section on structural capacity of concrete sheet pile modelled.

Chapter Four presents results and discussion of finite element analysis of concrete sheet pile models.

Chapter Five presents the conclusion of the study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Previous research studies related to reinforced concrete sheet piles can be categorized into the following three groups:

i. type of sheet pile commonly used
ii. analysis of the flexural strength of concrete sheet pile with corrugated section
iii. effect of perforation on the structural capacity

2.2 Type of Sheet Pile

Sheet Pile can be manufactured from different type of material such as steel, prestressed concrete and reinforced concrete, in which each of them has different advantage and disadvantage. They are commonly used in the construction industry. (Eskandari et al, 2011)

2.3 Steel Sheet Pile

Steel sheet pile is commonly used in the construction industry especially in Nordic countries and Western Europe. The innovative, easy-to-handle but rigid and durable pile joints, application of steel material technology and higher steel strength are the main reasons they are so popular. The importance of the resistance and stiffness of mechanical joints of slender steel piles is accentuated in soft soil conditions. The wide product range and different installation methods enable versatile applications from lightweight to heavily loaded structures in all soil conditions. In harbour structures bending resistance of the pile is often the dimensioning factor. The latest innovations are the highly rigid retaining wall structure based on steel piles (RD pile wall). RD pile wall is installed by drilling in all possible soil conditions. The steel piles can serve as energy piles that exploit renewable ground source energy for both heating and cooling. There has been wide co-operation in Finland between steel pile manufacturers, contractors, designers, manufacturers of piling equipment, researchers and authorities in developing steel pile technology for almost thirty years (Uotinena et al, 2013).

On the other hand, corrosion of steel structures in the marine environment is a major problem. The deterioration of this kind of structures is costly and difficult to predict both when designing new structures and when estimating the remaining service life time for existing structures (Wall et al, 2013).

2.4 Prestressed Concrete Pile

Before reinforced concrete sheet pile is introduced in Malaysia, prestressed concrete (PC) sheet pile with corrugated shape is widely used in Malaysia. Main manufacturers of prestressed concrete sheet pile includes Kobe Concrete, Hume Concrete and ACP prestressed Concrete. PC Corrugated sheet piles were tested by the Japanese Industrial Standard Committee and were formally given JIS approval under revised standard JISA-5326 on September 1, 1988 by the Japanese Minister of International Trade and Industry (Product Brochure: Kobe Concrete Prestressed Concrete Corrugated Sheet Piles, 2012).

2.5 Reinforced Concrete Pile

Prefabrication technology in Malaysia is called IBS, which is also known as modern methods of construction (MMC) or off-site manufacturing (OSM). Since 1960, IBS has been used in the construction industry globally but not in Malaysia. Malaysia is still practising the conventional methods which often cause delay in project, resulting in huge loss for the client due to the slow speed of construction, low quality and higher cost of construction (Wong et al, 2015). In 1994, Construction Industry Development Board (CIDB) was established in Malaysia and in 1998, CIDB implemented a 'IBS Score' to measure and access the IBS usage in buildings. Through the initiative by establishing CIDB, Malaysia has attempted to transform its conventional method of construction to prefabrication by using industrialised building systems (IBS) and changing productivity from project based into product based (Azman et al, 2012). Currently, In Malaysia, precast concrete is the most common IBS component used in the construction industry. Two pilot projects using precast concrete elements, as one of the IBS concepts, were launched in 1966 to produce high rise low cost flats in order to cope with the increasing housing demand. However, they created poor image to IBS due to low quality, leakages, unpleasant architectural appearances and other drawbacks (Rahman et al, 2006). Table 2.1 below shows the categorisation of off-site system in different countries.

