DESIGN, MODELLING AND OPTIMISATION OF AN INTERLOCKING STABILISED SOIL BLOCK (ISSB) MAKING MACHINE FOR IMPROVED PERFORMANCE

By

Oliver Samungole (BEng)
Computer No. 2015130815

A Dissertation Submitted to the University of Zambia in Partial Fulfillment of the requirements of a Master's Degree in Production Engineering and Management

THE UNIVERSITY OF ZAMBIA

LUSAKA

2020

DECLARATION

I, **Oliver Samungole**, do declare that this work is my own and that the work of other persons utilised in this dissertation has been duly acknowledged. This work presented here has not been previously presented at this or any other University for similar purposes.

Signature……………………………………..……Date………………………………………

APPROVAL

This dissertation by **Oliver Samungole** is approved as fulfilling the requirements for the award of the Master of Engineering in Production Engineering and Management by the University of Zambia.

Examiner 1: …………………….....Signature....…………………Date……………….……..

Examiner 2: …………………….....Signature....…………………Date……………….……..

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Name…………………..…………Signature.........................……Date………………

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ABSTRACT

In Zambia it is estimated that the existing housing stock stands at 2.5 million units catering for about 16 million people. The national housing deficit stands at more than 2 million houses and is compounded by urbanisation. Efforts have so far been made to use alternative building technology called Interlocking Stabilised Soil Block (ISSB) technology.

Currently, two manually operated compressing machines IBM-M1 and IBM-M2 have been developed by Technology Development and Advisory Unit (TDAU) of the University of Zambia (UNZA). However, the machines have challenges of low productivity and compressive strength which does not conform to the standards governing the performance of interlocking soil blocks. According to tests the two machines IBM-M1 and IBM-M2 machines have production rates of 232 and 283 blocks per eight-hour shift respectively which are by far lower than the 2200 blocks as produced by motorised machines. Compressive strength test was performed and the resultant mean failure loads for both machines were 3.9 MPa and 2.9 MPa respectively which is below the international standards of 6 to 7 MPa for compressed stabilised soil blocks.

In view of this shortfall a hydraulically operated ISSB machine (IBM-H1) was designed and fabricated and the machine production capacity improved by 239.22%. The mean block strength also improved significantly to 7 MPa and 6 MPa from 3.9 MPa and 2.9 MPa using 25% and 12% respectively of Portland cement content.

This study has drawn the conclusion that ISSB making machine production rate is affected by the mould loading rate, soil compression and block ejection time. Furthermore, the strength of ISSB blocks increases linearly as the block bulk density and the stabiliser quantity increases.

Key words: *Interlocking Stabilised Soil Block (ISSB), Technology Development and Advisory Unit (TDAU), Interlocking Block Maker-Manual 1 (IBM-M1), Interlocking Block Maker-Manual 2 (IBM-M2), Compressive strength.*

DEDICATION

This work is dedicated to my family, Stella my wife, Emmanuel, Favour and Stella (Jr), you have been a source of inspiration in all my studies. To my mother and late father this is for you too, I owe you a lot for your support and relentless encouragement to pursue higher education.

ACKNOWLEDGEMENT

I would like to sincerely thank my supervisors, Dr C.G.Chizyuka and Dr J.M.Chileshe for all their research support throughout the course of this study. I acknowledge and thank Mr Leonard Simukoko, Manager-TDAU for facilitating the use of workshop equipment. Furthermore, am indebted to all the lecturers in the School of Engineering who contributed immensely to this work up to this level. It will be folly indeed not mention and thank technicians whom I worked with so closely in all practical works of the project.

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LIST OF SYMBOLS

S	Standard Deviation
$\bar{x}$	Mean Value
α	Alpha
γ	Gamma
β	Beta
$\emptyset_0$	Initial Transmission Angle
θ_0	Initial Crank Angle
V	Velocity
t	Thickness
P	Pressure
r	Radius
l	Connecting Rod Length
Q_h	Hoop Stress
n	Rotation Speed
X_m	Maximum Stroke Length
A_{RT}	Mechanical Advantage
I	Moment of Inertia
E	Young's Modulus
η_{Vol}	Volumetric Efficiency
V_P	Pump Displacement
n_p	Pump Shaft Speed
$\eta_{t.p}$	Pump Efficiency

ACRONYMS AND ABREVIATIONS

TDAU	Technology Development and Advisory Unit
UNZA	University of Zambia
ISSB	Interlocking Stabilised Soil Block
IBM	Interlocking Block Maker
CEBs	Compressed Earth Blocks
SSB	Stabilised Soil Blocks
IBMM	Interlocking Block Making Machine
NHA	National Housing Authority
SNDP	Seventh National Development Plan
MNPD	Ministry of National Planning and Development
ASTM	American Society for Testing Materials
CAD	Computer Aided Design
CAE	Computer Aided Engineering
FOS	Factor of Safety

CHAPTER 1 INTRODUCTION

1.1 Background

Housing is one of the basic human needs and is ranked third after food and clothing (CAHF, 2016). In most developing countries housing is inadequate and the housing backlog has been increasing rapidly. One key reason for housing inadequacy is the increase in population (Racodi, 1997). Therefore, the investigation of alternative materials for the construction of low-cost housing has been the focus of many studies in many developing countries (Waziri et al, 2013).

Despite having one of the most progressive policies through the National Housing Authority (NHA) Act, the Housing Act, and the 1996 Housing Policy, Zambia has not achieved its objectives of producing sufficient affordable housing. This is reflected in the huge housing deficit of two million units (CAHF, 2016).

However, researchers worldwide have made significant efforts to find sustainable and affordable technologies to arrest the situation. The best approach so far is the development of technologies to increase the utilization of locally available building materials.

In Zambia, Technology Development and Advisory Unit (TDAU) of the University of Zambia developed a prototype Interlocking Stabilised Soil Block (ISSB) making machine for vertically oriented brick ejection. However, the main challenge with the design includes the low production rate and low resultant soil compaction strength. Further, TDAU has in the recent past produced another machine with a change in the brick orientation, ejection, and link mechanism but performance has remained as low as 280 bricks per 8-hour production shift.

Also, other researchers indicate that direct use of earth for ISSBs without modification for any form has a disadvantage of low performance. The shortcomings principally are low mechanical characteristics, unsatisfactory resistance to weathering and liability to volume change especially in the case of clay. These disadvantages can be improved to make the material compatible with the desired application in construction by combined chemical and mechanical action technically known as stabilisation (Waziri et al, 2013).

Generally, meeting the need for adequate housing for the population requires sustained investment and continued innovation, particularly in the appropriate technologies that lower the cost of construction and the cost to the environment. ISSB technology is one such technology which is also gaining recognition in developing countries (Adupa, 2009) and according to the Seventh National Development Plan (SNDP), the government of the Republic of Zambia stands ready to promote the development of quality, adequate and affordable housing units for all income groups in the country (MNPD, 2017).

The development of appropriate technologies for the production of low-cost building materials of good quality will speed up the provision of affordable urban housing in developing countries. One such technology is the use of stabilised-soil bricks. These have been in use in developing (African) countries for many years and have passed various stages of improvement in the production processes and quality (Kintingu, 2009).

Therefore, one of the expected key outputs of this research is a high performance manually operated ISSB making machine which will be achieved through the redesigning of an existing prototype ISSB machine.

1.2 Statement of the Problem

In Zambia, ISSB making machines are manufactured by TDAU. They are manually operated and currently have a production capacity of 280 blocks per day with a mean strength of compressive strength 3.5 MPa. The expected minimum strength for all load bearing blocks is 6 MPa.

Currently, work to develop the ISSB making machine has been going on by TDAU. Two prototypes have so far been developed IBM-M1 and IBM-M2 machines. The challenges of low productivity and soil compaction have not been fully addressed. Consequently, this has resulted in uncompetitive product demand and negatively affected housing and infrastructure development efforts.

It is for this reason that this research is being performed to improve the current TDAU ISSB making machine model for improved machine production capacity and compressive strength of the blocks.

1.3 Research Objectives

1.3.1 General Objective

The general objective of the study was to develop an ISSB making machine with improved performance characteristics.

1.3.2 Specific Objectives

The following were the specific objectives:

a) To study the existing prototype TDAU ISSB making machines.

b) To redesign an improved ISSB making machine.

c) To manufacture an improved ISSB making machine and carry out a performance test.

1.4 Study Rationale

The justification of this research can be drawn from the fact that it complements previous efforts by TDAU. Designing the improved ISSB making machine (IBM-H1) with regulated and increased compression pressure for stabilised soil compaction has improved the strength of the blocks.

Consequently, this study has helped improve the approach to continuous product development of the TDAU ISSB machine and act as a basis for the source of information required for design and development.

Furthermore, this research output is of greatly benefit to society in the area of alternative building materials. This is because the production rate and ISSB compressive strength has improved significantly.

Therefore, the expected key output is a high performance ISSB making machine which was achieved through redesigning of two existing TDAU ISSB prototype machines, IBM-M1 and IBM-M2.

1.5 Scope of the Study

The work was carried out in the Department of Mechanical Engineering, the University of Zambia using Solidworks CAD software and conventional machine tools in the workshop. The research did not include the development of ISSB machine optimisation algorithms but focused on increasing machine production capacity and compression pressure for improved ISSB strength.

1.6 Layout of the Dissertation

The main focus of this research was to design and manufacture an ISSB making machine for improved performance.

Chapter One explains the Interlocking block making machine, benefits of SSB block technology and an overview of existing ISSB machine designs technologies. Justification for this study to design and manufacture an ISSB making machine has been covered in this Chapter. The remainder of the dissertation has been arranged as follows:

Chapter Two covers the relevant literature about ISSB making machine designs. The main area of discussion in this chapter is the design of soil compressing mechanisms and how it affects the final product. The chapter also includes literature on CAD/CAE technology concerning machine design. Chapter Three focuses on the materials and methods used as well as the procedures employed in the production of the improved ISSB making machine.

Chapter Four explains processes used to design and manufacture the improved ISSB making machine. Chapter five contains results and discussion while the conclusions and recommendations are in Chapter six.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter gives the background of Stabilised Soil Block (SSB) technology and a general overview of ISSB design areas such as mechanical advantage, physical model simulation, and optimisation. Existing SSB compressing machine products have also been presented. It should be noted that the application of CAD in design and manufacturing is one of the major factors that have contributed immensely to the modern economic and competitive manufacturing and subsequently efficient and high product quality.

2.2 Interlocking Stabilised Soil Blocks

Stabilised soil blocks are compressed soil building blocks made from stabilised soil mixture using pressing machines. SSBs are potential alternative building materials whose production machines require continuous research and development. The production process involves compressing of soil mixed with the stabilisers such as cement, lime, and tarmac by using manually operated or motorised pressing machines. ISSBs are a further development of compressed earth bricks with both horizontal and vertical in and out-of-plane groves (Nambatya, 2015). The soil used is taken from one meter below the top soil, with any organic material and particles larger than 5 to 6 mm removed. Geometrically, as presented in Figure 2.1(a), they are defined as (220 to 230 mm) wide, (230 to 240 mm) long and (115 to 120mm) high while strength and density vary according to the compression and soil mixing ratios employed. ISSBs have a tongue and groove for locking purpose and Figure 2.1(b) shows the wall horizontal clearance created between tongue and grooves of the blocks which are also essentially provided for thermal control between the inside and external environment.

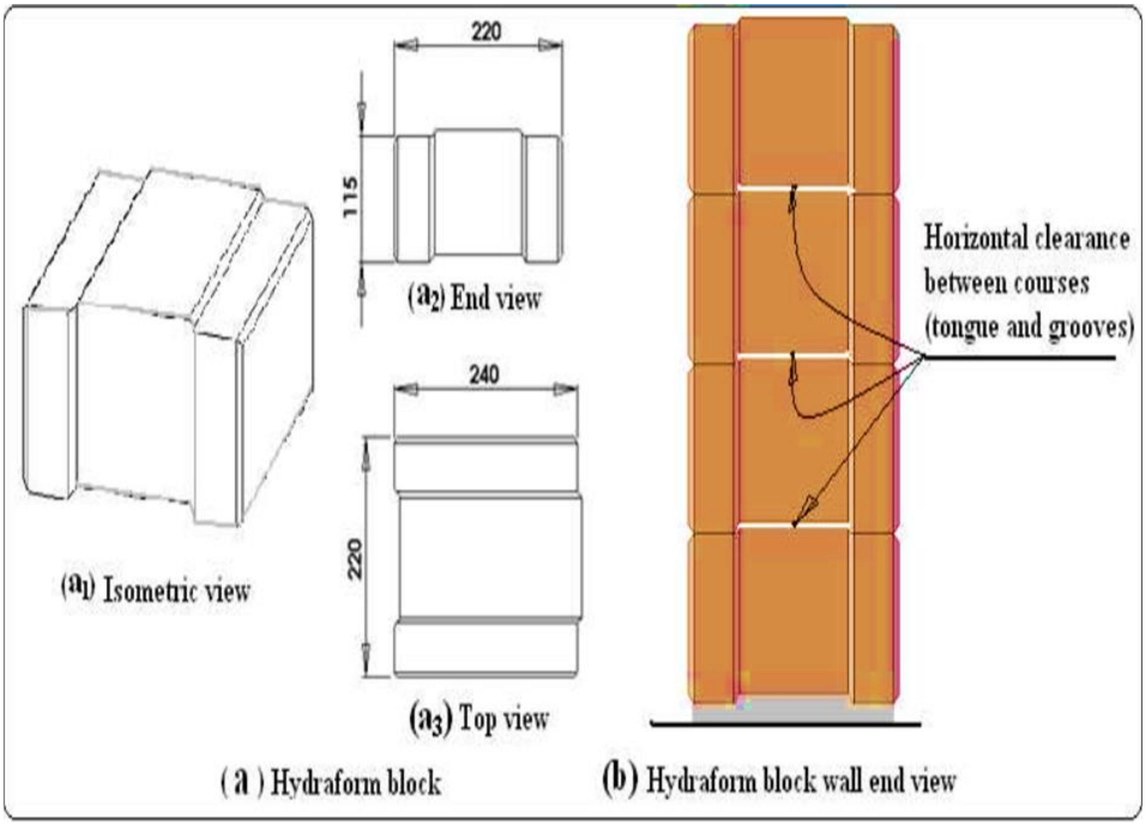


Figure 2.1: Hydraform Blocks. (Kintingu, 2009).

Motorised or manually operated pressing machines are used to achieve the required high compaction strength and density. The compressed soil is mixed with a stabiliser either lime or Portland cement and a considerable amount of water. The blocks are then allowed to cure for at least 14 days before they are used. Moreover, the compression must be sufficient to allow a fresh block to withstand the squeezing forces occurring when it is manually moved from machine to the curing area. The compressive strength largely depends on the soil composition, density, and percentage of stabiliser. Literature also shows soil mixture with 8% cement can yield blocks having a compressive strength of 4 to 5 MPa while for 10% cement the block strength is between 7 and 8 MPa (www.hydrafoamasia.com). A motorised machine (moulding pressure 4MPa to 10MPa) (Hydrafoam, 2004) is required to compact such block strength. According to the ASTM C 73-39, 3.5MPa is the minimum recommended compressive strength for compressed blocks.

Research has shown that improved levels of compaction have a significant effect on the compressive strength of the sample and the effectiveness of the cement as stabiliser added. The graph in Figure 2.2 presents data collected by Abas to indicate the relationships between cement content, compaction energy (defined in MPa pressure) and the resulting bulk density and subsequent 7-day wet compressive strength (cube). This is for laterite soil mixed with 25% sand (Abas, 2008).

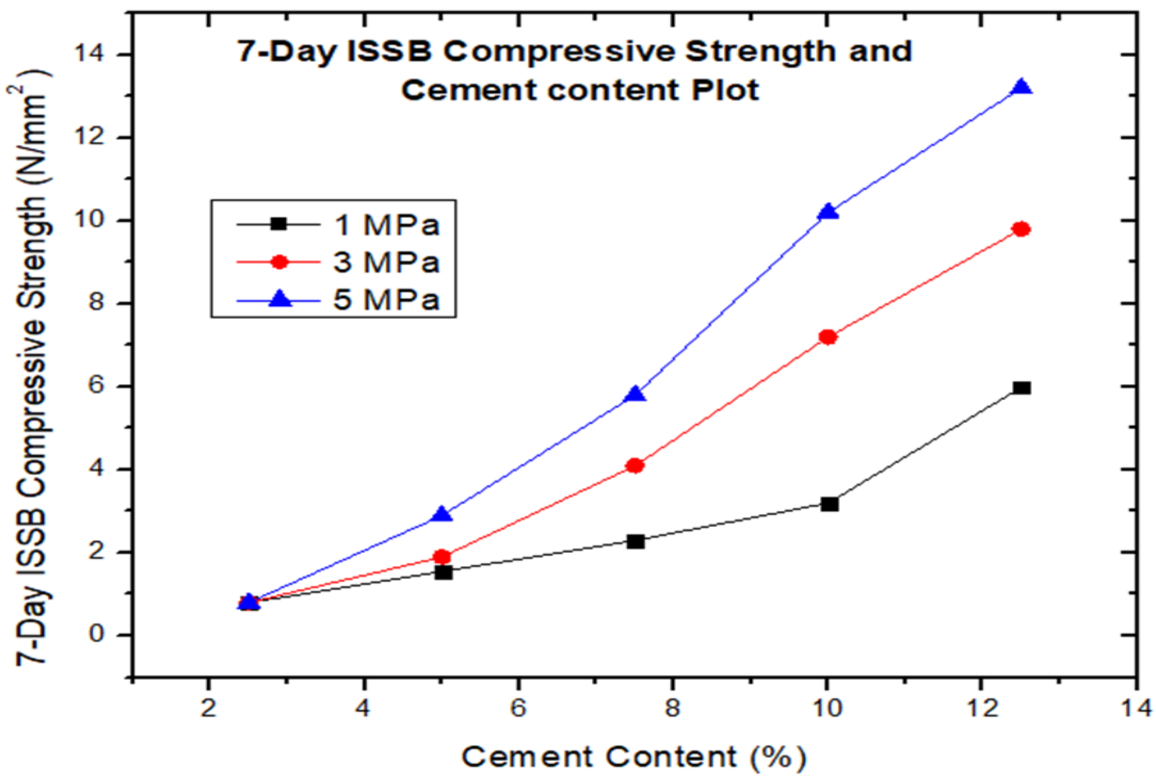


Figure 2.2: Cement Content Vs Compaction Pressure. (Abas, 2008).

Therefore, the compressive strength of SSB largely depends on the soil type, the form of stabiliser and the compaction pressure used to form the blocks. Further, the maximum compressive strengths of SSBs are obtained by proper mixing of suitable materials, compressing and curing. Thorough mixing is essential in the production of uniform and high-quality blocks. Equipment and methods adopted should, therefore, be capable of effective compaction (Onyeakpta and Onundi, 2014).

2.3 Benefits of Interlocking Stabilised Soil Blocks

As alternative building materials ISSBs have several advantages including the following:

i. Construction with interlocking block saves time and ample amount of mortar concrete compared to conventional masonry block laid with mortar.
ii. Areas prone to earthquake use the hollow Interlocking blocks with the strength improved with grout and reinforcement throughout the height of the wall to resist the effect of the earthquake, thus, providing adequate structural stability.
iii. Having formed the base course, other courses can be assembled by unskilled labour.
iv. Dismantling of the blocks in case of temporary structure does not cause damages
v. The cost of construction is relatively low.

Some of the disadvantages of Interlocking blocks are:

i. Standard skilled masonry labour is required to ensure proper horizontal and vertical alignment of the blocks, and that the corner and junction (T-joints) are right-angled, especially at the base course.
ii. Due to wind and rain seepage effect, the block wall need to be plastered.
iii. The mould, palettes groove edge may affect the block dimension, consequently hamper the alignment and stability of the wall if not adequately observed
iv. It is difficult to maintain the required tight tolerances for accurate construction of large walls through the moulding and cutting steps (UN-Habitat, 2015).

2.4 ISSB Compressing Machines

The idea of making blocks by compacting earth or mixing it with stabilising supplement is an old concept dating back thousands of years (Adupa, 2009). Previously and still customary in certain parts of the world, wooden moulds are used for making sun-dried or burned earth blocks. The turning point in the use of presses and in the way in which compressed earth blocks were used for building and architectural purposes came only into effect from 1952, following the invention of the famous little CINVA-RAM press, designed by engineer Raul Ramirez at the ClNVA centre in Bogota, Columbia (Guillaud, 1995)

Since then, the methods of producing earth block have progressed resulting in diverse motor-driven and manual presses which are either mobile or industrial-scale production units

ISSB making machines have been used in Zambia for a long time to produce ISSBs as alternative building materials. ISSB technology has proved to be an excellent substitute for concrete blocks but the full potential is yet to be realised because most of the commercially available machines are very expensive (Yakubu and Umar, 2015).

Originally, the simplest way to produce stabilised soil blocks involved tamping the processed soil in a mould with the help of a tamping rod. However, the degree of compaction could not easily be controlled.

Mechanised methods have been developed and the ISSB making machines can be broadly categorised as motorised and manual machines. The motorised machines are ideally suited for a mass production system, whereas the manual pressing machines are generally for decentralised production. The motorised ISSB making machine Figure 2.3 (a), generally use a hydraulic power pack to generate a large amount of compaction force with high production output. The manual machine Figure 2.3 (b), creates an adequate compaction force using animate energy. The soil mixture is first processed then compacted employing the static compaction process (Reddy, 2015).

(a) (b)

Figure 2.3: (a) Motorised ISSB making machine. (Leiyue Machinery, 2017)
(b) Manual ISSB Making Machine. (Kafum, 2018).

In 2015 Yakubu and Umar (2015) designed and constructed a multipurpose block making machine for the production of high quality and low cost stabilised compressed blocks. The motorised compressing machine was capable of producing 2215 plain bricks and 950 blocks per day. However, the machine had no provision for the production of ISSBs.

This research explored the improvement of the TDAU ISSB making machine to enhance its performance whose production output is between 250 and 300 blocks per day.

2.5 Block Pressing Direction and Dimensional Error

When moulding blocks, the compressed side in normal cases is the top or bottom. The conventional method of pressing blocks with a piston and a rectangular mould closely controls two of the three dimensions of the block and less closely the third dimension. The poorly controlled dimension is that in the direction of the Piston stroke, Figure 2.4, for example, the block height impinges on the top of the block. Moreover, the mould walls will be parallel and the Piston may not be exactly parallel with the base, thus the pressed face may be at a slight angle to the opposite face. Depending on the type of locking features the compaction force F_2 can be applied perpendicular to the end, top or front-back faces of the block (Kintingu, 2009).

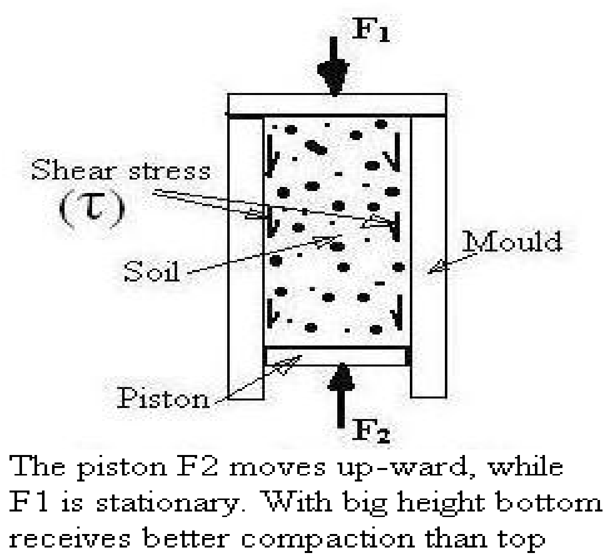


Figure 2.4: Schematic Diagram of an SSB Compressing Machine.
(Kintingu, 2009)

2.5.1 Perpendicular Compaction Force

For any given compaction pressure this minimises the force that has to be applied since the area of the block end is small. Therefore, minimising force allows the press linkages to be made less strong. As shown in Figure 2.4, the pressure inside the brick during moulding is likely to be more variable, as the piston-end (F_2) of the brick experiences full pressure (P) (Kintingu, 2009).

$$P_{Piston} = \frac{F_2}{A_{endface}} \tag{2.1}$$

Where:

P = Resultant pressure

F_2 = Applied piston force and

A = Surface area perpendicular to the applied force

2.5.2 Forces Applied Perpendicular to the Block's Top/Bottom Faces

According to research (*ibid*) the mode of pressing is essential if the top and/or bottom faces are of complex shape. Compressing stabilised soil along the top and bottom faces control the block width and length so that both internal and external wall surfaces are flat because of uniform block width as shown in Figure 2.5. From the accuracy of the block length, it is easy to maintain equal and constant overlaps for alternating courses (Kintingu, 2009). Therefore, it simplifies the process of estimating the block quantity in construction. This also facilitates the standardisation of measurements to multiples of block length or width. Although for constant-volume pressing all dimensions are fixed, only certain surfaces are 'wiped' during moulding and ejection, which does not affect dimensions.

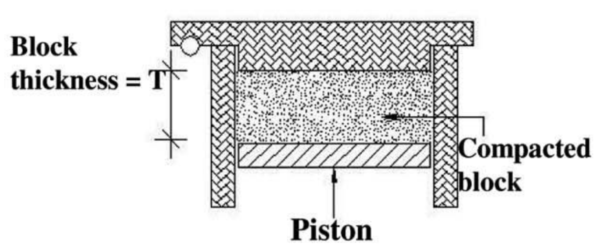


Figure 2.5: SSB Compaction to Top/Bottom Faces. (Reddy, 2015)

However, other variations in block dimensions made in a fixed-volume press might be caused by the following:

- Air trapped at piston or mould-end
- Expansion on the release of pressure (in the direction of the retreating piston)
- Distortion during de-moulding
- Rocking of the piston, so the pressed face is not perpendicular to other faces

2.6 ISSB Making Machine Link Mechanism

Generally, ISSB making machines have a casing to take up the soil mixture for the required block profile or shape. The casing thickness is carefully selected to stand the high compression load exerted during the compression process. For manually operated machines the compression is achieved by manual pressing based on the link bar mechanism employed. Usually, a crank-slider or crank-rocker mechanism is applied to translate rotary motion into a linear system for link bar transmission of compaction force.

The slider-crank mechanism is considered as one of the most used systems in the field of engineering. It is applied in pumps, compressors, steam engines, feeders, crushers, punches and pressing machines (Anis, 2012).

Furthermore, the slider-crank mechanism is central to diesel and gasoline internal combustion engines, which play an indispensable role in modern living. Mainly, the slider-crank mechanism consists of a crank, slider block, and connecting rod. This system works on the principle of converting the rotational motion of crank to the translational motion of the slider block. Therefore, linkage design involves determining dimensions of constituent links so that the linkage mechanism moves in a manner necessary to carry out the required task (Sandor and Erdman, 1988).

Consequently, Dicker (2013) concluded that the theory of machines and mechanisms is an important applied science that is used to understand the relationships between geometry and motions of machine parts. CAD/CAE Softwares are now used to predict the outcome of forces that produce motions.

In 2012, Anis used MSC Adams software to observe the response of the slider block and reaction forces between the crank and connecting rod as seen in Figures 2.6 and 2.7 respectively. The loaded slider-crank model generated different reaction force profiles under forces x, y and z. Therefore, the predicted reaction force after 1.5 minutes was 137.5N exerted by force y, Figure 2.7.

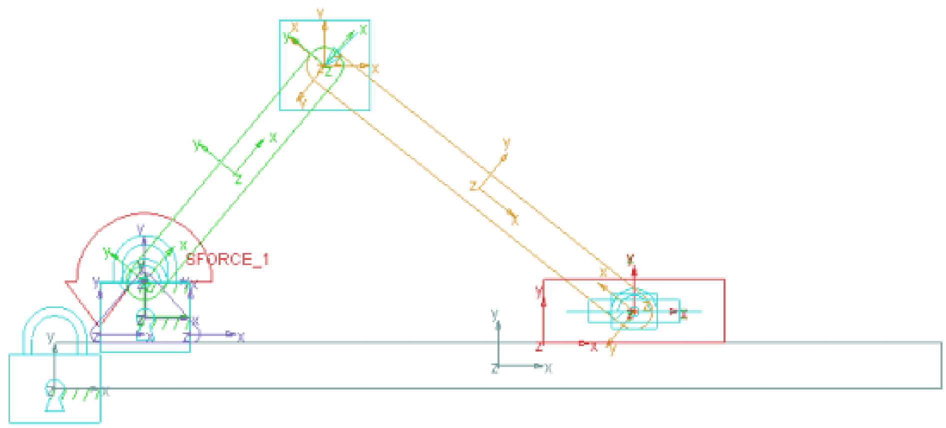


Figure 2.6: Slider Crank Mechanism Model with a Loaded Moment. (Anis, 2012).

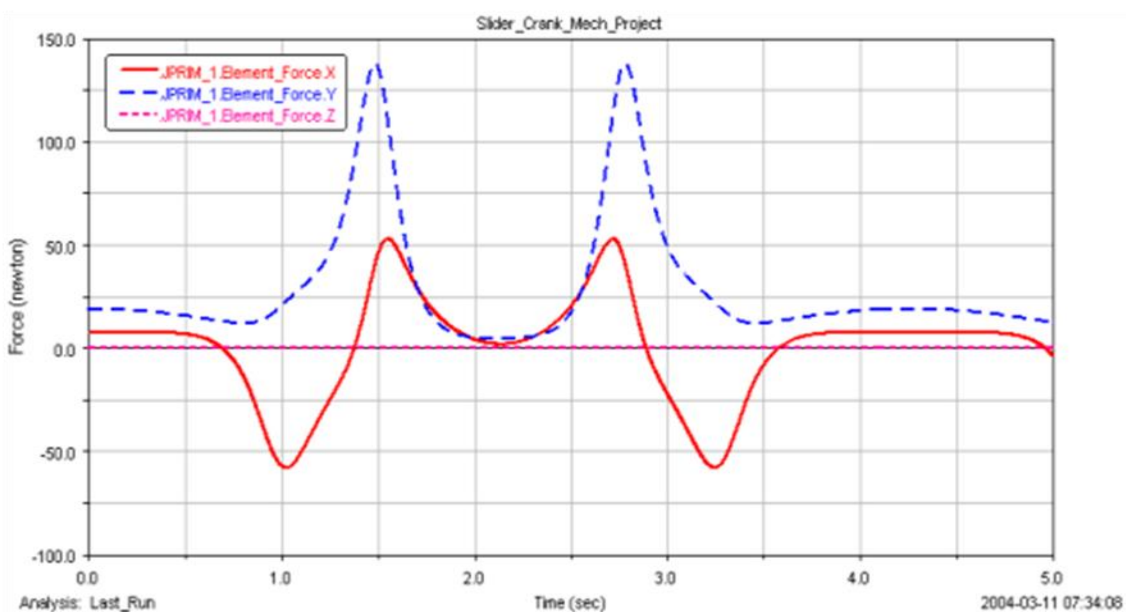


Figure 2.7: Joint Reaction Forces. (Anis, 2012).

For IBM-M1 and IBM-M2 machines, linkage mechanisms are greatly used to transmit compressional loads to achieve maximum compaction. This involves the application of minimal effort input for an amplified compressing force output.

2.7 ISSB Machine Force – Stroke Length Relationship

According to research, the manually operated ISSB making machine force–stroke relationship for different soils require large force towards the end of the compaction stroke Figure 2.8. This means that the mechanism of an ISSB making machine should be capable of providing gradually increasing force amplification as compaction proceeds, (Reddy, 2015). The toggle mechanism is ideally suited for this purpose, as it has a large mechanical advantage that produces a large output force at the end of the stroke. This force increases and approaches infinity as the angle between the links reduces. Therefore, Toggle mechanisms are used extensively for manually operated tools and clamps where a large force is required.

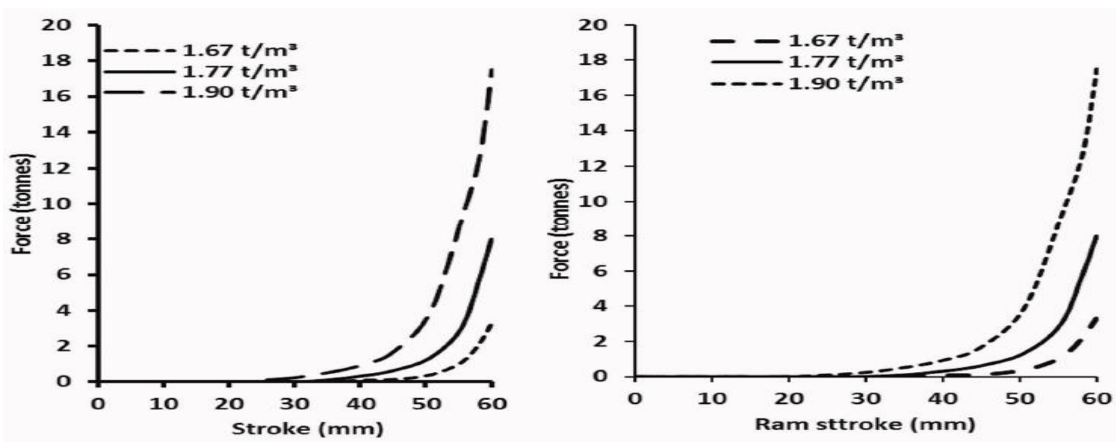


Figure 2.8: Force-Stroke Relationship. (Reddy, 2015).

TDAU has therefore designed two ISSB making machines as prototype machines using the principle of crank and slider (toggle) mechanism. The two machines IBM-M1 and IBM-M2 making machines compress the block horizontally and vertically respectively. In this case, the horizontal compressing machine, Figure 2.9, has fixed block height and width while the length is controlled along the stroke direction and achieved at maximum compressive loading. In 2009, Kintingu explored the design of ISSBs for enhanced wall construction in which he presented the advantage of fixed block length that it results in the maintenance of equal and constant overlaps for alternating courses (Kintingu, 2009). Therefore, this simplifies the process of estimating the number of blocks required in construction. However, due to factors such as machine wear, manufacturing error, the top and bottom plate covers of the block length tend to have marginal variances.

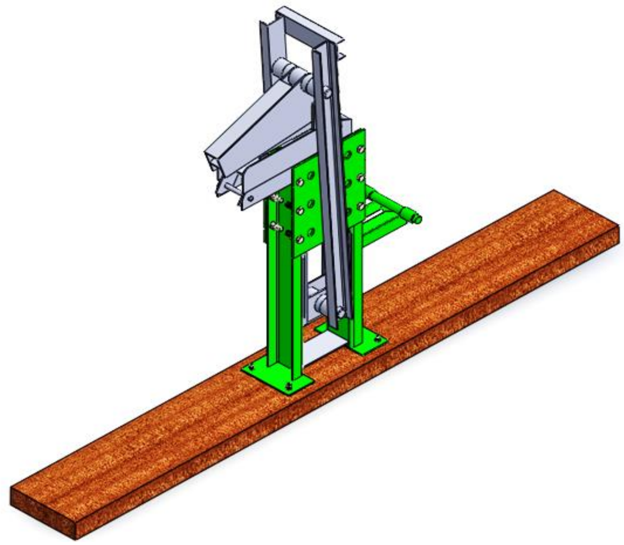


Figure 2.9: IBM-M1 Machine

2.8 Machine Efficiency

Simple machines are evaluated based on efficiency and mechanical advantage. While it is possible to obtain a larger force from a machine than the force exerted upon it, this refers only to force and not energy. According to the law of conservation of energy, more Work cannot be obtained from a machine than the energy supplied to it because Work = Force x Distance. Therefore, for a machine to exert a larger force than its initiating force or operator, that larger force must be exerted through a correspondingly shorter distance. (Chironis and Sclater, 1991).

2.9 Link Joint Mechanical Advantage

According to literature (*ibid*) the mechanical advantage of linkage is the ratio of the output torque exerted by the driven link to the necessary input torque required at the driver.

A link mechanism design aims to generate a maximum mechanical advantage. The toggle link mechanism principle is widely used to support processes such as clamping, pressing, bonding, etc. An important feature of toggle mechanism is capacity to generate large forces with relatively low torque input (Huang, 2011).

Chironis and Sclater further presented that for a four-bar linkage shown in Figure 2.10, the mechanical advantage is directly proportional to the sine of the angle γ between the coupler and the follower and inversely proportional to the sine of the angle β between the coupler and the driver. Hence, both these angles and the mechanical advantage, change continuously as the linkage moves.

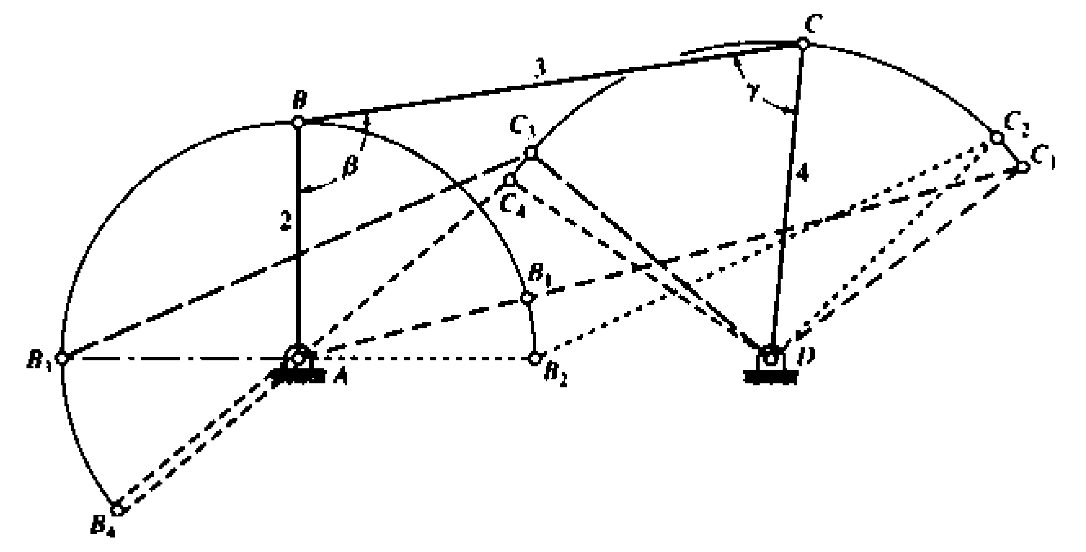


Figure 2.10: Four-Bar Linkage Mechanism. (Dicker, 2003).

When the sine of the angle β becomes zero, the mechanical advantage becomes infinite, thus, at such a position, only a small input torque is necessary to overcome a large output torque load. This is the case when the driver AB of Figure 2.10 is directly in line with the coupler BC, it occurs when the crank is in position AB_l and again when the crank is in position AB_4. It should be noted that these also define the extreme positions of travel of the rocker DC, and DC_4. When the four-bar linkage is in either of these positions, the mechanical advantage is infinite and the linkage is said to be in a toggle position (the angle β between the crank and the coupler equals 180^0). In position AB_4 the angle is 0^0 and in position AB_1, the angle is 180^0

In the case of the IBM-M2 machine shown in Figure 2.11, the machine uses the crank and slider (toggle) mechanism for the transformation of force required to compress soil mixture. Therefore, it is important in this study to understand the force transmission characteristics of the ISSB machine mechanism.

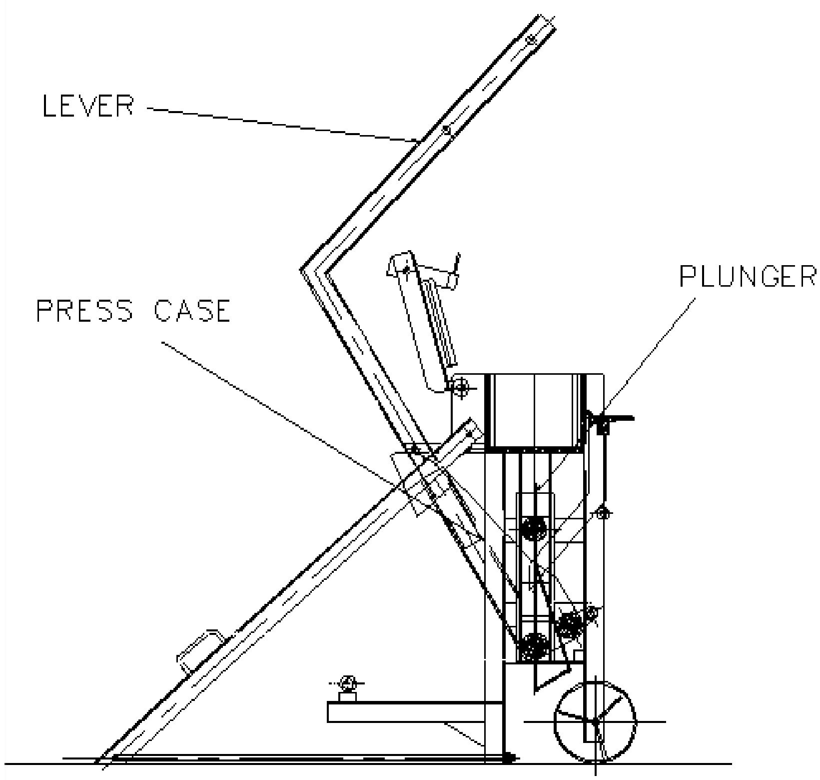


Figure 2.11: Schematic Drawing of IBM-M2 Machine

2.9.1 Forward Toggle Mechanical Advantage

In 2015, Reddy (2015) showed the determination of the mechanical advantage of a slider-crank bar mechanism. This was achieved by considering a typical free body diagram of a ram press, presented in Figure 2.12, in which angles $\emptyset_0$and θ_0 were taken as initial transmission and crank angles respectively of the toggle link mechanism for a manually operated ISSB making machine. For a crank-slider mechanism the maximum value of the stroke length CC' depends on the initial angle θ. As angle θ approaches zero the point C moves to C'

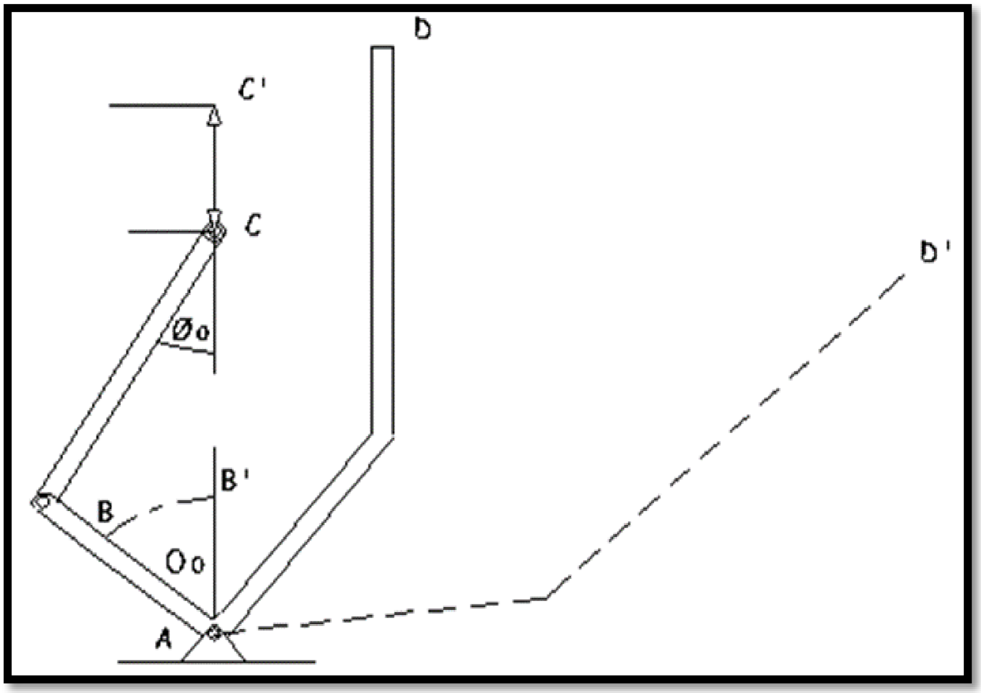


Figure 2.12: ISSB Linkage Mechanism System (Reddy, 2015).