Table 1.1 Categorisation of off-site system

Countries	**Categorisation of off-site system**
US	Off-site preassembly US Hybrid system Panellised system Modular building
UK	Component manufacture and subassembly UK Non-volumetric preassembly Volumetric preassembly Modular building
Australia	Non-volumetric preassembly Australia Volumetric preassembly Modular building
Malaysia	Precast concrete systems Formwork systems Steel framing systems Malaysia Prefabricated timber framing systems Block work systems Innovative product systems

2.6 Comparison between concrete sheet pile and steel sheet pile

Rivo Builders (M) Sdn. Bhd introduced precast concrete sheet pile in year 2004 (Product Brochure Rivo Sheetpile, 2012) in which the product is widely used in various application in construction industry due to several advantages over the conventional steel sheet pile. Table 2.2 shows the comparison between two different type of sheet pile.

Table 1.2 Comparison between concrete sheet piles and steel sheet piles

Concrete Sheet Piles	**Steel Sheet Piles**
Robust with rigid concrete section in special profiles	Flimsy, possibility of buckling susceptible to transverse bending failure
Special cement and thicker cover	Corrosion, vulnerable to adverse exposure conditions
Inherent durable properties of concrete	Protective coating: not practical and costly
Maintenance free with concrete structure	Short lifespan, high maintenance costs
Stable price, less affected by price fluctuation	Escalating costs of steel

2.7 Analysis of the flexural strength of concrete sheet pile with corrugated section

Corrugated shape is chosen because they have better capabilities. Corrugated sheet piles perform at their best when being driven in, they can be placed with greater accuracy. Corrugated shape is the relative new shape which was introduced in 2008 in Malaysia. Due to the advancement of precast concrete technology in Malaysia, precast concrete sheet piles have been widely used in many applications such as river embankment, retaining structures and coastal protection (Ong at el, 2015). The capacity of the precast concrete sheet pile tested using the a four-point flexural test which has been carried out previously is higher than the estimate capacity by 1.48 times and 1.49 time (Tan et al, 2014).

2.8 Effect of perforation on structural capacity

Perforated steel plate is cost efficiency where the shape of the perforation will greatly impact the structural capacity of the structure. From previous research, results obtained for circular, square and rectangular perforation shows that the ultimate shear capacity was influenced significantly with size of perforation, nearly 30% drop of shear capacity when the depth of perforation was increased to half the web depth of girders (Darehshouri et al, 2013).

Meanwhile, according to (Hamoodi et al, 2013), it was found that the presence of perforation in the web section of plate girder had reduced the ultimate shear load about 51%. Shear strength was considerably reduced by the presence of web perforation and it decrease with increase in the perforation sizes (Hamoodi et al, 2013).

2.9 Nonlinear behaviour of concrete

Nonlinear analysis is a tool suitable for engineer as a practical technique for design and verification of concrete structures. For some design and analysis problems, a linear analysis may not be sufficient when considering the requirement of satisfying a serviceability limit states such as calculating the deflections and crack widths. For new structures, a nonlinear analysis may be performed on the structure after initial proportioning using a plasticity-based design procedure based on a linear elastic analysis. Nonlinear analysis can assist in the evaluation of complex geometry or poorly detailed structures where the effects of localized cracking can be investigated. The model or structure may be poorly modelled by linear analysis. Situations where nonlinear analysis should be used are resistance of structures to extreme events, pushover analyses for structural capacity computation, resistance to fire, estimation of P- effects and so on and so on (Sabau et al, 2011).

The idea of perforated-corrugated web profile in achieving efficient structural steel section can reduce the weight of the steel section and may achieve similar performance to those without perforation. Perforated concrete shows nowadays a high potential for many construction and building engineering applications. In particular, it is shown that the acoustic behaviour of perforated concrete can be modelled using a dual porosity approach based on the knowledge of the non-acoustic properties of the matrix granular material and geometrical data.

This system facilitates passing the pipes of utility services through its perforation as well as it has a good-looking appearance. Three main factors were studied; namely, the percentage of mass loss (14% 19% and 26%) due to the provided perforation, the reinforcement configurations around the perforation (orthogonal reinforcement, circular stirrups, and cross-bars) and the perforation shape (circular and oval) (Gohar et al, 2017).