Let the point $CC' = X_m$ = Maximum stroke length

The expression for Mechanical advantage is $A_T = \left|\frac{L\dot{\theta}}{\dot{X}}\right|$ (2.7.1)

$$A_T = \frac{L}{rSin\theta\left[1 + \frac{\left(\frac{r}{l}\right)Cos\theta}{\left\{1-\left(\frac{p}{l}\right)^2 Sin\theta\right\}^{\frac{1}{2}}}\right]} \quad (2.7.2)$$

Asymptotic behavior of A_T

$As\ \theta \to 0, Sine\ \theta \to \theta, Cos\ \theta \to 1$

$$\lim_{\theta \to 0} A_T = \frac{L}{r\theta\left(\frac{r}{l}+1\right)} \quad (2.7.3)$$

$Again\ as\ \theta \to 90^0, Sine\ \theta \to 1.0, Cos\ \theta \to 0$

$and\ A_T = \frac{L}{r}$

The value of θ varies between the initial angle θ_0 and zero. From Equation 2.7.3 it is clear that to achieve maximum amplification towards the end of the stroke (i.e. when θ→0) the r/l ratio should be close to zero. Hence, to keep ‘AT’ large for a given value of θ, L/r should be large and r/l should be close to zero. In practice, it is difficult to have exceedingly small r/l ratios (*ibid*).

2.9.2 Reverse Toggle Mechanical Advantage

Reddy (2015) also indicated that for the reverse toggle system the value of θ varies between the initial angle θ_0 and 0. Equation 2.7.6 describes the behaviour of ART as θ tends to zero. For a particular value of θ, ‘ART’ will be large if L/r is large and if r/l is close to 1.0. Equations 2.7.3 and 2.7.6 indicate that, for particular values of θ, L and (r)/l, the reversed toggle will always have a better amplification than the toggle mechanism.

The expression for mechanical advantage is $A_{RT} = \left|\frac{L\dot{\theta}}{\dot{X}}\right|$ (2.7.4)

$$A_{RT} = \frac{L}{rSin\theta\left[\frac{\left(\frac{r}{l}\right)Cos\theta}{\left\{1-\left(\frac{p}{l}\right)^2 Sin\theta\right\}^{\frac{1}{2}}} - 1\right]} \quad (2.7.5)$$

Asymptotic behavior of A_T

$As\ \theta \to 0, Sine\ \theta \to \theta, Cos\ \theta \to 1,\ Sin^2\theta \to 0$

$$\lim_{\theta \to 0} A_{RT} = \frac{L}{r\theta\left(\frac{r}{l} - 1\right)} \quad (2.7.6)$$

$Again\ as\ \theta \to 90^0, Sine\ \theta \to 1.0, Cos\ \theta \to 0$

$and\ A_{RT} = \frac{L}{r}$

2.10 Displacement Expression of the Crank – Slider Mechanism

The travel or displacement of the Crank – slider system forms an important effect on the compression ratio during force transmission of a pressing machine. In the case of an ISSB compressing machine and according to literature (Ambekar, 2007) the displacement of an inline crank and slider can be determined.

Consider Figure 2.13 showing crank OC of a slider-crank mechanism in a position making angle θ with the inner dead position OC_1. Let the crank and connecting rod lengths be r and l respectively.

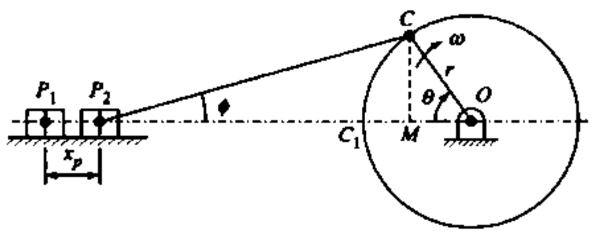


Figure 2.13: Crank – Slider Mechanism. (Ambekar, 2007).

When the crank is at inner dead centre position OC_1, the connecting rod CP lies along the line of stroke and for this position

$$OP_1 = (l + r)$$

When the crank rotate through θ in clockwise direction the distance of piston from crank shaft centre is given by

$$OP_2 = (lcos\emptyset + rcos\theta)$$

Thus displacement x of the piston P from the dead centre inner position is given by

$$x_p = (OP_1 - OP_2)$$

$$= r(1 - cos\theta) + l(1 - cos\emptyset)$$

$$= r[(1 - cos\theta) + l/r(1 - cos\emptyset)] \qquad (2.8.1)$$

Again from right angled triangles CMO and CMP_2,

$$CM = lsin\emptyset = rsin\theta$$

$$sin\emptyset = \left(\frac{r}{l}\right) sin\theta$$

$$cos\emptyset = \sqrt{1 - sin^2}\emptyset = \frac{r}{l}\sqrt{(l/r)^2 - sin}\theta$$

$$cos\emptyset = \frac{1}{n}\sqrt{n^2 - sin^2}\theta = \sqrt{1 - \left(\frac{sin\theta}{n}\right)^2} \qquad (2.8.2)$$

Now invoking the binomial expansion

$$(1 - x)^n = 1 - nx + \frac{n(n-1)}{2!}x^2 + \frac{n(n-1)(n-2)}{3!}x^3 + \cdots$$

We have the R.H.S of the equation (2.8.2) as

$$\left(1-\frac{1}{n^2}sin^2\theta\right)^{1/2} = 1-\frac{1}{n^2}sin^2\theta-\frac{1}{8n^4} - \ sin^4\theta-\frac{1}{16n^6} - \ sin^6\theta \ldots$$

$$Also \ \ (1-cos\emptyset) = \frac{1}{n^2}sin^2\theta+\frac{1}{8n^4}+sin^4\theta+\frac{1}{16n^6}+sin^6\theta \ldots \qquad (2.8.3)$$

Again substituting for $cos\emptyset$ from (2.8.2) in (2.8.1),

$$x_p = r(1-cos\theta)+n\left[1-\frac{1}{n}\sqrt{n^2-sin^2\theta}\right]r$$

$$= r(1-cos\theta)+\left[n-\sqrt{n^2-sin^2\theta}\right]r \qquad (2.8.4)$$

2.11 Determination of Forces Acting in Mechanisms

Mechanisms are used not only for producing program motions but also for transmitting forces necessary both for performing working processes and overcoming the inertia of moving links. For this reason, the geometric investigation must be completed by the analysis of forces in the process of mechanism design.

The investigation of geometric conditions for the transmission of forces is conducted through a mechanism based on a simplified physical model, which may be called a static model. With the help of static model equilibrium, conditions of a mechanism in different positions are essentially investigated. Moreover, it is assumed that in every position investigated only forces caused by workloads are taken into consideration whereas friction forces are neglected (Kolovsky, 2000).

Generally, the critical factor concerning force analysis of a static model is to determined generalised forces to be applied to the input links of a mechanism. In this case, Kozlovsky considered a crank slider mechanism Figure 2.14, for force determination in link mechanism.

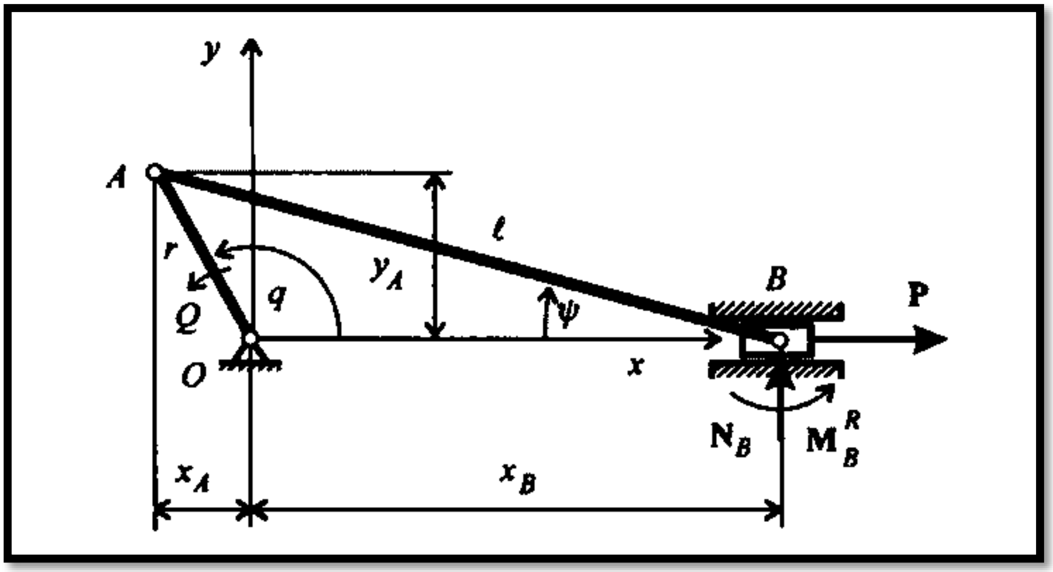


Figure 2.14: Force Determination in the Slider-Crank Mechanism (Kolovsky, 2000).

Firstly, the moment equations are considered for all external forces (i.e. for forces N_B, P and moment M_B^R) with respect points B, A and O. Taking into account that joints A and B are "passive," i.e. that at these joints no balancing forces are applied and that at joint O a force moment Q is applied and the following is obtained:

$$\sum M_B = M_B^R = 0, \qquad \sum M_A = N_B(x_B - x_A) + Py_A + M_B^R$$

$$\sum M_O = N_B x_B + M_B^R + Py_O + Q = 0 \tag{2.9.1}$$

Solving these equations for unknown reactions N_B, M_B^R and the moment Q are calculated.

Since $rcosq + \sqrt{l^2 - r^2 \, sin^2 q}, \; x_A = rsinq, \;\; y_O = 0$

From equation (2.9.1)

$$M_B^R = 0, N_B = -P\frac{y_A}{x_B - x_A} = -P\frac{rsinq}{\sqrt{l^2 - r^2 \, sin^2 q}}$$

$$Q = -N_B x_B = P\frac{rsinq}{\sqrt{l^2 - r^2 \, sin^2 q}}\left(rcosq + \sqrt{l^2 - r^2 \, sin^2 q}\right)$$

$$= P\left(rsinq + \frac{r^2 \, sinq.cosq}{\sqrt{l^2 - r^2 \, sin^2 q}}\right) \tag{2.9.2}$$

2.12 Physical Product Modelling and Simulation

Modelling and simulation involve the use of physical and logical representation of a given system to generate and help determine decisions and make a prediction about the system. This approach is widely used in various areas such as part design, manufacturing, and product development (Hughes, 2012).

It's a process that includes model creation as a representation of the construction and working of some system of interest. The main goal of a model is to enable prediction of the effect of the changes to the system of a close representation of the real system and incorporate most of its salient features. This should not be so complex and impossible to understand and experiment with it. An important issue in modelling is model validity. Model validation techniques include simulating the model under known input conditions and comparing model output with system output (*ibid*).

Recent approach to design and manufacturing involves the application of modelling and simulation software. Hughes (2012) analysed a toggle mechanism by modelling and simulation, Figure 2.15, to investigate sensitivity to link sizes and compliance materials

Hughes analysed a toggle mechanism to investigate and evaluate the impact that a change in length of links or change in the choice of material for the compliant element within the linkage has on the stress within the linkage. Therefore, Figure 2.15 is an illustration of a CAD modelled toggle mechanism showing the mesh for stress analysis in Finite Element Analysis (FEA).

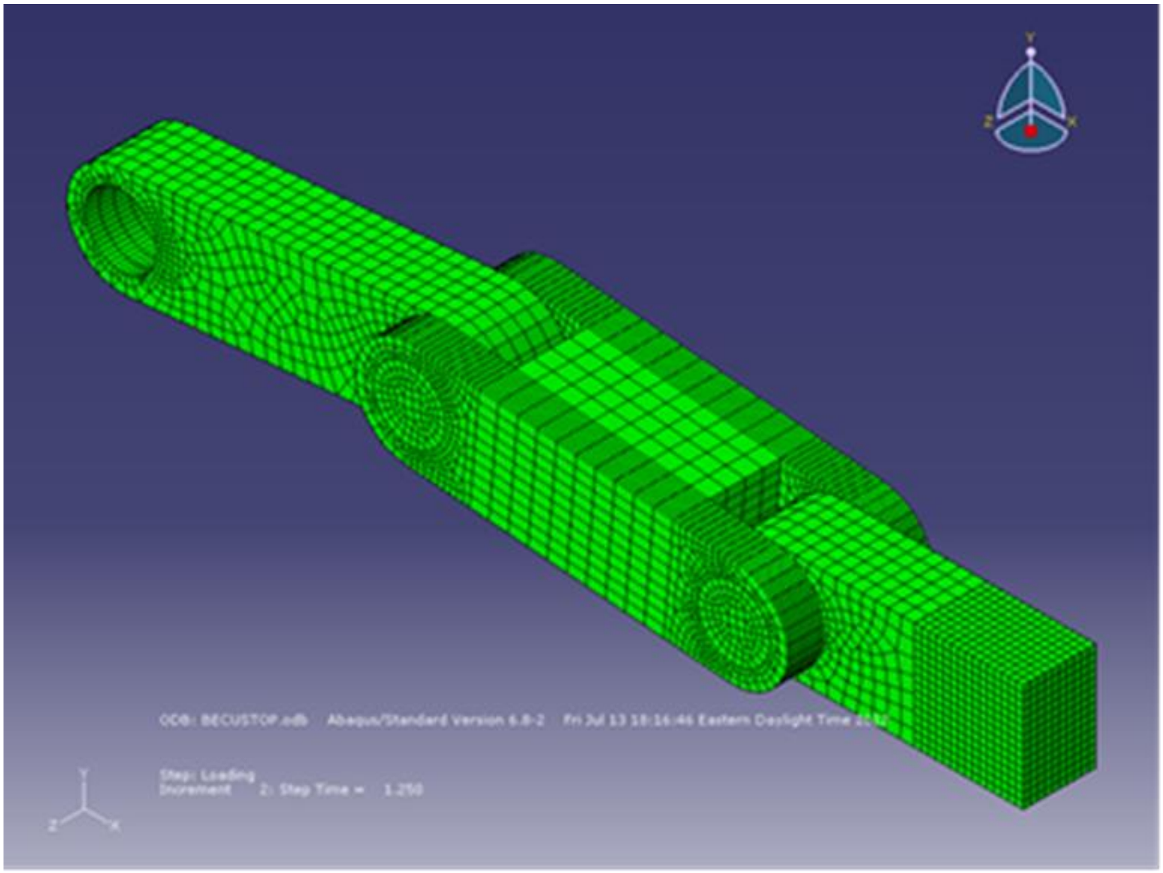


Figure 2.15: Modelled Linkage using CAD Software. (Hughes, 2012)

Further, modelling and simulation may be carried out systematically according to the flow as presented in Figure 2.16 by Kuang-HuaChang (2006). In this case, the analysis procedure starts by building a CAD model based on the concept of design using CAD software. Then the model can either be imported to a mechanism package in case of limitations. This may be preceded by definition of Joints, Constraints and input forces which are known critical input values required for analysis. For force balance definition, this is an inverse static analysis in which a resulting reaction force is derived from a specific static configuration.

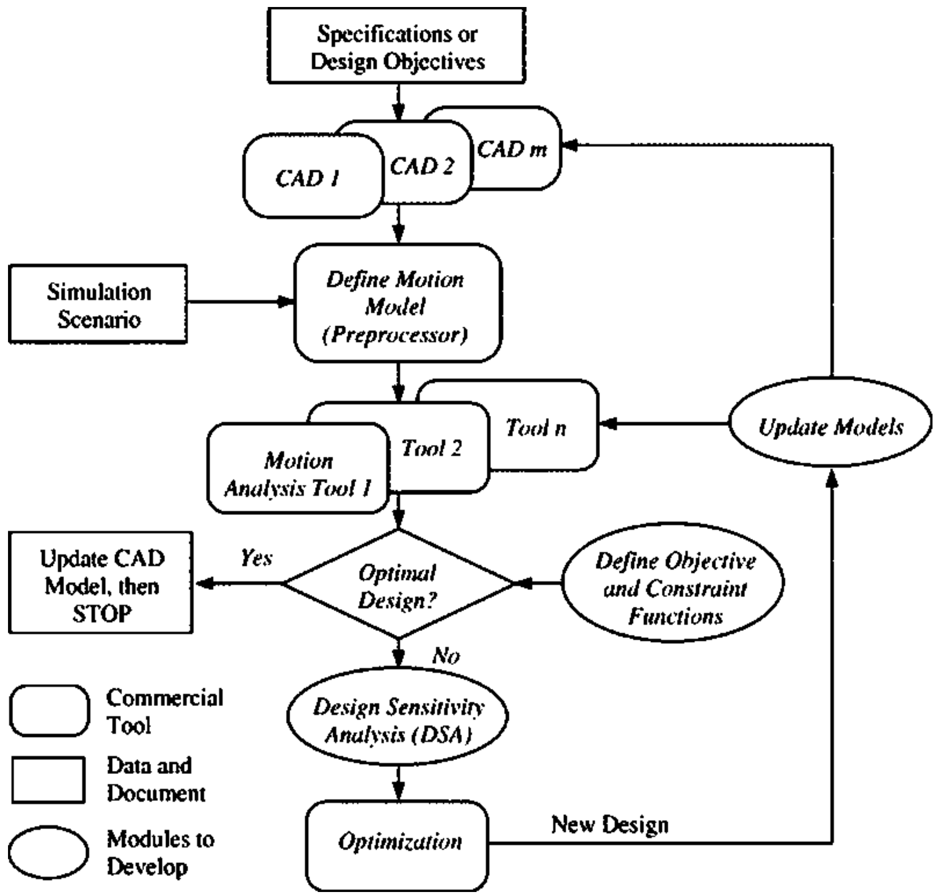


Figure 2.16: Flow of the CAD-Based Mechanism Optimization.
(Kuang-HuaChang, 2006).

CHAPTER 3 METHODS AND MATERIALS

3.1 Introduction

It is important to note that effective manufacturing of complete machines, mechanisms and any other engineering components can now be effectively and economically achieved by the application of CAD/CAE software. The purpose of this research was to improve the ISSB machine design for enhanced performance by using CAD/CAE software. This was achieved by studying the existing machines (IBM-M1 and IBM-M2) operating principle. In this chapter, the research objectives, methodology design used, experiments and tests performed are elaborated.

3.2 Research Design

3.2.1 General Method

In this study, the general method involved the study of IBM-M1 and IBM-M2 machines. Experiments were done to assess their performance in terms of resultant block strength, production rate and machine production capacity. Based on the results, design concepts of the IBM-H1 machines were generated. To determine the optimal material thickness and strength required to withstand compression forces, deformation and stress simulation on the concept design machine parts was done using Solidworks 2017, CAD software. The optimum values were subsequently used to design the IBM-H1. Furthermore, the designed IBM-H1 machine as shown in Figure 3.1 was manufactured and tested.

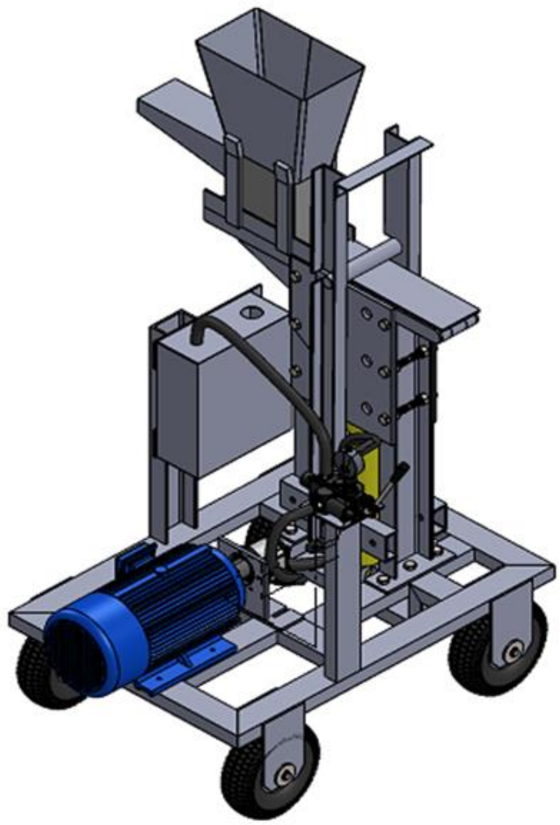


Figure 3.1: IBM-H1 Machine

3.2.2 Specific Procedures.

The following is the procedure that was followed:

- Study the functional system of the ISSB machine.
- Creating a 3D Model and simulation for the existing machine using CAD software.
- Concept redesign modelling.
- Stress simulation and material optimisation.
- Construction of the IBM-H1 machine
- Performance testing

Figure 3.2 shows a typical systematic design and production flowchart which was adopted in the design and manufacture of the IBM-H1 in this study.

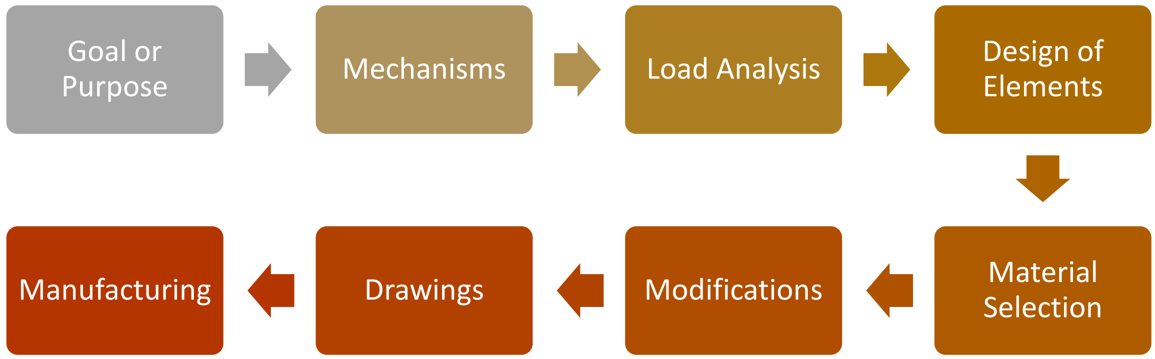


Figure 3.2: Typical Systematic Design and Production Flowchart.

Following is a description of the steps followed in the flowchart:

- Goal or Purpose: This is the required complete knowledge of the machine's components and processes.
- Mechanisms: Selecting the group of mechanisms that assist in providing the machine with the desired motion.
- Load Analysis: After the concept design is completed, it must be analysed with all the appropriate loads.
- Material Selection: Selection of appropriate materials based on function, cost, and availability. This is very important and requires special attention.
- Design of Elements: Conducting Finite Element Analysis, static and dynamic load case analysis to analyse the forces acting on each element.
- Modification: Once the design of elements is concluded, the elements may be modified for an optimised design.
- Drawing: Preparation of detailed drawings of each component and presented to turn the design from concept to manufacturing.
- Manufacturing: Once the design phase is complete, the concept idea on paper is accepted and proceeds to manufacture.

3.2.3 Research Site

It is important to note that laboratory experiments, fabrication, machining and performance tests were conducted from the Department of Mechanical Engineering in the School of Engineering at the University of Zambia.

3.3 **Simulation of HISSB Model Parts**

Solidworks simulation employs a generative method for the support of design optimisation. Design variables vary between their respective lower and upper bounds. These design variables are combined to create individual design scenarios. Finite element analyses are carried out for all scenarios generated. Among the scenarios evaluated, feasible designs are collected and within the feasible designs, the best design that yields the lowest value in the objective function is identified as the solution to the design problem (Kuang-Hua Chang, 2006).

In this research simulation and optimisation of materials for analysis of stress and deformation was done. Production of compressed earth blocks involves the application of high compressive force to achieve acceptable block strength according to the stabiliser composition. Therefore, the determination of material stresses and deformation using modern CAD software, Solidworks 2017, was carried out on a highly stressed IBM-H1 machine design model. To have optimal material weight of available compression forces material optimisation was done on machine frame and side cover plate.

3.4 Experiments and Tests

3.4.1 ISSB Block Making Process

Generally, block making activities using a manually operated ISSB machine involves a sequence of processes as shown in Figure 3.3.

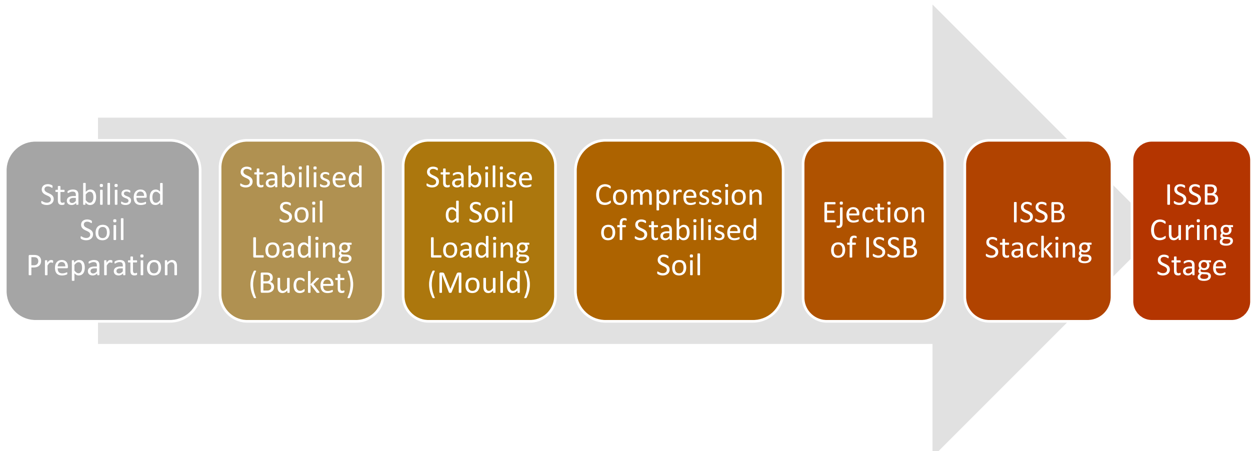


Figure 3.3: Manual Block Making Sequence of Activities

The process starts with the preparation of soil which include sieving, stabiliser mixing, adding water, loading of a pre-determined amount of stabilised soil mixture in the bucket and then in the mould casing. Soil compression takes place after closing the machine lid while the block ejection follows immediately after soil compaction and the sequence ends with block stacking. The process above was conducted using the IBM-M1 and IBM-2 machines under similar conditions and the cycle time was recorded for each block. In real-time ISSB making production is generally done in batches, whereby each batch operation consists of mixing and preparing the soil for several blocks and making the blocks in the machine.

Therefore, in this research batch operation was applied and the stabiliser used was Portland cement. Consequently, the batches of mixed stabilised soil mixture were being compacted within the initial and final setting time of mixture for effective strength. According to ASTM 403C, initial setting time is considered as the time taken to achieve a penetration resistance of 3.5 MPa which is an arbitrary value as shown in Figure 3.4, and measured based on penetration resistance of mortar sieved from concrete (Piyasena *et al*, 2013).

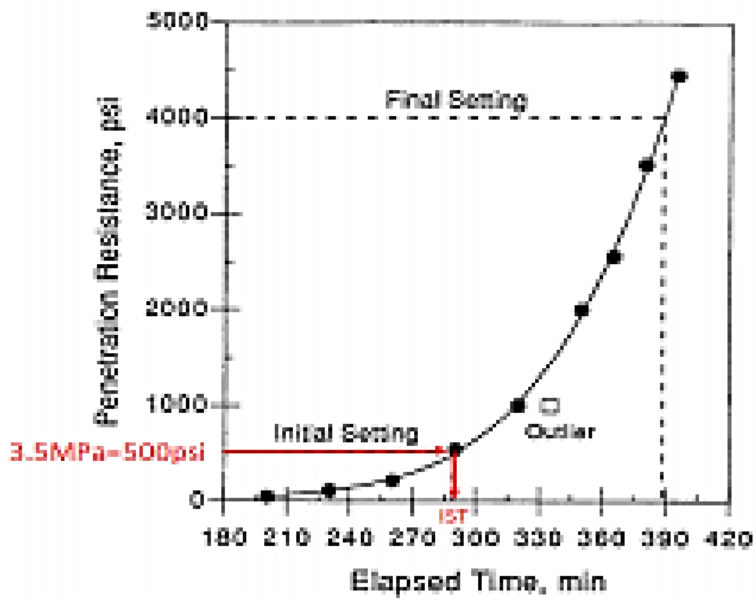


Figure 3.4: Penetration Resistance vs Elapsed Time. (Payasena *et al*, 2013)

3.4.2 ISSB Making Machine Production Cycle Time

Cycle time is the time the machine needs to produce one product. Therefore, it is an important factor in any production arrangement. The faster a machine can produce parts, the more products can be produced within a specific time and the higher the returns. Therefore, the production cycle time for manual TDAU ISSB was studied.

To determine ISSB production time, a time study method approach was employed and observation sheets were constructed Appendix A. A stopwatch was used to time individual cycle duration processes of stabilised soil block production. Process times were recorded and averaged after a fifteen sample blocks were made. Standard deviations were computed to give measures of variances in the performance times. The mean duration for each process was added yielding the cycle time for a unit block.

3.4.3 Block Compressive Strength Testing

The measurement of compressive strength is an important factor in any analysis of masonry units. To determine the compressive strength of the IBM-M1 and IBM-2 machines, specimens were made and tested according to ASTM C67-07. In this experiment the variable factor was the stabiliser (Portland cement) composition. Fifteen sample blocks of different stabiliser compositions of 10 % 12 % 17 %, 25 % and 50 % were prepared and cured for 21 days as shown in Figure 3.5. The 75 individual sample blocks with nominal dimensions of 240 mm x 220 mm x 120 mm were then tested using the compressive testing machine as presented in Figure 3.6. Average compressive strength for IBM-M1 and IBM-M2 blocks were determined and compared for each stabiliser composition have been presented in Appendix B. The method was repeated for the HISSB making machine. However, in this case, two variables were used, pressure and soil stabiliser as shown in Appendix C.

Figure 3.5: Curing of Interlocking Blocks.

Figure 3.6: ISSB Compressive Strength Testing.

3.5 **Compression Force Determination of the IBM-M1 and M2 Machines**

In this research, it was required to determine the force required to generate pressure for block compaction to the required wet compressive strength. Therefore, a rig was designed as shown in Figure 3.7 by modifying a manual hydraulic press. The ISSB making machine was mounted between the hydraulic ram and the press base. Then the piston displacement values were measured by attaching a digital Vernier calliper to the ram. Six sample blocks were made and the compressive strengths recorded at eight intervals of displacement for the range of 20 mm to 150 mm. Consequently, based on the results the optimum force was calculated at 150mm piston displacement giving the maximum pressure of 1.4 N/mm^2 and by calculation using Equation 3.4, the cylinder output force is 7,038N.

$$F = P.A.\eta_{hm} \tag{3.4}$$

Where:

F = Cylinder output force (N)

P = Pressure inside the cylinder (Pa)

A = Effective piston area (m^2)

η_{hm} = Hydro mechanical efficiency

Figure 3.7: Modified Rig using a Manually Operated Hydraulic Press.

CHAPTER 4 DESIGN AND MANUFACTURING OF THE IBM-H1 MACHINE

4.1 Introduction

This chapter outlines the design of the IBM-H1 machine concept, operating principle and machine parts. The chapter also presents a detailed IBM-H1 CAD/CAE design model and the manufacturing process. It should be noted that the design process was carried out using Solidworks 2017, CAD software.

4.2 Concept Design Generation

A product concept is an approximate description of the technology, working principle and form of the product. It is a concise description of how the product will satisfy the user. A concept is usually expressed as a sketch or as a rough three-dimensional model and is often accompanied by a brief textual description. The degree to which a product satisfies the users and can be successfully commercialised depends to a large measure on the quality of the underlying concept. A good concept is sometimes poorly implemented in subsequent development phases, but a poor concept can rarely be manipulated to achieve commercial success (Ulrich and Eppinger, 2003).

In this study three concepts were generated, manually operated Horizontal Compressing ISSB (HCISSB) making machine, Vertically Compacting ISSB (VCISSB) making machine and hydraulically operated ISSB (IBM-H1) machine.

4.3.1 HCISSB Making Machine Design Concept

The concept of design and development is a process of developing ideas to solve specified design problems. In this research, three concepts were created. The first one being a manual HCISSB making machine, Figure 4.1. The design characteristics include manual and horizontal block compaction using the principle of the toggle link mechanism. The machine is fitted with a hopper for holding enough soil mixture at once while the mould casing has a quick return lid opening.

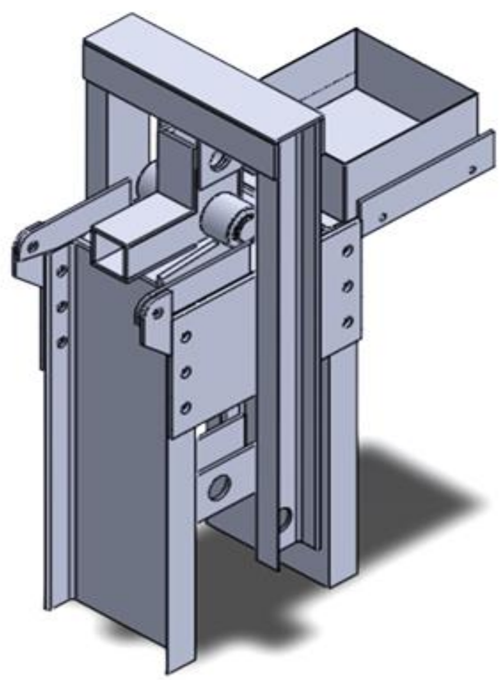


Figure 4.1: HCISSB Making Machine.

4.3.2 HISSB Making Machine

The second concept design is a motorised and vertically compacting HISSB making machine mounted with a double-acting hydraulic cylinder between the base and the bottom block cover plate and is powered by an induction motor as shown in Figure 4.2. This concept is similar to the first one except that in this case the block compression and ejection processes are to be accomplished by the hydraulic ram. The hydraulic system may include a 3/4 manual flow control valve fitted with a pressure gauge for pressure regulation. Further, according to design, the soil conveyor is to be mounted below the hopper and operated manually.

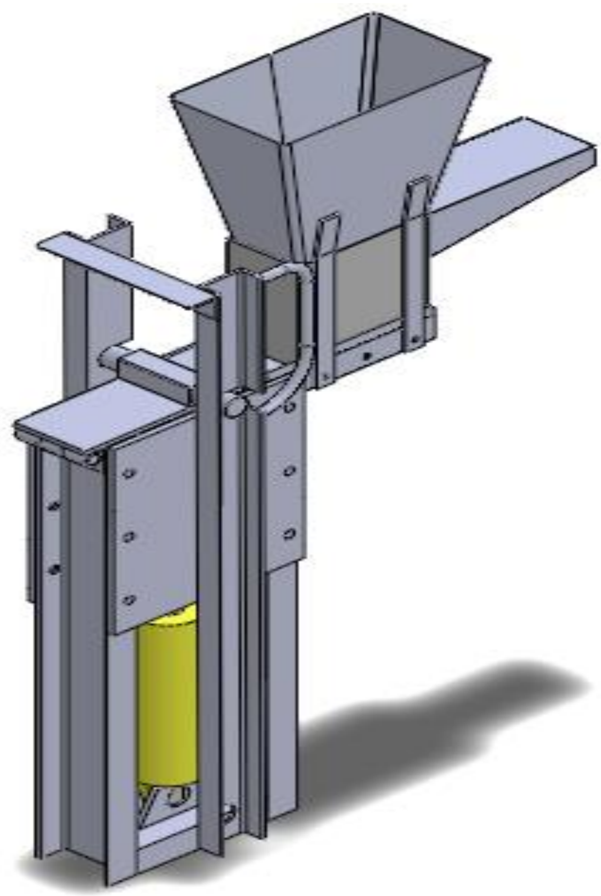


Figure 4.2: IBM-H1 Machine Concept.

4.3.3 VCISSB Making Machine

This concept is based on Toggle-link mechanisms which are widely used in product manufacturing such as pressing machines, lifting equipment, motion transmission, etc. Based on their singular characteristics, the mechanisms can be used to generate a large output force from a small input force. Hence, the mechanism is particularly used for tasks that demand large forces. Therefore, horizontally compacting ISSB making machine design, Figure 4.3, incorporates the toggle link mechanism using human effort to generate high compressive force output. The lid opens at a predetermined bottom plate upward linear displacement after which the block ejection begins. This concept is based on the TDAU interlocking block making machine called IBM-M2

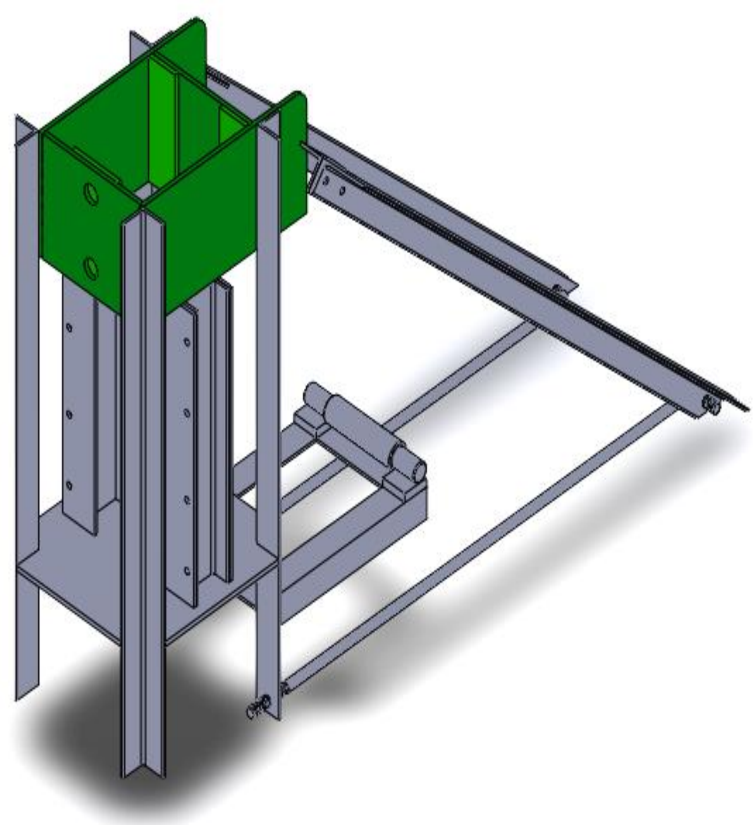


Figure 4.3: VCISSB Making Machine

4.4 `Concept Analysis and Selection

Concept selection is often performed in two stages as a way of managing the complexity of evaluating dozens of product concepts. The first stage is called concept screening while the second one is referred to as concept scoring. Each is supported by a decision matrix which is used for rating. It is based on a method developed by Stuart Pugh in the 1980s and is often called Pugh concept selection (Ulrich and Eppinger, 2003). The purpose of this stage is to narrow down and improve the number of concepts.

Concept scoring is used when the increased resolution will better differentiate among competing concepts. In this stage relative importance of selecting criteria is weighed and focuses on more refined comparisons concerning each criterion. The concept scores are determined by the weighted sum of the ratings (*ibid*). Therefore, Table 4.1 illustrates the scoring matrix used in this research.

Table 4.1: Block Making Machines Design Concept Weighting.

			DESIGN CONCEPTS		
ROW	**CRITERIA**	**WEIGHTS (%)**	**HCISSB**	**IBM-H1**	**VCISSB**
1	Easy to open Lid	80.0	100.0	100.0	80.0
2	Easy to close Lid	80.0	100.0	100.0	70.0
3	Simplicity to eject block	80.0	50.0	100.0	100.0
4	Mould soil filling	70.0	40.0	90.0	40.0
5	Portability	70.0	100.0	40.0	100.0
6	Weight of machine	50.0	80.0	50.0	60.0
7	Operating pressure	90.0	40.0	100.0	50.0
8	Production capacity	90.0	40.0	90.0	60.0
9	Easy to pick block	60.0	80.0	80.0	70.0
10	Rate of production	80.0	40.0	100.0	50.0
Weighted Average			**1.89**	**2.13**	**1.91**

Figure 4.2, IBM-H1 machine was considered as the best option for the design and manufacture of an improved TDAU ISSB making machine for high productivity.

Generally, hydraulic compressing equipment operate efficiently and perform with higher precision for large loads (Matti, 2002).

Other advantages are as follows;

- Good power to weight ratio of hydraulic systems small components
- Easy and flexible transfer of energy with hydraulic hoses and piping
- Possibility to remove the actuation from hydraulic power generation due to easy transfer of hydraulic energy
- Hydraulic systems are self-lubricating
- The possibility to control hydraulic systems manually or with modern electronics

However, some disadvantages of a hydraulic system are that it can cause accidents arising from hose rapture and it is expensive since it needs several additional hydraulic system accessories to operate.

4.5 IBM-H1 Machine Design and Function

The process design includes all activities involved from the original concept to the finished product. This can be creation of a new product or development of an existing one. For many years designers sought ways to describe and analyse three-dimensional designs without building physical models (Shih, 2014). With the advancement of computer technology, the creation of three-dimensional models on a computer offers a wide range of benefits. Computer models are easily interpreted and easily altered. Simulation of real-life load can be applied to computer models and the results graphically displayed.

Solidworks is a suite of programmes, including the Finite Element Analysis (FEA) module (Solidworks Simulation), which is used to facilitate a concurrent engineering approach to design, analyse and manufacture engineering products (*ibid*).

Therefore, during the design of the IBM-H1 machine, parts were designed and modelled using this CAD software. Dynamic factors were essential during the design of the IBM-H1 machine parts to achieve compression and block ejection. Consequently, consideration was made to determine power drive, piston speed and pump speed.

4.5.1 Mould Casing Plates

Mould casing plates are the side covers of the ISSB making machine mould. They are subjected to direct forces during the compression process. An experiment was carried out to determine the resultant force. A manually operated hydraulic press was modified as shown in Figure 3.7 of Chapter three, by mounting a displacement and a load measuring instruments, a digital Vernier calliper and the hydraulic pressure gauge. Ten samples of the same soil mass, weighing 10.1kg were compressed gradually at different displacements.

By conversion, the optimal compression load of 1,432.92 N was achieved for the IBM-M1 and M2 machines. Furthermore, using Equation 4.1, the pressure exerted on each cover plate was determined as 0.1357 MPa.

$$P = 0.5\left(\frac{F}{A}\right) \tag{4.1}$$

Where:

P = Pressure exerted of plates

F = Resultant force

A = Area of plates

4.5.2 Hydraulic Cylinder Base

The hydraulic cylinder base shown in Figure 4.4 is an integral part of the HISSB making machine. Welded across the mainframe the knuckle joint of the cylinder is anchored on it. A 38 mm diameter pin is used to take up the repeated force on the frame. Based on the assumed working pressure of 10 MPa, stress simulation showed the minimum and maximum values of 7.587×10^4 MPa and 1.887×10^8 MPa respectively and allowing a marginal maximum material deflection of 3.385×10^{-1}mm.

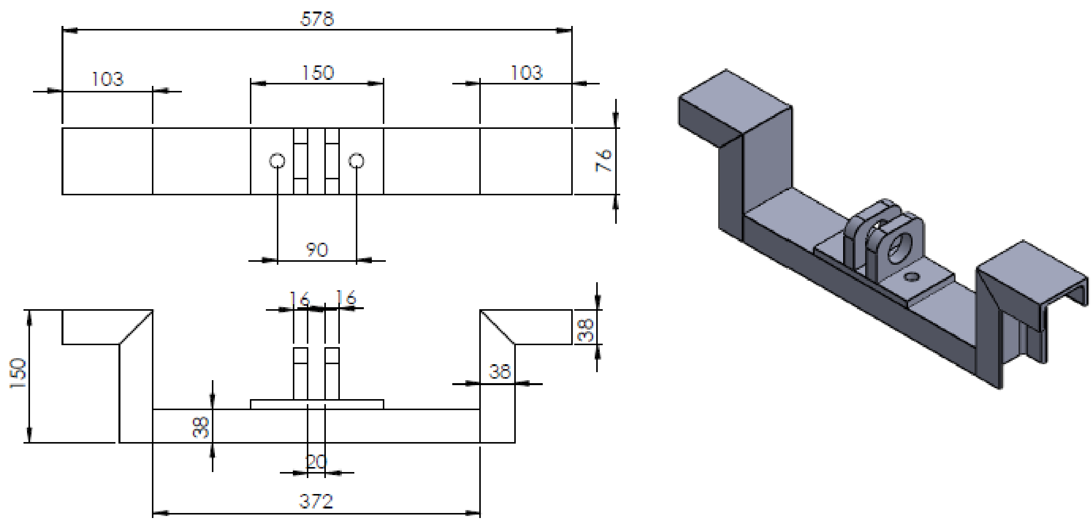


Figure 4.4: Hydraulic Cylinder Base General Assembly

4.5.3 Hydraulic Cylinder Design

Hydraulic cylinders convert hydraulic power into linear mechanical force. Depending on the cylinder construction, movement can be hydraulically powered in one direction and the return movement done with a spring or by the load. In this case, the cylinder is called single-acting cylinder. If the cylinder is hydraulically powered in both directions, it is then referred to as a double-acting cylinder (Mikkola, 2014).