Considerable prior research in concrete penetration and perforation has been conducted for considering the effect of projectile on reinforced concrete. Experimental investigations of concrete penetration typically take the form of either penetration into concrete, in which depth of penetration is reported. However, despite decades of research on the penetration and perforation of concrete, breaching double reinforced concrete, removing both concrete and reinforcement remains a difficult problem. Understanding the energy required to perforate concrete and reinforcement will enlighten development of tools for breaching DRC. To better understand the kinetic energy required for a blunt-nosed projectile to perforate a reinforced concrete target a parametric numerical study was conducted. Parameters considered in the study include the projectile initial velocity, mass, length-to-diameter ratio, and impact orientation (Meyer, 2015).

2.10 Summary

Sheet Pile can be manufactured from various type of material, and they are being widely used in the modern construction. In Malaysia, prefabrication technology which is also known as IBS, a modern method of construction or off-site manufacturing. Currently, in Malaysia, precast concrete is the most common IBS component used in the construction industry. Rivo Builders (M) Sdn. Bhd. Introduced precast concrete sheet pile in year 2004 in which the product is widely used in various application in construction industry due to several advantages over the conventional steel sheet pile. The advantages include the durability and robustness of concrete sheet piles, stable price and maintenance free properties for concrete sheet piles. Corrugated shape is chosen for sheet pile due to better structural capacities. Corrugated shape is the relative new shape which was introduced in 2008 in Malaysia. Perforation on sheet pile can reduce the cost of production, but it greatly impacted the structural capacity of the structure. Therefore, it is necessary to carry out study on effect of perforation in web of concrete sheet piles on their structural capacity.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Analysis of the model is carried out using ANSYS and LUSAS software. ANSYS and LUSAS model and analyse sheet piles with corrugated cross-section. The model is designed as a solid element and analysed considering nonlinear material behaviour of concrete. Figure 3.1 illustrates the detailed dimension of the corrugated section of the Rivo T495-T120 used in this research (Product Brochure Rivo Sheetpile, 2012). Earth face of the concrete sheet pile is the face where the surface of the sheet pile is in contact with the soil in the real practice, whereas Air Face is the other face where it is usually in contact with air.