Double-acting cylinders are designed such that pressure can be applied in the inlet port, providing linear power in two directions. This system is not in any sense different in principle of operation from every normal hydraulic cylinder. It produces fluid flow and pressure in two directions, and only one end of the piston is connected to the point of application where work is done as shown in Figure 4.5.

Therefore, in this research, a double-acting hydraulic cylinder similar to the one in Figure 4.6 was used to provide the force required for the compression and ejection of stabilised soil blocks.

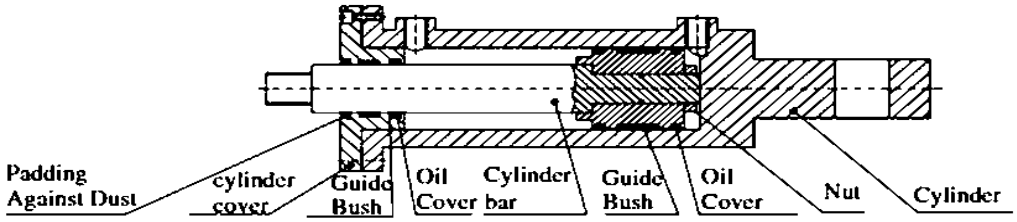


Figure 4.5: Double Acting Hydraulic Cylinder (Young, 2011).

The following are some of the assumptions which were considered in the design of the cylinder:

- Atmospheric pressure: 1.0135×10^5 Pa
- Stroke length: 400mm
- Cylinder output force: 1,500 N
- The design factor of safety: 4
- Material for cylinder: Low carbon steel.
- Tensile stress: 430 MPa
- Yield stress: 215 MPa
- Young's Modulus Elasticity $210*10^9$ N/mm^2 (low carbon steel)

a) Diameter of Cylinder Bar

The cylinder bar is one of the stressed cylinder parts due to the compressive forces encountered during operation without buckling. In practice, the bar is more likely to fail by buckling under the compressive load than by bending (*ibid*). In this case, the bar behaves like a column and is subjected to buckling. Therefore, Euler's Formula for long column calculation as presented in Equation 4.2 was applied to obtain the hydraulic cylinder bar diameter of 25.5 mm. According to literature (DNV, 2002), as a control calculation, an Euler break load may be found for a cylindrical bar with the same dimensions as the piston rod and with a length corresponding to the fully extracted cylinder.

$$P = \frac{\pi^2 * E * I}{L^2 * K^2} \tag{4.2}$$

Where:

P = Buckling Load (N)

L = Length between mountings in fully extracted position (m)

I = Moment of inertia (m^4)

E = Young's Modulus (Carbon steel)

K = End fixing factor

Applying Equation 4.2 for buckling load determination the cylinder bar diameter was calculated using Equation 4.3 (Emagbetere *et al*, 2017). However, according to the buckling chart of cylinder bars (rods) shown in Appendix E, the closest bar diameter is 40 mm for the cylinder output load of 1500 N (152.91 Kg).

$$55200 = \frac{\pi^2 * (210 * 10^9) * I}{(0.4^2 * 0.7^2)}$$

$$I = 2.08 * 10^{-8} \quad m^4$$

$$I = \frac{\pi d^4}{64} \tag{4.3}$$

$$2.08 * 10^{-8} = \frac{\pi d^4}{64}$$

$$d \ = 25.5\, mm$$

b) Determination of Hoop Stress

In the design of hydraulic cylinders, the outer cylinder diameter and its wall thickness are calculated largely depending on the capacity of the cylinder and its working pressure (Khan, 2009). Therefore, Lame's formula, (Equation 4.4), was used to determine the hoop stress Q_h for the cylinder. Q_h varies across the cylinder wall from a maximum value on the inner surface to a minimum value on the outer surface of the cylinder, as expressed in Equation 4.4, (Yong and Qiang, 2010). Q_h is a mechanical stress defined for cylindrical objects such as pipes and tubing.

$$\sigma_h = \frac{p_i r_i^2 - p_o r_o^2}{r_o^2 - r_i^2} + \frac{(p_i - p_o) r_o^2 r_i^2}{(r_o^2 - r_i^2) r^2} \tag{4.4}$$

Where:

σ_h = Lame hoop stress (MPa)

r = Radius at which hoop stress is calculated (mm)

r_o = External pipe radius (mm)

r_i = Internal cylinder radius (mm)

p_o = External pressure of cylinder (MPa)

p_i = Internal pressure of cylinder (MPa)

c) Determination of Cylinder Wall Thickness

The cylinder wall thickness may be calculated using the formula of determining the wall thickness of a thin-walled cylindrical pressure vessel. Since the form of the vessel is cylindrical, the Hoop stresses are critical as they are twice as big as axial stresses. Therefore, using Equation 4.5 the minimum wall thickness of 6.52 mm was determined.

$$t = \frac{npr}{Q_h} \tag{4.5}$$

$$= \frac{np4 * 10 * 75}{460} = 6.52\ mm$$

Where:

t = Cylinder wall thickness (mm)

p = Pressure inside the cylinder (MPa)

r = Cylinder radius (mm)

Q_h = Maximum allowable hoop stress (MPa)

n = Factor of safety

d) Determination of Hydraulic Pump Speed

When choosing a pump, the pump volumetric flow rate and pressure are required based on which the rotation speed and drive power required from the prime mover can be calculated. The volumetric flow rate produced by the pump depends on the rotation speed, a displacement and volumetric efficiency which were assumed to be 1400 rev/min, 0.032 m^3/rev and 1 respectively. The volumetric efficiency of the cylinder can lower the movement speed but in general the leaks are so small that calculations are done with η_{vol} = 1 (Mikkola, 2014). The rotation speed was based on the available prime mover's manufacturer specification.

$$Q = \eta_{vol}.n.V_k \tag{4.6}$$

Where:

Q	=	Volumetric flow rate (m^3/s)
V_k	=	Displacement per revolution (m^3/rev)
η_{vol}	=	volumetric efficiency
N	=	Rotation speed (rev/s)

Therefore, according to the equation 4.6, the calculated volumetric flow was 0.8 m^3/s

e) Determination of Piston Speed

The movement speed of the cylinder piston depends on the volumetric flow rate and the effective piston area. The volumetric efficiency of the cylinder can lower the movement speed. However, the leaks are so small that calculations are done with the volumetric efficiency of 1 (Khan, 2009). Therefore, using 0.032 m^3/s as volumetric flow and invoking Equation 4.7, (Mikkola, 2014) the theoretical piston speed was determined as 0.43m/s.

$$V = \frac{Q.\eta_{Vol}}{A} \tag{4.7}$$

Where:

V	=	Movement speed (m/s)
η_{Vol}	=	Volumetric efficiency
Q	=	Volumetric flow rate (m^3/s)

f) Determination of Drive Power

The power requirement of the pump depends on several factors including the pump and motor efficiency, the differential pressure and the fluid density, viscosity and flow rate. The drive power which is also known as absorbed power represents the energy imparted on the fluid being pumped to increase its velocity and pressure.

Therefore, the 5 kW total power required from the motor was determined using Equation 4.8. This is especially important when choosing an induction motor to avoid overheating during prolonged machine operation.

$$P_{in} = \frac{P.\left(V_p.n_p\right)}{600{,}000.\eta_{t.p}}\ , kW \tag{4.8}$$

Where:

P_{in}	=	Power (kW)
P	=	Pressure (bar)
V_P	=	Pump displacement (cm^3/rev)
n_p	=	Pump shaft speed (rpm)
$\eta_{t.p}$	=	Pump efficiency

4.5.4 IBM-H1 Hydraulic Circuit System

The circuit system for the IBM-1H making machine was designed to control a 4/3 double-acting cylinder as shown in Figure 4.6.

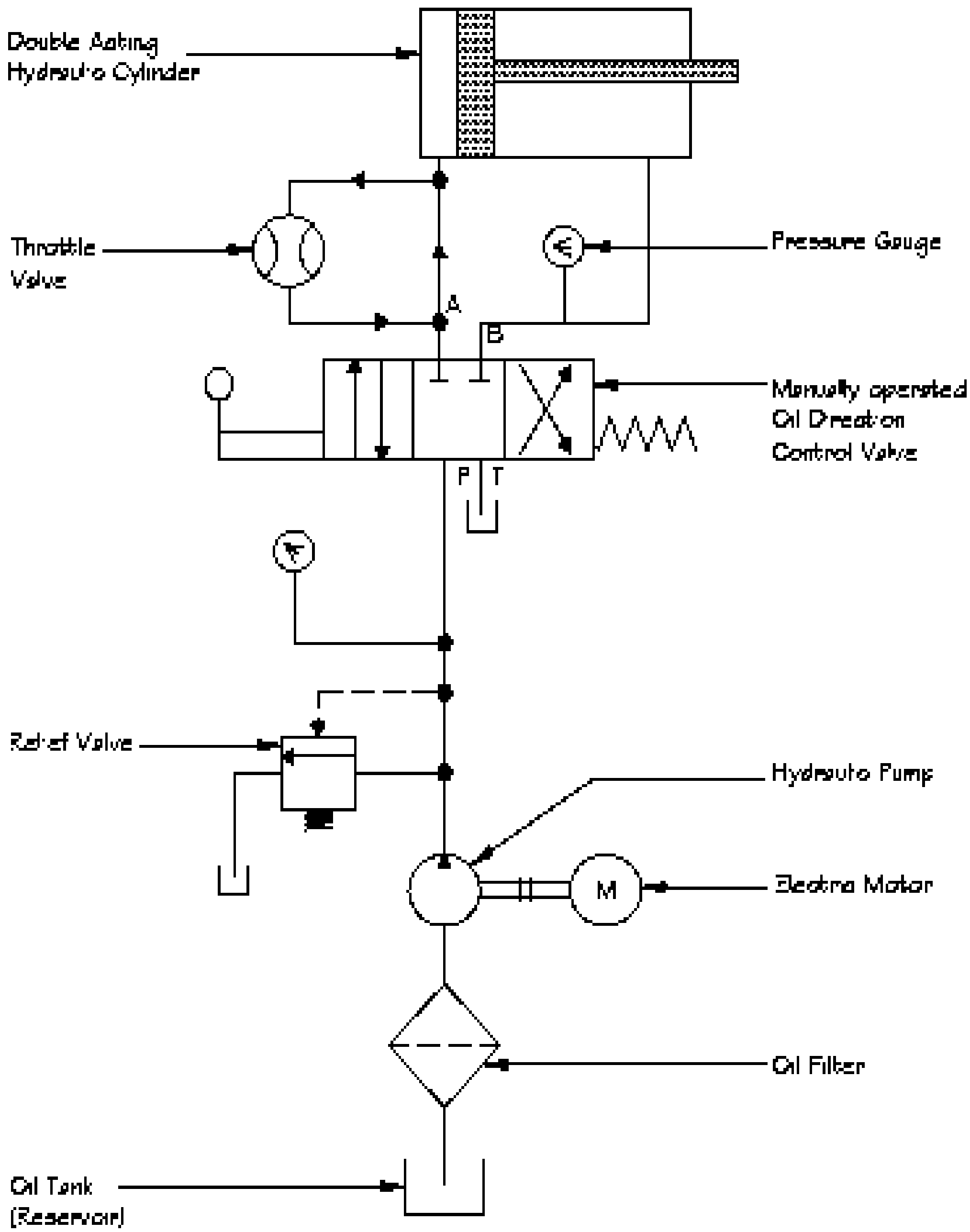


Figure 4.6: IBM-H1 Machine Hydraulic Circuit.

The control system was designed to operate as follows:

(i) When the 4/3 valve is in its neutral position, the cylinder is hydraulically locked and the pump unloads back to the tank.

(ii) When the 4/3 valve is actuated into the flow path, hydraulic fluid flows through port P to A into the hydraulic cylinder which, as a result, extends to the right. Oil in the rod end of the cylinder is free to flow back to the tank through the valve at port B through port T.

(iii) When the 4/3 valve is actuated into the right-envelope configuration, the cylinder retracts as oil flows from port P through port B. Oil in the blank end is returned to the tank via the flow path from port A to port T.

At the end of each stroke, there is no system demand for oil. Thus, the pump flow goes through the pressure relief valve at its set pressure level. The same occurs when the valve is deactivated back into its neutral position.

4.6 Material selection for the IBM-H1

In engineering design processes each of the stages requires decisions about the materials of which the product is to be made and the process for making it. The choice of material is dictated by the design (Ashby, 2002). The materials property charts are designed for use in the selection of materials. Property limits and material indices are plotted onto them, isolating the subset of materials which are the best choice for the design. Since any material has attributes such as density, strength, cost and resistance to corrosion, design demands a certain profile of these: a low density, high strength, a modest cost and resistance to water (*ibid*).

Material property chart or Ashby's chart is one of the quantitative methods for initial screening of materials. Initial screening is important in order to narrow down the choices to a manageable number for subsequent detailed evaluation. There is an immensely wide variety of material to choose from, hence screening out materials that cannot meet the requirements or fail within the constraint given.

Furthermore, narrowing of material list is done by the ranking which is basically the ability to maximise the performance of the material.

In this research, material selection to resist failure was based on the attributes such as mechanical properties, physical properties and shape.

The Ashby's charts which were used to minimise the weight and save the cost of product manufacturing include Young's Modulus – Density chart, Young's Modulus – strength chart and Young's Modulus – Cost Chart.

4.6.1 Young Modulus – Density Chart

Many applications require stiff materials, these materials lie on the top right of the chart and for applications that require low density, materials lie to the left of the chart as shown in Figure 4.8. The IBM-H1 machine design required materials with high stiffness because of the high force resulting from hydraulic pressure system. Therefore, from Figure 4.7, selection of materials with high modulus was done, in this case steels.

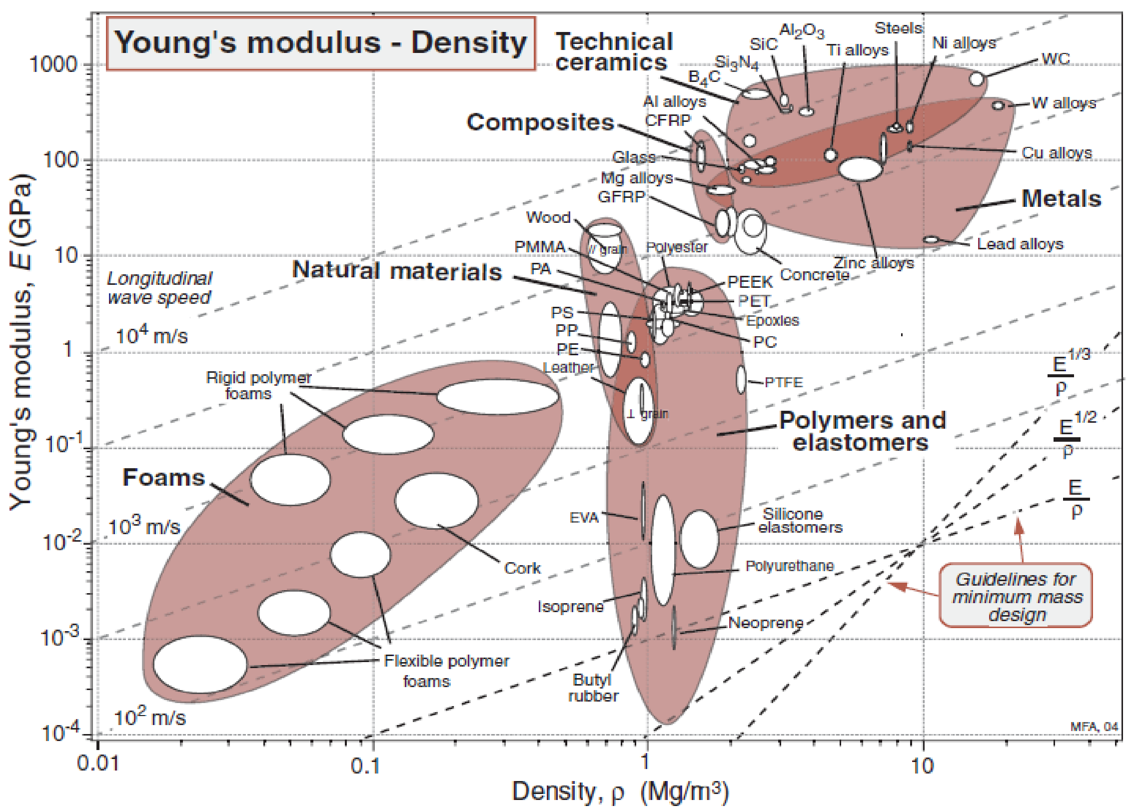


Figure 4.7: Young's Modulus vs Density. (Ashby, 2005)

4.6.2 Young's Modulus – Cost Chart.

Materials with high strength and low modulus lie towards the bottom right. Such materials tend to buckle before they yield when loaded as panels or columns. Those near the top left have high modulus and low strength, they end to yield before buckling (Ashby, 2005).

The chart shown in Figure 4.8 has numerous applications, among them: the selection of materials for springs, elastic hinges, pivots and elastic bearings, and for yield-before-buckling design. In this research it was used as a guide for yield-before-buckling and the possible materials were Beryllium, Cast Iron, Mg alloys, Steels and Ceramics under engineering alloys. Because of its availability, machinability and weldability low alloy steel under steels family was suitable.

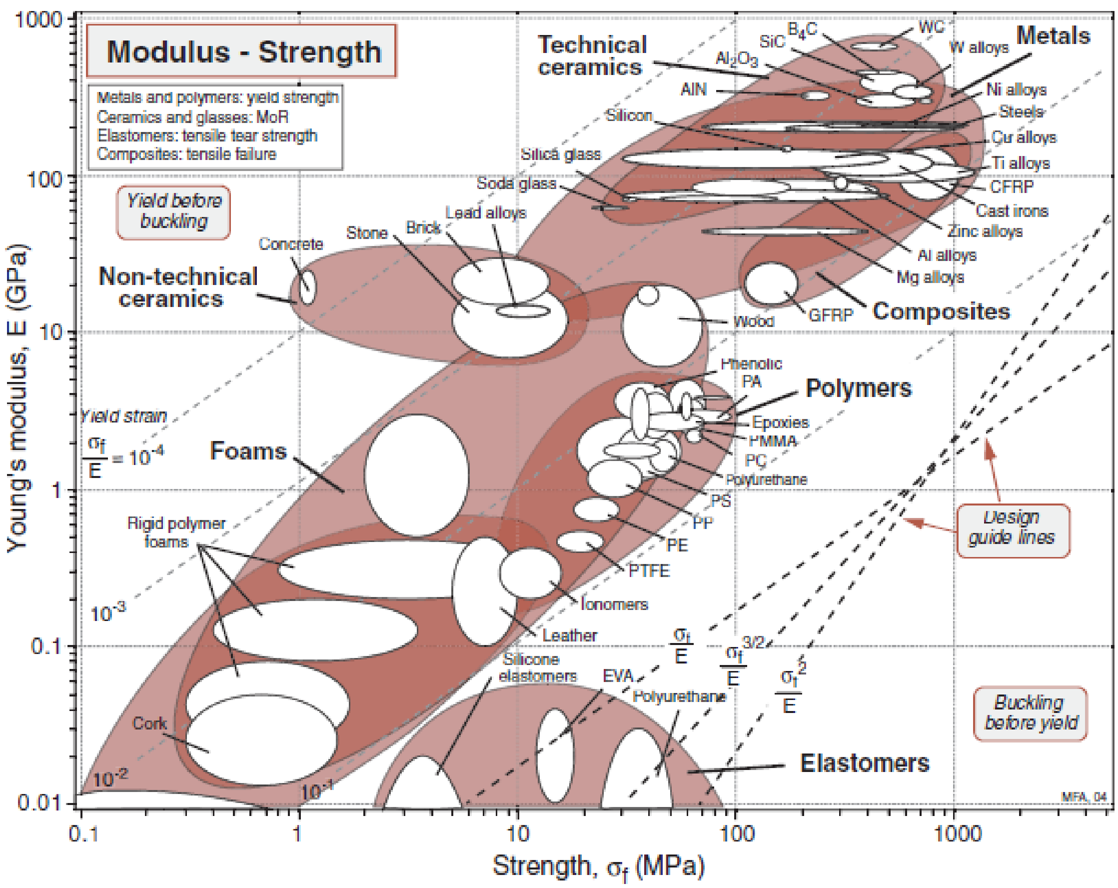


Figure 4.8: Young's Modulus vs Strength. (Ashby, 2005)

4.6.3 Young's Modulus – Cost Chart

Figure 4.9 shows the range of materials against cost. The figure shows that Nickel, copper, high alloy steels, brass have an increasing cost with brass the cheapest while nickel the most expensive.

This leaves low alloy steels as the best possible material in the selection system. It is however noticed that low alloy steels have a low corrosion resistant to moisture which in this research has been compromised against the cost and availability. Corrosion of the mould happens gradually after a long period and sometimes it is because of not cleaning the moulds for maintenance purposes.