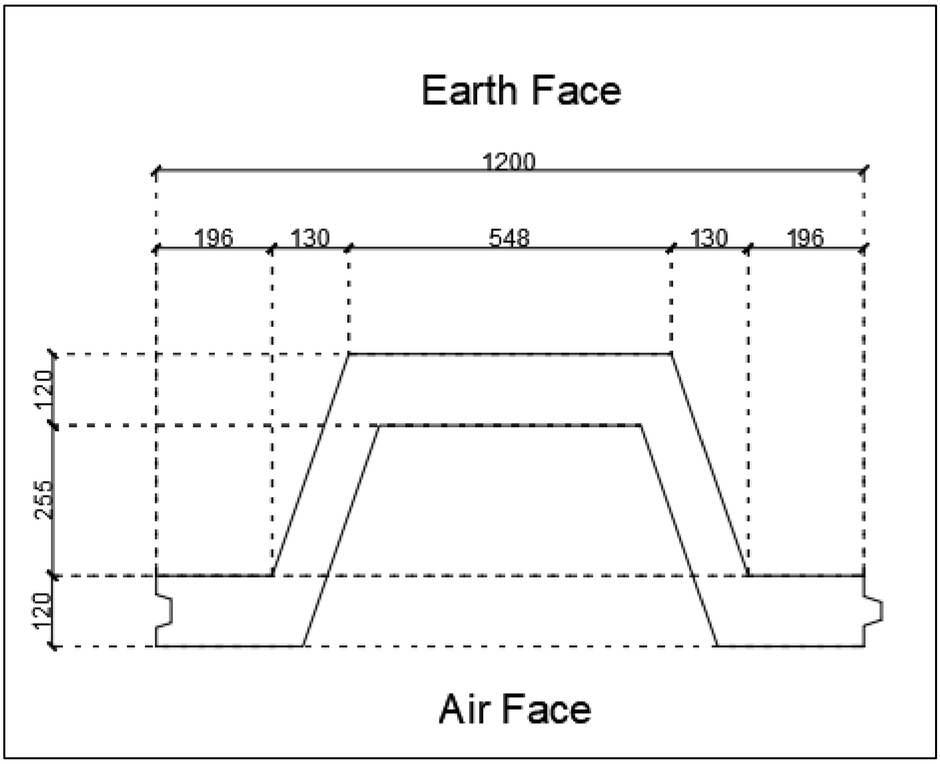

Figure 3.1 Corrugated Cross Section of Rivo T495-T120

3.2 Model of Concrete Sheet Piles

In this research study, 26 models including the controlled model without perforation have been designed and simulated to determine the deformation and normal stress due to bending. The material used in the modelling and analysis is Plain Ordinary Portland Cement Concrete. No reinforcement is provided. Characteristic strength of the concrete, f_{ck} is designed as 30 N/mm^2. The concrete sheet pile is designed with pinned supported at both end with concentrated load at the mid-span. The perforation is introduced at the web section of the concrete sheet pile, the perforation is of circular shape and is introduced with different combination of spacing and diameter of the Perforation. Moreover, the perforation is restricted to be introduced over the area as shown in the shaded area in Figure 3.2 to prevent any damage to the flange section of the concrete sheet pile.

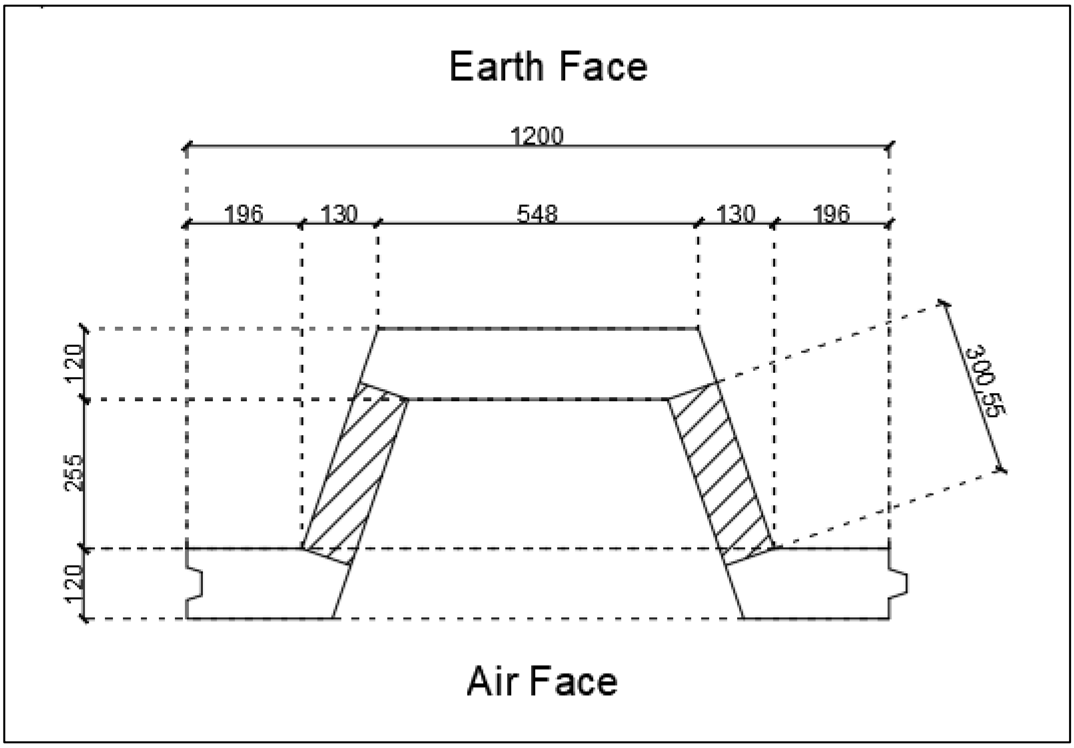

Figure 3.2 The proposed area for perforation

In summary, the model is design according to the following parameters:

- Dimension: Width, w: 1200mm, Depth, d: 700mm, Length, L: 12000mm
- Shape of the Perforation: Circular
- Materials used: Plain Ordinary Portland Cement, (no reinforcement)
- Concrete grade: 30
- Characteristic strength of concrete, f_{ck}: 30 N/mm^2
- Support conditions: Simply supported
- Loading: Concentrated load at mid-span
- Analysis results: Deformation and normal stress due to bending
- Type of element: Thick Shell element

The parameters to be investigated are spacing between each perforation and diameter of the perforation with the symbol S and D used to denote clear spacing between each perforation and diameter of the perforation, respectively. There are 5 cases of different spacing and 5 cases of perforation's diameter with total of 26 models including the controlled model which were simulated and analysed.

Table 3.1 The models with different combination of S and D

Clear Spacing between each Perforation, S (mm)	Diameter of the Perforation, D (mm)	Model
-	-	Controlled
300	80	A1
	120	A2
	160	A3
	200	A4
	240	A5
500	80	B1
	120	B2
	160	B3
	200	B4
	240	B5
700	80	C1
	120	C2
	160	C3
	200	C4
	240	C5
900	80	D1
	120	D2
	160	D3
	200	D4
	240	D5
1100	80	E1
	120	E2
	160	E3
	200	E4
	240	E5

3.3 Finite Element Linear Analysis using ANSYS and Finite Element Analysis Nonlinear Analysis using LUSAS

ANSYS and LUSAS are used to analyses the concrete sheet pile with different combination of clear spacing and dimeter of the perforation. Table 3.2 shows the concrete properties used in the software.

Table 3.2 Properties of concrete used in ANSYS and LUSAS

Density	2300 kg m^{-3}
Coefficient of thermal expansion	1.4E-5 C^{-1}
Young's modulus	30 GPa
Poisson's ratio	0.18
Bulk modulus	1.5625E+10 Pa
Shear modulus	1.2172E+10 Pa
Tensile Ultimate Strength	4 MPa
Compressive Ultimate Strength	40 MPa

3.4 Concrete Sheet Pile Models

Below are some sample models which have been analysed by ANSYS and LUSAS.