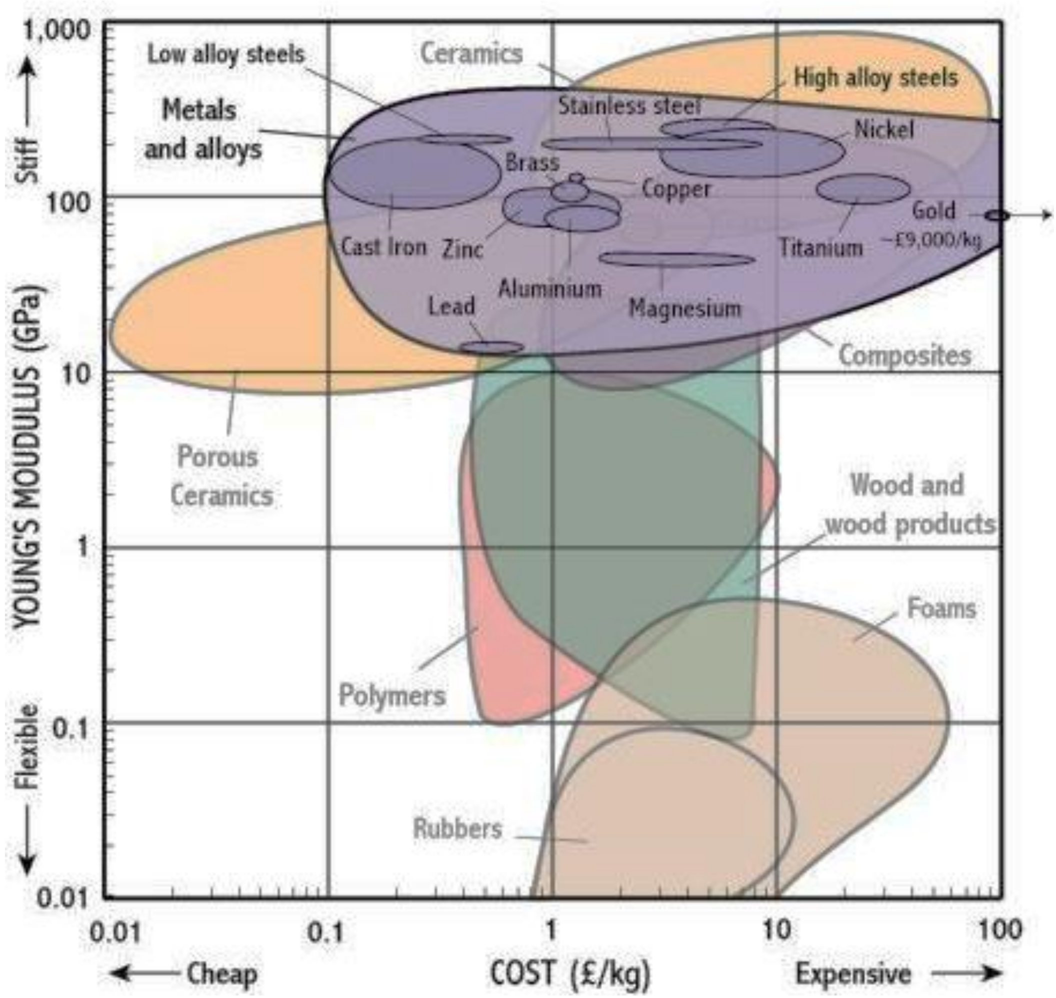


Figure 4.9: Young's Modulus vs Cost. (Ashby, 2005).

4.7 Fabrication of the IBM-H1 Machine

The manufacturing process was dominated by fabrication processes and characterised by machining of a few components such as pins, cover plates, bushes, etc. Consequently, the production of the IBM-1H machine was such that all steel section materials were locally sourced. The manufacturing process involved the use of permanent and temporal joining of metal parts by welding and use of bolts and nuts respectively. Each machine component was fabricated separately before they were joined or welded together as outlined in Table 4.2.

Table 4.2: IBM-H1 Fabricated Parts and Processes.

No.	Components	Description	Equipment used
1.0	Main frame	380x310x8 mm and 120x6 mm RSC open at top and bottom. Bolted by M16X50 Mild Steel Bolts and Nuts	Abrasive cutting, disc, Drilling Machine and Shielded Metal Arc Welding (SMAW)
2.0	Hopper	Prism development of 1.5 mm sheet metal 400 mm height, and 600 mm slanting surfaces	Abrasive cutting disc, Drilling Machine and SMAW
3.0	Soil conveyor/Feeder	220x120x200x1.5 mm welded box Open on top and bottom	Abrasive cutting disc Drilling Machine and SMAW
4.0	HISSB Lid	220x120x16 mm Rectangular M/S cut to form block locking profiles.	Oxyacetylene cutting, Shaping machine. Drilling Machine and SMAW
5.0	Hydraulic Cylinder Base	120x76x10 mm Thick plate cut to fit 76x38 Rolled Steel Channel (RSC)	Abrasive cutting disc, Oxyacetylene cutting, Shaping machine. Drilling Machine and SMAW
6.0	Hydraulic Cylinder Bracket	Two similar bars cut, drilled and welded to 76x38x5 mm RSC	Abrasive cutting disc, Drilling Machine and SMAW
7.0	Induction Motor Base	L-Shaped bracket fabricated using 80x80x5 mm Rolled Steel Angle (RSA)	Abrasive cutting disc, Drilling Machine and SMAW
8.0	Pump Support Bar	6 mm welded angle plate, drilled and bolted using M10 Bolts and Nuts	Abrasive cutting disc, Drilling Machine and SMAW
9.0	Lid Opener Cam	Diameter 10 mm Bar bended to provide Lid Pin/Locker travel profile	Oxyacetylene cutting, Shaping machine. Drilling Machine and SMAW

Figure 4.10 shows the fabrication of a mould casing subassembly for the IBM-H1 machine while the final assembled IBM-H1 machine is as presented in Figure 4.11.

Figure 4.10: Fabrication of the IBM-H1 Mould Stand and Casing.

Figure 4.11: Final Assembled IBM-H1 Machine.

CHAPTER 5 RESULTS AND DISCUSSION

5.1 Introduction

This chapter presents the analysis of results obtained in this study and the discussion based on the research findings. These include machine performance assessment, the compressive strength of the blocks with variable stabiliser soil mixture ratios and the manufacture of the IBM-H1 machine.

5.2 Simulation and Optimisation of ISSB Making Machine Parts

Figures 5.1 shows results of the deformation simulation of a 380x400x10 mm cold rolled mild steel plate for IBM=H1 machine side cover plate. The two same plates are bolted on each side of the 120x50x8 mm cold rolled steel channel to form the mould casing Appendix D3. Therefore, both plates are subjected to stress and deformation due to the resultant pressure generated during stabilised soil compression. Therefore, under maximum operating cylinder pressure of 10 MPa, the maximum deformation was 1.016×10^{0} mm which was is negligible for any effect to geometric features of the IBM-1H machine and the blocks According to literature Compressed Earth Blocks Standards (CDI - CRATerre-EAG, 1998) the most commonly employed full compressed earth blocks have the following theoretical moulding dimensions and nominal dimensions:

- Length: 295 mm
- Width : 140 mm
- Height: 90 mm to 95 mm.

These blocks are used as a reference here for the terms of the specifications which follow. For CEBs of different dimensions, tolerances should be adjusted using a linear mathematical relationship. The measurements given are the net block dimensions, not counting any hollows or indentations. Special blocks can be developed using other main formats. Dimensional tolerances are as follows:

- Length: + 1 to - 3 mm
- Width : + 1 to - 2 mm
- Height: + 2 to - 2 mm

In addition, the difference between the corresponding dimensions of two CEBs of any kind from the same supply must not exceed 3 mm for the length, 2 mm for the width and 3 mm for the height.

An optimal thickness of the cover plate shown in Figure 5.1 was determined using a CAD software, Solidworks 2017 version. Based on the optimisation results shown in Table 5.1, the achieved thickness of 8 mm from the initial 10 mm was optimal for the operating compression pressure of 10 MPa.

Furthermore, stress simulation to determine maximum normal stress of the cover plate was done as shown in Figure 5.2. Therefore, at the pressure of 10 MPa, the minimum and maximum normal stress values were 4.216×10^0 and 9.282×10^3 MPa respectively. Consequently, the yield strength for the plate was 6.204×10^2 MPa which is far below the maximum normal stress value.

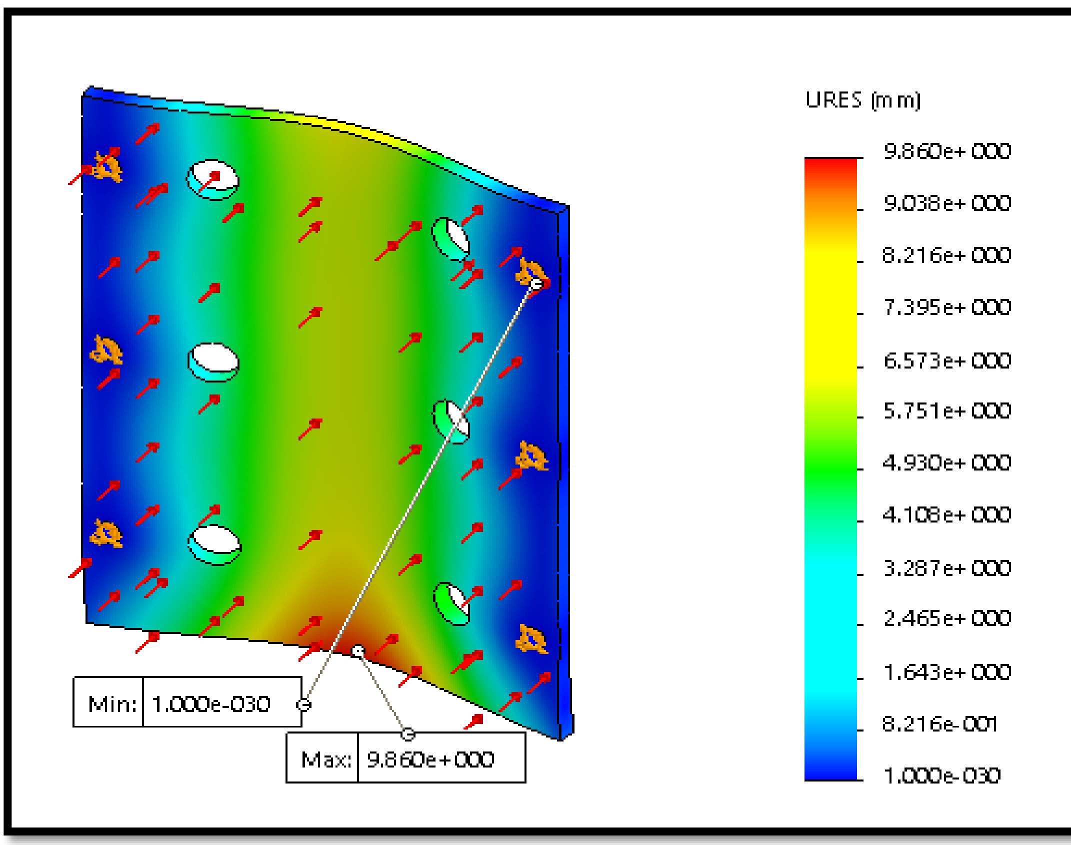


Figure 5.1: Deformation of IBM=M1 Side Cover Plate

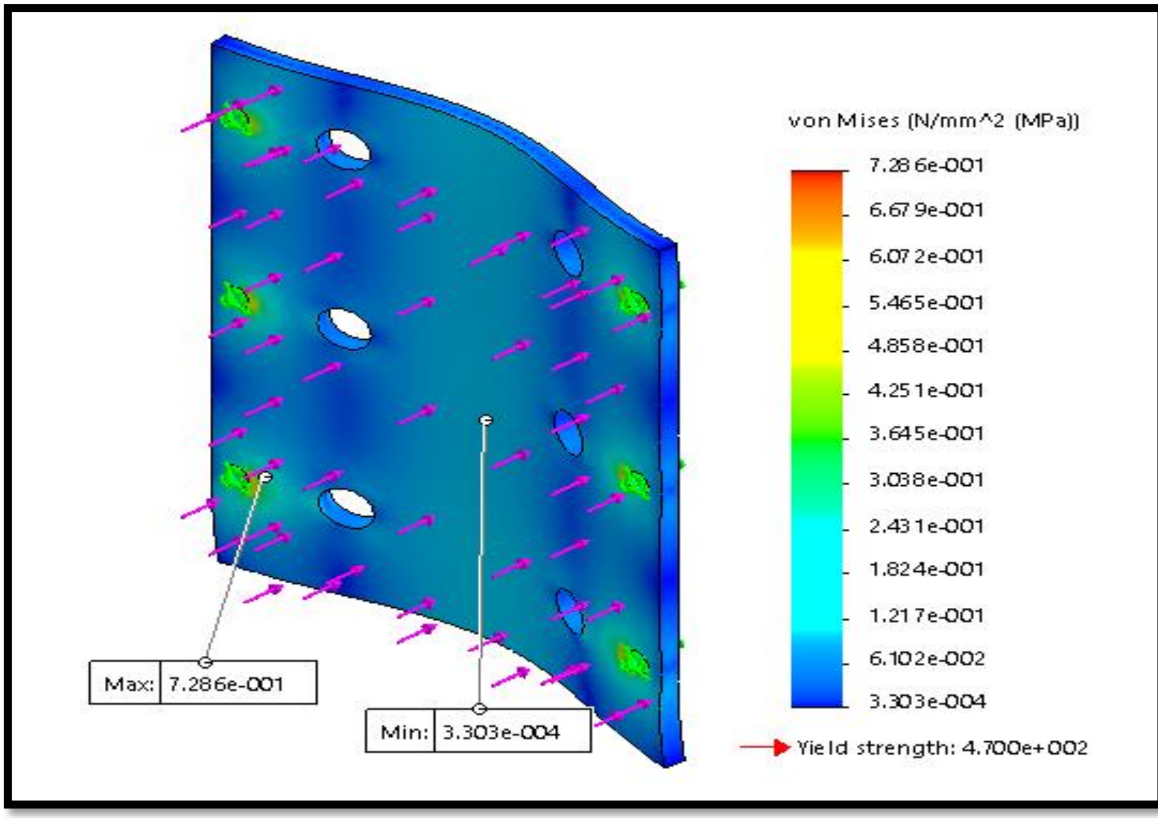


Figure 5.2: Stress Analysis of IBM-M1 Side Cover Plate

Table 5.1: Mould Side Cover Optimisation Results.

Component name	Units	Current	Initial	Optimal	Scenario1	Scenario2
Thickness	mm	9.86422	9.86422	**8**	8	12
Stress1	N/mm^2 (MPa)	1.0064	1.0064	**1.4573**	1.4573	0.71101
Mass1	g	1208.88	1208.88	**980.42**	980.42	1470.63

Figure 5.3 shows the Rolled Steel Channel (RSC) IBM-H1 cylinder base bar stress simulation results. The selected material yield stress is 4.700 x 10^2 N/m^2 and by the maximum operating pressure of 10 MPa, the 76x40x5 mm optimised bar attained minimum and maximum stresses of 3.303 x 10^{-4} N/m^2 and 7.286 x 10^{-1} N/m^2 respectively. Therefore, by using 4 as the FOS and since the maximum stress is less than that of the yield stress, no failure is expected at maximum operating pressure. Optimisation results are shown in Table 5.2.

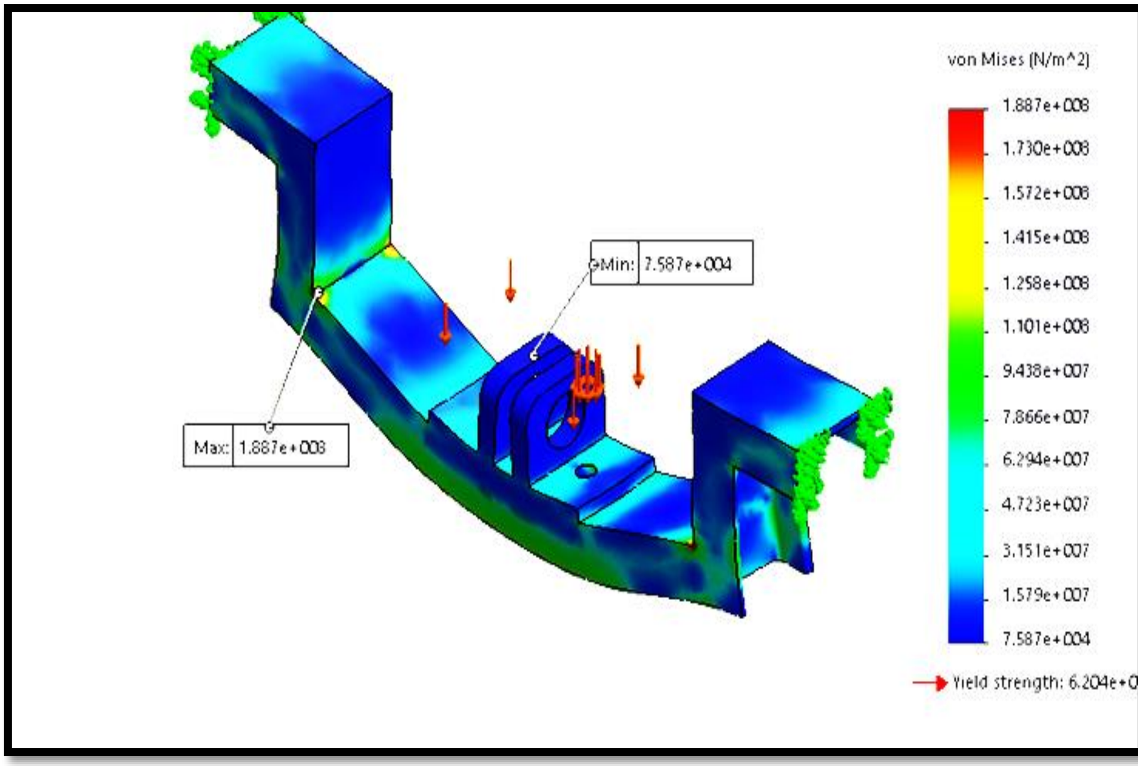


Figure 5.3: IBM-H1 Cylinder Base Simulation Stress Analysis

Table 5.2: Cylinder Support Bar Optimisation Results.

Component name	Units	Current	Initial	Optimal	Scenario1	Scenario2
Height	mm	40	40	**40**	30	40
Width	mm	78	78	**76**	70	70
Fillet	mm	4	4	**2**	2	2
Chamfer	mm	2	2	**2**	1.5	1.5
Stress2	N/mm^2 (MPa)	1.2092	1.2092	**1.178**	1.5744	1.2137

Furthermore, Figure 5.4 shows the deformation simulation for the same cylinder base bar of the IBM-H1 machine. It can be seen that the maximum deformation was 3.385x10^{-1} mm at maximum operating cylinder pressure, which does not affect compression results

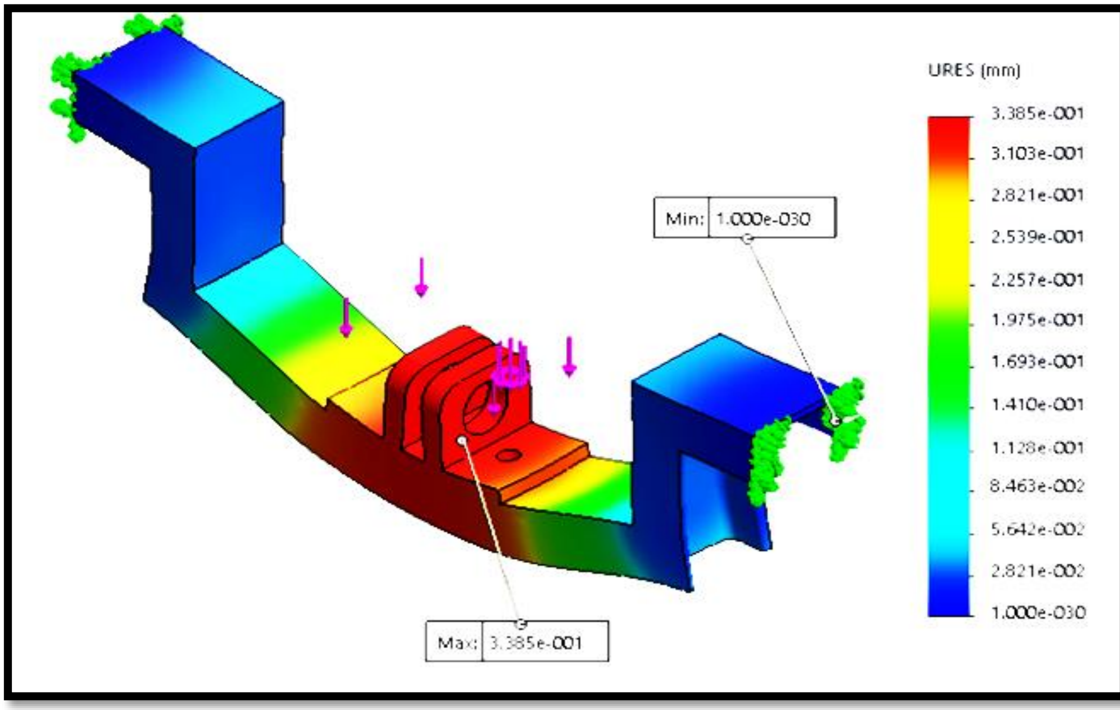


Figure 5.4: IBM-H1 Cylinder Base Simulation Deformation Analysis

5.3 ISSB Making Machine Block Production Cycle Time

Different machine process times per block as produced using the three ISSB making machines IBM-M1, IBM-M2 and IBM-H1 are shown in Figure 5.5. Tests were done using the same stabilised soil and maintained other conditions. Results indicate that loading, compression and ejection have a significant effect on the rate of ISSB production with loading taking the longest time. Tests carried out have shown significant improvement in terms of machine capacity and production rate. The mean cycle time per block was 121 and 140 seconds for the IBM-M1 and IBM-M2 machines as shown in Appendix G1 and G2. The IBM-H1 machine showed the shortest mean cycle time of 31 seconds per block. Therefore, using the IBM-H1 machine and based on the IBM-M1 and IBM-M2 machines, the performance improvement in production cycle time was 78.6. Furthermore, it should be noted that the higher standard deviation values for stabilised soil loading, lid opening and compression time for IBM-M1 and IBM-M2 machines were because of inconsistencies arising from the manual method of soil loading and compression. Stabilised soil is loaded every after one block and while soil compression is characterised by ramming.