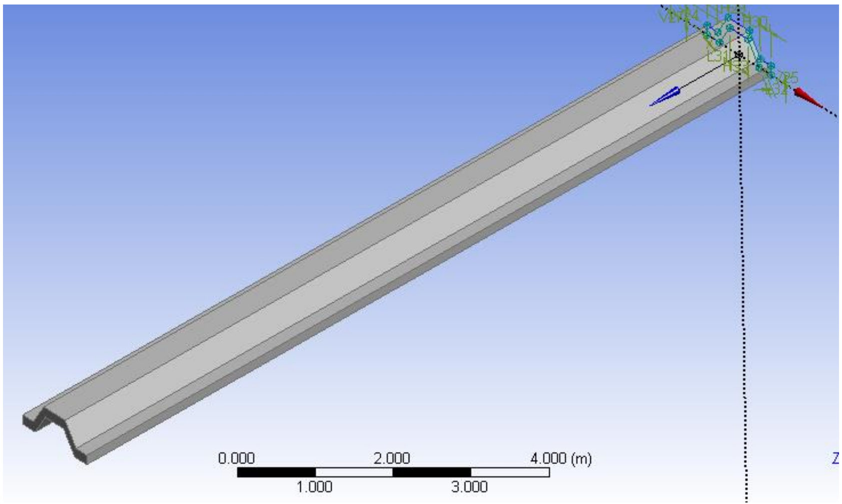

Figure 3.3 Controlled Model

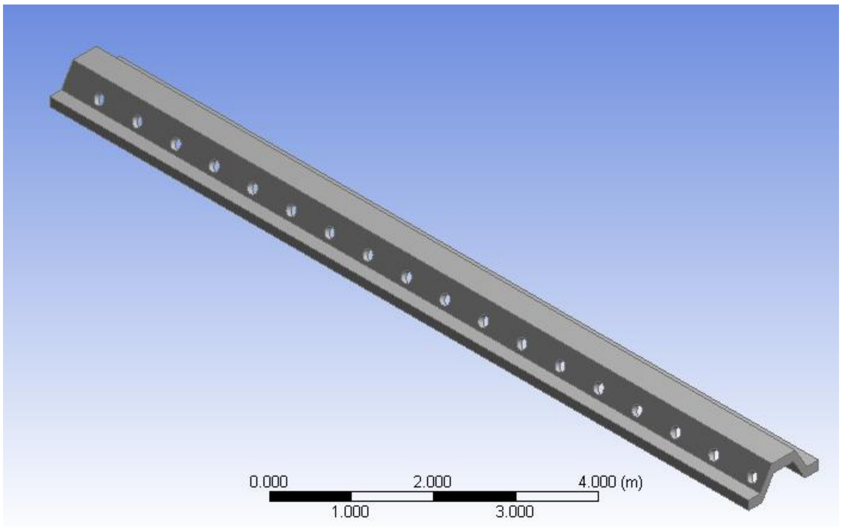

Figure 3.4 Model with S=500mm and D=160mm

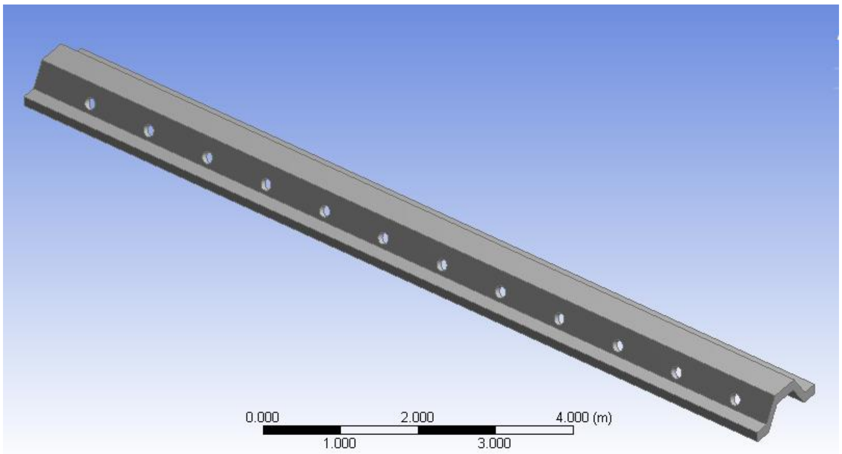

Figure 3.5 Model with S=800mm and D=160mm

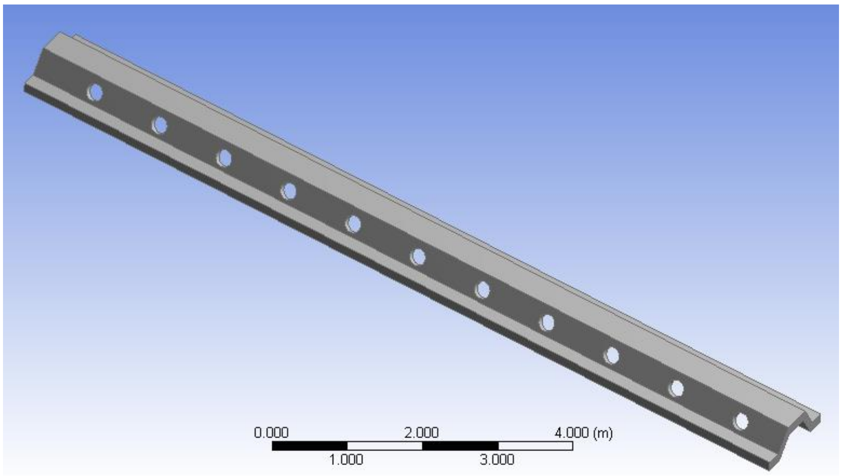

Figure 3.6 Model with S=800mm and D=240mm

Figure 3.3 to Figure 3.6 show the concrete sheet piles modelled by using ANSYS. From the 26 models analysed, the percentage of total area of perforation and percentage of reduction in structural capacity from each model is tabulated using the relations as shown in Equation 3.1 and Equation 3.2.