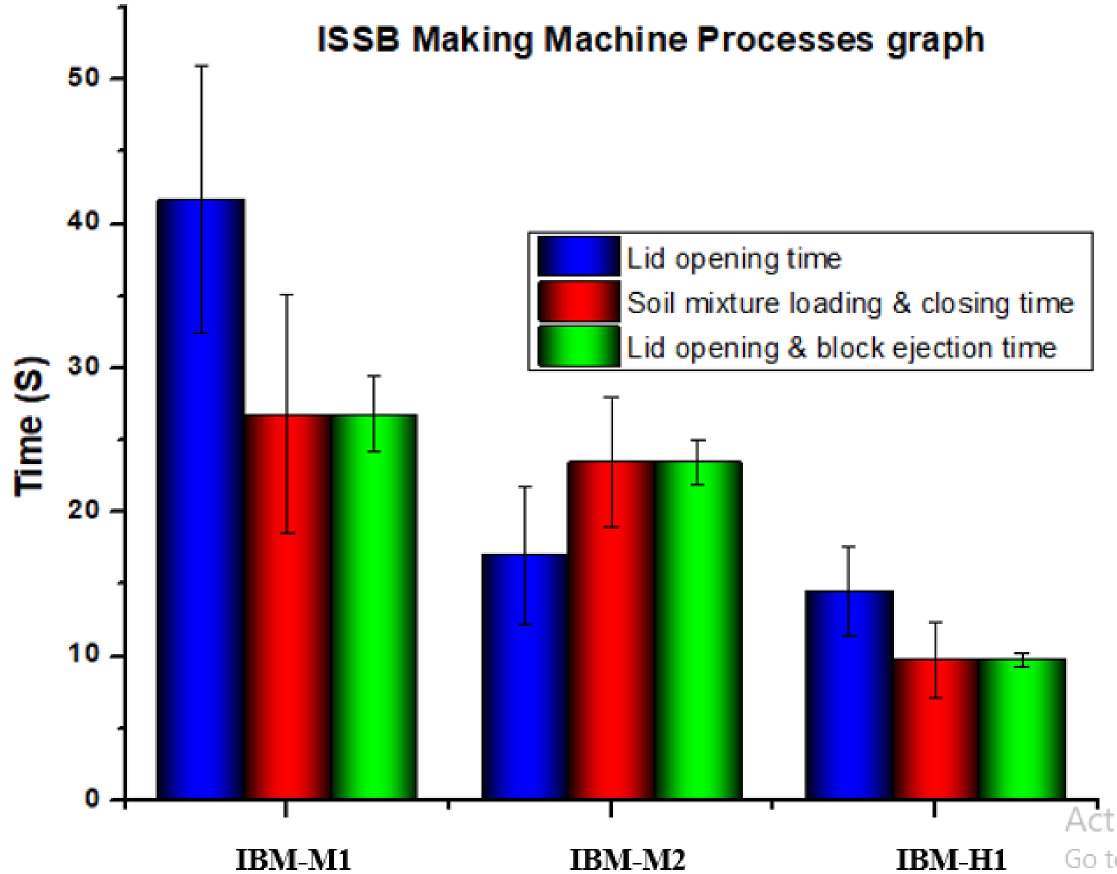


Figure 5.5: IBM-M1, IBM-M2 and IBM-H1 Production Cycles.

In Appendix F individual production cycle times per block for three machines IBM-M1, IBM-M2 and IBM-H1 are shown. Based on this data the mean production cycle time and the corresponding standard deviation values shown were determined using OriginPro 8.5, a statistical software. Generally, similar values were obtained as shown in Appendix G. Considering the information in Appendix F and the descriptive statistics shown in Appendices G1 and G2 there were significant differences between the means. The shortest cycle time was 30.93 seconds for the improved ISSB making machine, while the IBM-M1 and M2 machines the production rates of 140.20 and 120.67 seconds per block were achieved. Therefore, this confirms the significant production cycle time reduction by 78.60 % as an improvement for using IBM-H1making machine.

5.4 ISSB Strength Test Results

Figure 5.6 shows the compression strength plotted against different cement contents for manually compressed ISSBs. The low compression pressure of 1.4 MPa of the IBM-1 and M2 machines resulted in lower compressive strength than the minimum required strength of 6 MPa for the load bearing compressed blocks. The high standard deviation recorded for blocks with 50% cement content can be attributed to inconsistency resulting from irregular manual compression of the stabilised soil mixture.

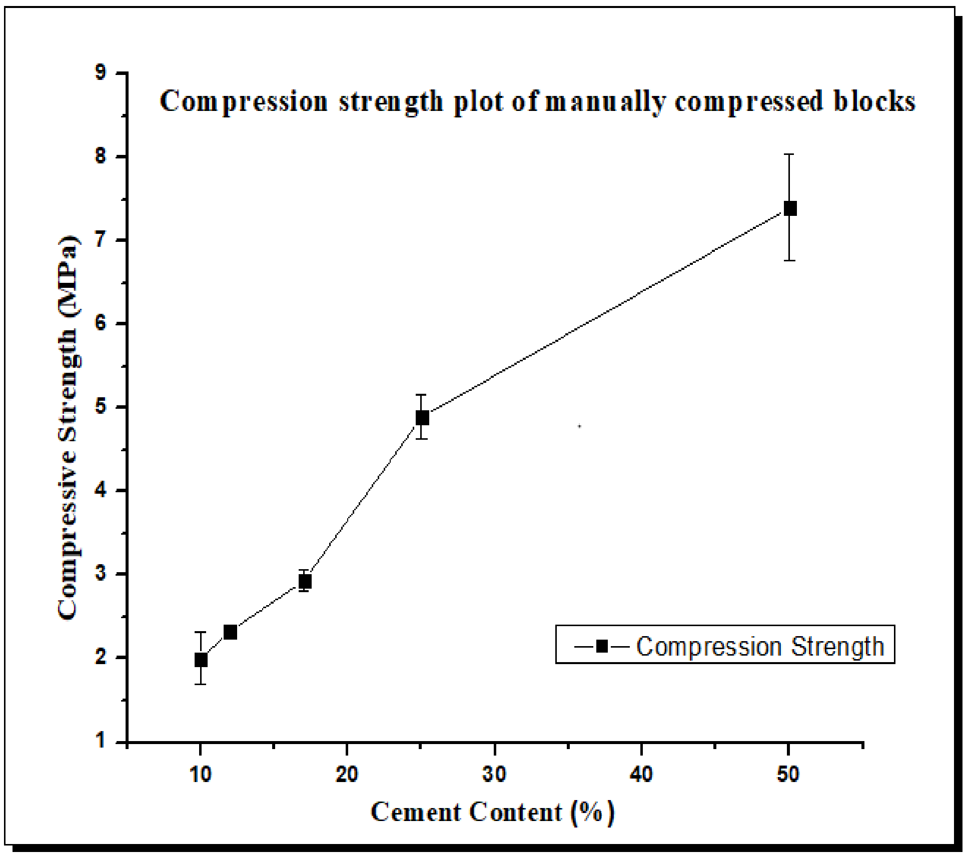


Figure 5.6: **S**trength changes with variable cement contents for IBM-M1 machine.

Figure 5.7 shows the plot of IBM-H1 compressive strength against the compression pressure at different cement contents. The highest block strength achieved was for the 50% soil sample. Stabilised soil compressed to the pressure of 8 MPa yielded blocks with the compressive strength above 6 MPa, which is the minimum required strength for all load bearing compressed stabilised soil blocks. The results in Figure 5.7 also shows minimal standard deviations for the four curves 10%, 12%, 17% and 25% because of controlled soil compression apart from the soil with 50 % cement content. This is because of limited space for the movement of soil particles resulting from high stabiliser content. Therefore, the strength of blocks remained irregular.

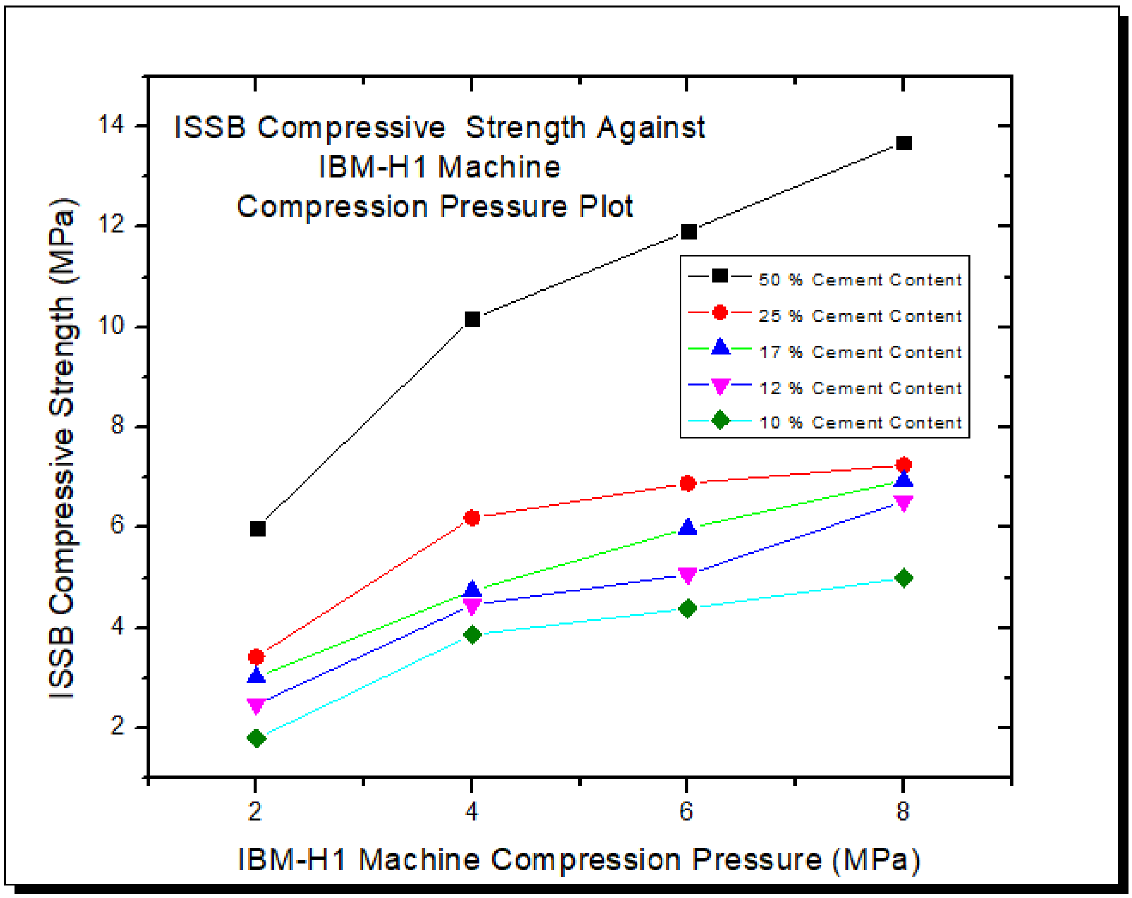
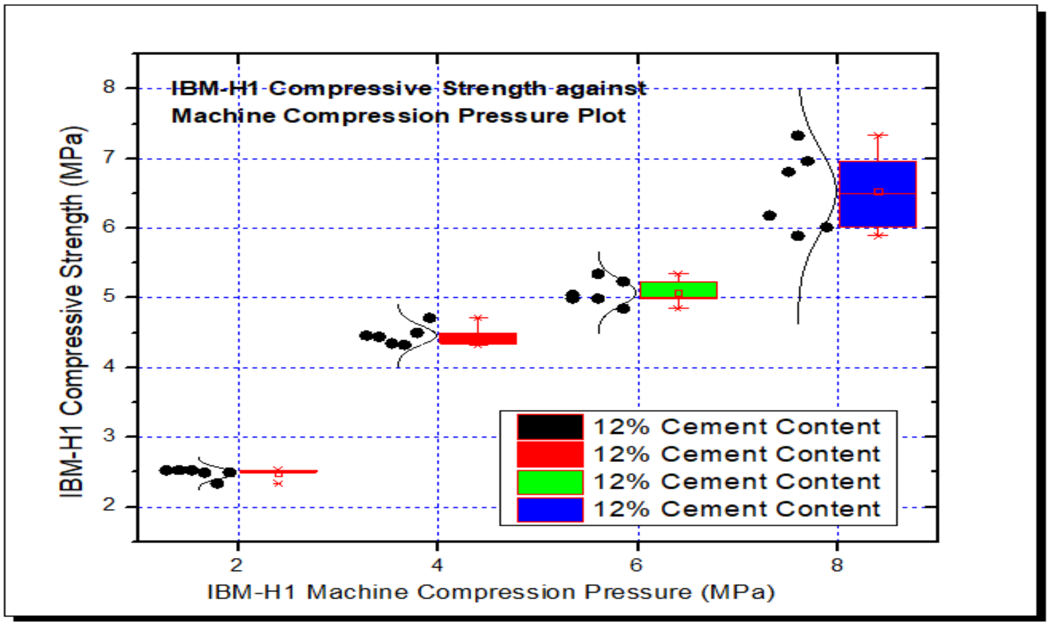


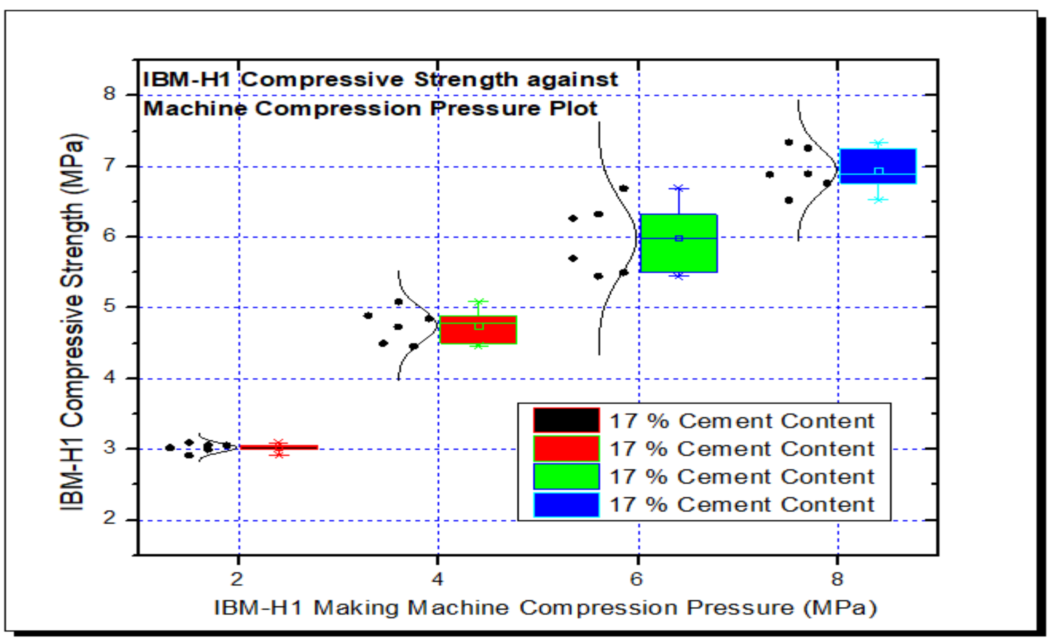
Figure 5.7: Compressive strength changes with variable cement contents at different compressive pressure for IBM-H1 machine.

The highest block strength recorded was 13.8 MPa for 50% cement content blocks compressed at 8 MPa. Economically the ideal compression pressure should be above 6 MPa for soil with 12 and 17 % cement content.

Furthermore, Figure 5.8(a) and 5.8 (b) plots demonstrates the distribution and variability of the strength of the IBM-M1 blocks using cement content of 12% and 17% respectively. Applying pressure of 8 MPa the strength distribution was uneven in both cases.



(a)



(b)

Figure 5.8 (a) (b): Distribution and Variability of Block Strength for IBM-H1 Machine by Varying Pressure (a) 12% Cement Composition (b) 17% Cement Composition

Figure 5.9, shows the distribution and variability of block strength for manual ISSB machine by varying cement composition. Strength range was evenly distributed for all cement composition apart from the 50% composition. It should be noted that the TDAU manual ISSB making machine compression mechanism has no compression force regulator. Therefore, the compression displacement is fixed and the maximum compression is manual. Consequently, the uneven distribution and variability of block strength with 50% cement composition has limited space for soil particle movement due to high stabiliser content. The resulting plot of Figure 5.9 also shows that the compressive strength of the blocks is affected by the amount of stabiliser content.

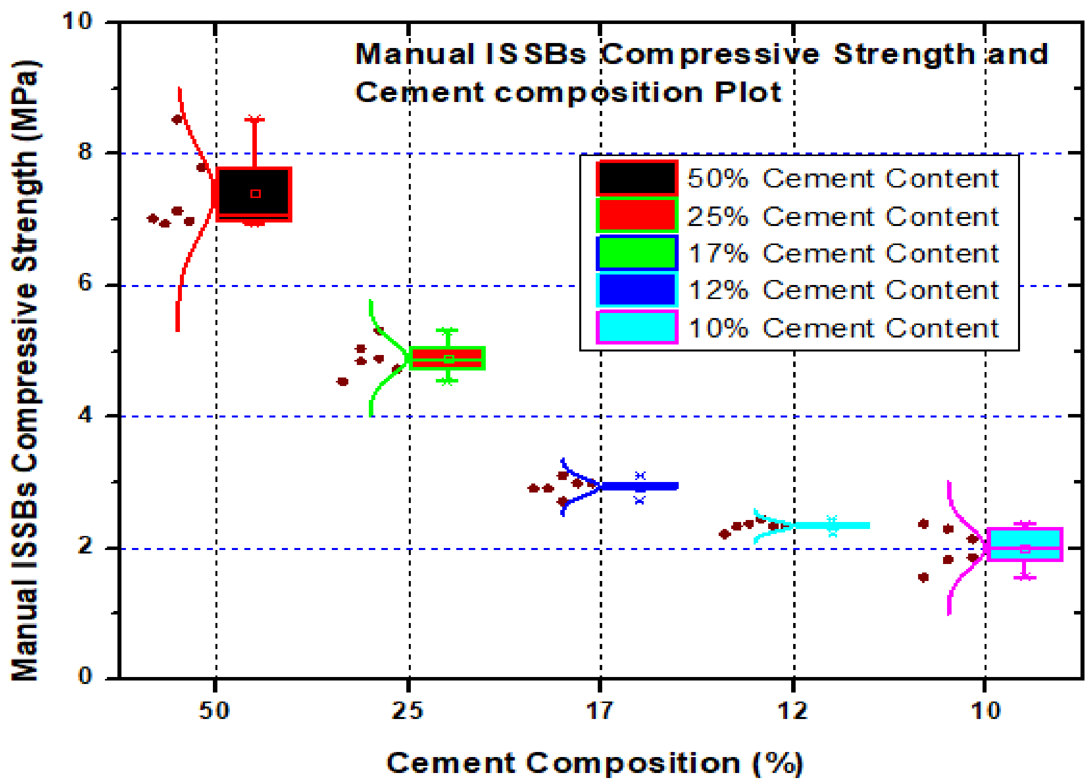


Figure 5.9: Distribution and variability of block strength for manual ISSB machine by varying cement composition

CHAPTER 6 CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

This final chapter presents the conclusions and recommendations based on the results and discussions presented in chapter five.

6.2 Conclusion

The ISSB making machine was successfully redesigned, manufactured and tested with improved performance. It is seen that CAD/CAE is generally important to use in product design and manufacturing. Additional systems and mechanisms were designed and incorporated in the ISSB making machine general arrangement resulting in improved production rate.

Due to the enhanced compression system, the compressive strengths of the blocks made using the new designed machine were much higher than those from the manually operated ISSB making machines. The reduced block production cycle time for the TD IBM-H1 block making machine also resulted in an increased machine production capacity of 960 blocks per day.

In this study, the approach of comparing TD IBM-M1 and TD IBM-M2 machine designs shows that there is a significant distinction between the two machines. This includes the effect of compression on the strength of ISSBs. Therefore, increased piston displacement for the TD IBM-H1 machine resulted in improved soil compaction for the block.

Consequently, based on the results of this study, it is clear that an improved machine performance and block strength meeting international standards were achieved.

The designed and manufactured IBM-H1 had distinct features and functions such as compression, block ejection and soil mixture loading. Hydraulic system was incorporated for enhanced soil compaction and increased ejection time and based on performance test results there was significant improvement on block strength and machine capacity.

The limitations of this research were lack of laboratory equipment to determine wet compressive pressure. However, this was achieved by using modified hydraulic. Furthermore, lack of some hydraulic components on local market was also a challenge.

6.3 Recommendations

A follow-up study concerning the design and manufacture of ISSB making machines must be undertaken to consider automating the block making processes which should include soil preparatory, conveyance and block picking stage, etc. This will further enhance machine capacity and reduce the cost of production while maintaining the quality of blocks.

The results in chapter five show that motorised ISSB making machines yield blocks with high density and compressive strength due to enhanced compression force generated by the hydraulic system. Therefore, it would be worthwhile to design and manufacture a multiple mould ISSB making machine for increased production rate.

Furthermore, extended future studies should also consider the following thematic areas:

i. To investigate ISSBs aging period of different soil types.
ii. Compressed stabilised soil block strength prediction for various soil types.
iii. Design of an ISSB making with movable top and bottom compressing plates.

REFERENCES

Abas, M. A., (2008). Compression Strength of Soil Cement Cube. *International Journal of Civil Engineering and Geo-Environment.* pp. 1-9

Adupa, R., Perez, P., and Mauricio, A., (2009). Interlocking Stabilised Soil Blocks: Appropriate Earth Technology in Uganda. UN-HABTAT, Nairobi.

Ambekar, A.G., (2007). *Mechanism and Machine Theory*. 1st Edition. New Delhi-110001: Printice Hall of India.

Anis, A., (2012). Simulation of Slider Crank Mechanism Using MSC Adams Software. *International Journal of Engineering & Technology IJET*, Vol:12 (No:04), pp. 108-112.

Ashby, M. F., (2005). Materials Selection in Mechanical Design. 3rd ed. Pergamon Press, United States of America

Bhojne, S. A., Keste, A. A., and Gawande, S. H., (2008). Investigation on the effect Design Parameters of Toggle Clamping Mechanism on Output Force. *International Engineering Research Journal*, pp. 50 7-513.

Bodner, A., and Mcginnis, L. F., (2002). A Structured Approach to Simulation Modeling of manufacturing systems, Atlanta, Georgia 30332-0205, U.S.A.

Boubekeur, S., and Houben, H., (1998) Compressed Earth Block Standards. CDI - CRATerre EAG 144p

CAHF,. (2016). *Challenges of Affordable Housing Delivery in Zambia*, Lusaka: Center for Affordable Housing Finance Africa.

Chironis,N., and Sclater, N. P., (1991). *Mechanisms and Mechanical Devices Source Book.* Fourth Edition. New York: McGraw-Hill.

Dicker, J. J., Shigley, J. E., and Pennock, G. R., (2013) Theory of Machines and Mechanism Third Edition, pp. 308 New York. Oxford University Press.

Edward, G., (2008). Concrete construction engineering Handbook. Second Edition, pp 21-24, New Jersey CRC Press.

Guillaud, H., Joffroy, T., and Odul, P., (1995). *Compressed Earth blocks: Manual of design and construction.* CRATerre-EAG, Ausder Arbeit von GATE. Germany: Braunschweig Vieweg.

Huang, M., Lin, T., and Fung, R., (2011). Key Design Parameters and Optimal Design of a Five Point Double - Toggle Clamping Mechanism. *Elservier*, Vol. 35, pp. 4304 - 4320

Hughes, J. P., (2012). *Analysis of a Toggle Mechanism: Sensitivity to Link Sizes*, Connecticut: Thesis report, Rensselaet Polytechnic Institute Hartford.

Hydrafoam., (2004). *Hydrafoam Training Manual.* Johannesburg 220 Rondebult road: Libradene boksburt, Sunward park 1470.

Kafum, E., (2018). Construction Machinery Catelogue.

Kccpr., (2012). Hydraulic Cylinder Catalogue. www.kccpr.com

Khan. Q. S., (2009). *Design and Manufacturing of Hydraulic Cylinder.* Mumbai, India: TANVEER Publications.

Khandani, S., (2005). *Engineering Design Process*, Califonia: Initiatives for Science and Math Education (IISME).

Kintingu, S. H., (2009). *Design of Interlocking bricks for Inhanced wall construction, flexibility alignment, accuracy and load bearing*: Thesis, The University of Warwick, London.

Kolovsky, M. Z., Evgrafov, A. N., Semenov, Y. A., and Slousch, A. V., 2000. *Advanced Theory of Mechanisms and Machines.* 1st Edition. New York: Springer.

Kuang-HuaChang, K. H., (2006). *Design Parameterization and Tool Integration for CAD-based Mechanism Optimization*. Elsevier , 37(12), pp. 779-796.

Leiyue Machinery., (2017). *Catalogue of Leiyue Heavy Machinery Industry, Co., ltd-* www.hljcoal.com.

Matti, V., Heikki, K., and Jyrki, V., (2002). Hydraulitekniikan perusteet. Vantaa: WSOY.

Mikkola, T., (2014). *Design of Hydrailic Cylinder for Hand held Tool*: Mechanical and Production Technology, Thesis: Oulu University of Applied Sciences.

MNPD., (2017). *Seventh National Development Plan*, Lusaka: Ministry of National Planning Development.

Multiquip, M. Q., (2011). *Compaction Handbook.* Carson

Nambatya, M. M., (2015). Investigating the Rationale for Material Selection in Tropical Housing Projects in Uganda - A case for Interlocking Stabilised Soil Block Technology: Thesis, ST.EDMUND'S COLLEGE

Ondruska, J., and Biath, P., (2012). Idealized Compression Ratio for a Screw Briquetting Press. *Acta Polytechnica*, 52(2), pp. 13-16.

Onyeakpta, O., and Onundi, L., (2014). Improvement on the Design and Construction of Interlocking Blocks and its Moulding Machin. *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)* ,olume 11, Issue 2, pp.49-66 .

Piyasena, R. R. C., Premerathne, P. A. T. S., Perera, B. T. D., and Nanayakkara S M A,. (2013). *Evaluation of Initial Setting Time of Fresh Concrete*, pp 47-52

Racodi, C., (1997). *The Urban Challenge in Africa – Growth and management*, of its life. UNUP-952.

Rahman, A.H.M.M., Ferooz, M.G., and Talukder, M.D.H., (2011). Assessment of Soil Compaction–A Project Study. www.banglajol.info/index.php/MIST

Reddy, V., (2015). Design of a Manual Press for the Production of a Manual Press for Production of Compacted Stabilised Soil Blocks. *CURRENT SCIENCE*, Volume 109, NO. 9, pp. 1651-1659.

Sandor, E.K., and Erdman, G.E., (1988). *Advanced Mechanism Design: Analysis and Synthesis.* Vol 2. Prentice-Hall.

Shih, R.H., (2014). *Introduction to Finite Element Analysis Using SolidWorks Simulation*. Oregon: www.SDCpublications.com.

Swampnil, H.P., (2016). Research on Interlocking Stabilised Soil Bricks (ISSB)-A Literature Survey. *International Journal of Research in Engineering and Technology*, Volume 05 pp. 2321-7308.

Uicker, J. J., Pennock, G.R., and Shigley, J. E., (2003). *Theory of Machines and Mechanisms.* Third Edition. New York: Oxford University Press.

Ulrich, K.T., and Eppinger, S.D., (2003). *Product Design and Development*. New Delhi: Tata McGraw-Hill Publishing Company Limited .

UN-HABITAT., (2009). *Appropriate Earth Technology in Uganda*: ISBN: 1184/09E, pp 50.

Waziri, B.S., Lawan, Z.A., and Mala, M., (2013). Properties of Compressed Stabilized Earth Blocks (CSEB) For Low Cost Housing Construction: A Preliminary Investigation. *International Journal of Sustainable Construction Engineering & Technology*, Vol 4, No 2,(ISSN: 2180-3242), pp. 39-46.

Yakubu, S.O., and Umar, M.B., (2015). Design, Construction and Testing Of a Multipurpose Brick/Block Moulding Machine. *American Journal of Engineering Research (AJER),* 04(2320-0936), pp. 33-43.

APPENDICES

APPENDIX A: ISSB TIME STUDY OBSERVATION SHEET

Time study observation sheet			
Identification of operation:			Date:
Start time :9:06 End time :10:48	Operator: Mr .Tembo	Approval :	Observer: O.Samungole

Element description and breakpoint		Cycles																Summary			
		No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	T_{SUM}	T_{AV}	PR	NT
1.	Soil preparation		9.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
2.	Filling machine mould	T	30.8	30.8	23.3	20.9	21.6	22.3	24.6	19.9	31.7	16.0	16.2	20.7	14.9	17.2	27.7	338.6	22.6	0.9	27.12
3.	Lid closing and compaction	T	29.8	24.9	24.2	40.8	13.4	23.6	19.5	20.4	22.9	23.1	24.2	15.8	20.6	18.6	26.2	348.0	23.2	0.9	27.84
4.	Lid opening and ejection	T	10.9	10.6	10.5	10.2	6.4	8.8	9.4	8.8	14.8	7.5	10.3	6.3	9.4	8.3	15.0	147.2	9.8	0.9	11.84
5.	Stacking the block	T	24.8	21.2	19.3	13.9	8.8	16.7	10.0	9.4	15.4	12.8	30.3	14.1	15.3	21.0	11.7	244.7	16.3	0.9	19.56

APPENDIX B: COMPRESSIVE STRENGTH OF MANUAL TDAU ISSBs

B1: 50% Cement Composition

Sample No.	Weight (Kg)	Thickness(mm)	Force (Kgf)	Strength (Mpa)	Density (Kg/m^3)
1	9.18	109.00	36,000.00	6.98	1,664.43
2	9.75	110.00	36,800.00	7.13	1,751.71
3	9.86	110.00	36,200.00	7.02	1,771.47
4	9.83	110.00	44,000.00	8.53	1,766.08
5	9.87	107.00	35,800.00	6.94	1,822.98
6	9.75	109.00	40,200.00	7.79	1,767.78
Mean	**9.71**	**109.17**	**38,166.67**	**7.40**	**1,757.41**
	0.25	**1.17**	**3,292.21**	**0.64**	**51.69**

B2: 25% Cement Composition

Sample No.	Weight (Kg)	Thickness(mm)	Force (Kgf)	Strength (Mpa)	Density (Kg/m^3)
7	9.69	110.00	25,200.00	4.89	1,740.93
8	9.88	110.00	27,400.00	5.31	1,775.06
9	9.63	115.00	25,000.00	4.85	1,654.92
10	9.75	115.00	24,400.00	4.73	1,675.55
11	9.76	115.00	23,400.00	4.54	1,677.26
12	9.7	115.00	26,000.00	5.04	1,666.95
Mean	**9.74**	**113.33**	**25,233.33**	**4.89**	**1,698.45**
SD	**0.26**	**2.58**	**1,370.64**	**0.64**	**48.02**

B3: 17% Cement Composition

Sample No.	Weight (Kg)	Thickness(mm)	Force (Kgf)	Strength (Mpa)	Density (Kg/m^3)
13	9.92	117.00	16,000.00	3.10	1,675.62
14	9.49	117.00	14,000.00	2.71	1,602.99
15	9.83	115.00	15,000.00	2.91	1,689.29
16	9.78	115.00	15,400.00	2.99	1,680.70
17	9.78	117.00	15,000.00	2.91	1,651.97
18	9.73	117.00	15,400.00	2.99	1,643.53
Mean	**9.76**	**116.33**	**15,133.33**	**2.93**	**1,657.35**
SD	**0.14**	**1.03**	**665.33**	**0.13**	**31.86**

B4: 12% Cement Composition

Sample No.	Weight (Kg)	Thickness(mm)	Force (Kgf)	Strength (Mpa)	Density (Kg/m^3)
19	9.75	116.00	12,600.00	2.44	1,661.10
20	9.76	117.00	12,200.00	2.37	1,648.59
21	9.76	118.00	12,000.00	2.33	1,634.62
22	9.73	118.00	12,000.00	2.33	1,629.60
23	9.72	118.00	12,000.00	2.33	1,627.92
24	9.56	118.00	11,400.00	2.21	1,601.13
Mean	**9.71**	**117.50**	**12,033.33**	**2.33**	**1,633.83**
SD	**0.08**	**0.84**	**388.16**	**0.07**	**20.42**

B5: 10% Cement Composition

Sample No.	Weight (Kg)	Thickness(mm)	Force (Kgf)	Strength (Mpa)	Density (Kg/m^3)
25	9.92	119.00	9,400.00	1.82	1,647.46
26	9.61	120.00	8,000.00	1.55	1,582.67
27	10.01	121.00	11,800.00	2.29	1,634.93
28	10.12	120.00	12,200.00	2.37	1,666.67
29	9.97	120.00	11,000.00	2.13	1,641.96
30	9.67	120.00	9,600.00	1.86	1,592.56
Mean	**9.88**	**120.00**	**10,333.33**	**2.00**	**1,627.71**
SD	**0.2**	**0.63**	**1,608.31**	**0.31**	**32.95**

APPENDIX C: COMPRESSIVE STRENGTH TEST RESULTS OF HISSBs

C1: 50% Cement Composition.

	Block Measurements							
ID No.	Lentgth(mm)	Height(mm)	Width(mm)	Weight(kg)	Area (mm2)	Max Load (kgf)	Strength (N/mm2)	ılk Density(Kg/m
				RATIO 1:2/PREASSURE 2MPa				
1	248.00	120	220	10.30	54,560.00	32,200.00	5.79	1,573.19
2	247.00	120	220	10.20	54,340.00	33,000.00	5.96	1,564.23
3	257.00	120	220	10.70	56,540.00	33,200.00	5.76	1,577.05
4	257.00	120	220	10.70	56,540.00	34,800.00	6.04	1,577.05
5	250.00	120	220	10.50	55,000.00	35,000.00	6.24	1,590.91
6	246.00	120	220	10.20	54,120.00	34,000.00	6.16	1,570.58
MEAN	**250.83**	**120**	**220**	**10.43**	**55,183.33**	**33,700.00**	**5.99**	**1,575.50**
SD	**4.96**	**0.00**	**0.00**	**0.23**	**1,090.42**	**1,093.62**	**0.19**	**8.93**
				RATIO 1:2/PREASSURE 4MPa				
1	232.00	120	220	10.50	51,040.00	55,400.00	10.65	1,714.34
2	234.00	120	220	10.50	51,480.00	57,200.00	10.90	1,699.69
3	233.00	120	220	10.50	51,260.00	53,400.00	10.22	1,706.98
4	234.00	120	220	10.50	51,480.00	44,000.00	8.38	1,699.69
5	237.00	120	220	10.50	52,140.00	56,200.00	10.57	1,678.17
6	234.00	120	220	10.50	51,480.00	54,000.00	10.29	1,699.69
MEAN	**234.00**	**120**	**220**	**10.50**	**51,480.00**	**53,366.67**	**10.17**	**1,699.76**
SD	**1.67**	**0.00**	**0.00**	**0.00**	**368.13**	**4,795.69**	**0.91**	**12.09**
				RATIO 1:2/PREASSURE 6MPa				
1	225.00	120	220	10.30	49,500.00	55,000.00	10.90	1,734.01
2	224.00	120	220	10.50	49,280.00	61,600.00	12.26	1,775.57
3	225.00	120	220	10.40	49,500.00	65,600.00	13.00	1,750.84
4	225.00	120	220	10.40	49,500.00	59,600.00	11.81	1,750.84
5	224.00	120	220	10.20	49,280.00	58,800.00	11.71	1,724.84
6	230.00	120	220	10.20	50,600.00	61,000.00	11.83	1,679.84
MEAN	**225.50**	**120**	**220**	**10.33**	**49,610.00**	**60,266.67**	**11.92**	**1,735.76**
SD	**2.26**	**0.00**	**0.00**	**0.12**	**496.83**	**3,495.52**	**0.69**	**32.52**
				RATIO 1:2/PREASSURE 8MPa				
1	220.00	120	220	10.30	48,400.00	66,200.00	13.42	1,773.42
2	223.00	120	220	10.50	49,060.00	67,000.00	13.40	1,783.53
3	223.00	120	220	10.50	49,060.00	65,400.00	13.08	1,783.53
4	220.00	120	220	10.40	48,400.00	62,600.00	12.69	1,790.63
5	224.00	120	220	10.50	49,280.00	64,000.00	12.74	1,775.57
6	230.00	120	220	10.70	50,600.00	67,800.00	13.14	1,762.19
MEAN	**223.33**	**120**	**220**	**10.48**	**49,133.33**	**65,500.00**	**13.08**	1,778.14
SD	**3.67**	**0**	**0**	**0.13**	**807.33**	**1,933.91**	**0.31**	**9.98**

C2: 25% Cement Composition.

	Block Measurements							
ID No.	Lentgth(r	Height(mm)	Width(mm)	Weight(kg)	Area (mm2)	Max Load (kgf)	trength (N/mm2	ulk Density (Kg/m3
RATIO 1:4/PREASSURE 2MPa								
1	265.00	120	220	10.10	58,300.00	16,600.00	2.79	1,443.68
2	265.00	120	220	10.20	58,300.00	20,000.00	3.37	1,457.98
3	255.00	120	220	10.30	56,100.00	21,000.00	3.67	1,530.01
4	260.00	120	220	10.30	57,200.00	22,400.00	3.84	1,500.58
5	257.00	120	220	10.30	56,540.00	21,200.00	3.68	1,518.10
6	260.00	120	220	10.30	57,200.00	19,000.00	3.26	1,500.58
MEAN	**260.33**	**120**	**220**	**10.25**	**57,273.33**	**20,033.33**	**3.43**	**1,491.82**
SD	**4.08**	**0.00**	**0.00**	**0.08**	**898.15**	**2,037.32**	**0.38**	**33.96**
RATIO 1:4/PREASSURE 4MPa								
1	235.00	120	220	10.20	51,700.00	28,800.00	5.46	1,644.10
2	235.00	120	220	10.20	51,700.00	33,800.00	6.41	1,644.10
3	230.00	120	220	10.00	50,600.00	32,800.00	6.36	1,646.90
4	235.00	120	220	10.30	51,700.00	31,400.00	5.96	1,660.22
5	235.00	120	220	10.30	51,700.00	35,000.00	6.64	1,660.22
6	238.00	120	220	10.20	52,360.00	34,000.00	6.37	1,623.38
MEAN	**234.67**	**120**	**220**	**10.20**	**51,626.67**	**32,633.33**	**6.20**	**1,646.49**
SD	**2.58**	**0.00**	**0.00**	**0.11**	**568.04**	**2,239.35**	**0.42**	**13.59**
RATIO 1:4/PREASSURE 6MPa								
1	225.00	120	220	10.20	49,500.00	41,400.00	8.20	1,717.17
2	235.00	120	220	10.10	51,700.00	36,800.00	6.98	1,627.98
3	230.00	120	220	10.30	50,600.00	36,400.00	7.06	1,696.31
4	225.00	120	220	10.20	49,500.00	35,600.00	7.06	1,717.17
5	235.00	120	220	10.00	51,700.00	26,800.00	5.09	1,611.86
6	225.00	120	220	10.20	49,500.00	35,000.00	6.94	1,717.17
MEAN	**229.17**	**120**	**220**	**10.17**	**50,416.67**	**35,333.33**	**6.89**	**1,681.28**
SD	**4.92**	**0.00**	**0.00**	**0.10**	**1,081.51**	**4,755.91**	**1.01**	**48.48**
RATIO 1:4/PREASSURE 8MPa								
1	225.00	120	220	10.40	49,500.00	29,200.00	5.79	1,750.84
2	230.00	120	220	10.50	50,600.00	37,800.00	7.33	1,729.25
3	225.00	120	220	10.30	49,500.00	37,400.00	7.41	1,734.01
4	225.00	120	220	10.40	49,500.00	40,600.00	8.05	1,750.84
5	228.00	120	220	10.10	50,160.00	38,800.00	7.59	1,677.96
6	225.00	120	220	10.30	49,500.00	37,000.00	7.33	1,734.01
MEAN	**226.33**	**120**	**220**	**10.33**	**49,793.33**	**36,800.00**	**7.25**	**1,729.48**
SD	**2.16**	**0.00**	**0.00**	**0.14**	**475.25**	**3,939.54**	**0.77**	**26.86**

C3: 17% Cement Composition.

	Block Measurements							
ID No.	Lentgth(mm)	Height(mm)	Width(mm)	Weight(kg)	Area (mm2)	Max Load (kgf)	Strength (N/mm2)	lk Density(Kg/m
RATIO 1:6/PREASSURE 2MPa/Moisture Content								
1	253.00	120	220	10.10	55,660.00	17,000.00	3.00	1,512.16
2	245.00	120	220	10.00	53,900.00	16,800.00	3.06	1,546.07
3	245.00	120	220	10.00	53,900.00	17,000.00	3.09	1,546.07
4	245.00	120	220	10.00	53,900.00	16,000.00	2.91	1,546.07
5	248.00	120	220	10.00	54,560.00	17,000.00	3.06	1,527.37
6	245.00	120	220	9.80	53,900.00	16,600.00	3.02	1,515.15
MEAN	**246.83**	**120**	**220**	**9.98**	**54,303.33**	**16,733.33**	**3.02**	**1,532.15**
SD	**3.25**	**0.00**	**0.00**	**0.10**	**715.14**	**393.28**	**0.06**	**16.08**
RATIO 1:6/PREASSURE 4MPa								
1	230.00	120	220	9.90	50,600.00	24,400.00	4.73	1,630.43
2	230.00	120	220	10.30	50,600.00	23,200.00	4.50	1,696.31
3	230.00	120	220	10.10	50,600.00	23,000.00	4.46	1,663.37
4	228.00	120	220	10.00	50,160.00	25,000.00	4.89	1,661.35
5	228.00	120	220	9.90	50,160.00	26,000.00	5.08	1,644.74
6	230.00	120	220	9.80	50,600.00	25,000.00	4.85	1,613.97
MEAN	**229.33**	**120**	**220**	**10.00**	**50,453.33**	**24,433.33**	**4.75**	**1,651.70**
SD	**1.03**	**0.00**	**0.00**	**0.18**	**227.22**	**1,155.28**	**0.24**	**28.79**
RATIO 1:6/PREASSURE 6MPa								
1	220.00	120	220	9.90	48,400.00	31,200.00	6.32	1,704.55
2	221.00	120	220	9.90	48,620.00	27,000.00	5.45	1,696.83
3	222.00	120	220	9.90	48,840.00	31,200.00	6.27	1,689.19
4	219.00	120	220	9.90	48,180.00	28,000.00	5.70	1,712.33
5	219.00	120	220	9.90	48,180.00	27,000.00	5.50	1,712.33
6	220.00	120	220	9.90	48,400.00	33,000.00	6.69	1,704.55
MEAN	**220.17**	**120**	**220**	**9.90**	**48,436.67**	**29,566.67**	**5.99**	**1,703.30**
SD	**1.17**	**0.00**	**0.00**	**0.00**	**257.19**	**2,559.43**	**0.51**	**9.02**
RATIO 1:6/PREASSURE 8MPa								
1	215.00	120	220	9.90	47,300.00	35,000.00	7.26	1,744.19
2	216.00	120	220	9.80	47,520.00	33,400.00	6.90	1,718.57
3	215.00	120	220	10.10	47,300.00	35,400.00	7.34	1,779.42
4	216.00	120	220	10.00	47,520.00	31,600.00	6.52	1,753.65
5	215.00	120	220	9.80	47,300.00	32,600.00	6.76	1,726.57
6	215.00	120	220	10.00	47,300.00	33,200.00	6.89	1,761.80
MEAN	**215.33**	**120**	**220**	**9.93**	**47,373.33**	**33,533.33**	**6.94**	**1,747.37**
SD	**0.52**	**0**	**0**	**0.12**	**113.61**	**1,440.37**	**0.31**	**22.57**

C4: 12% Cement Composition.

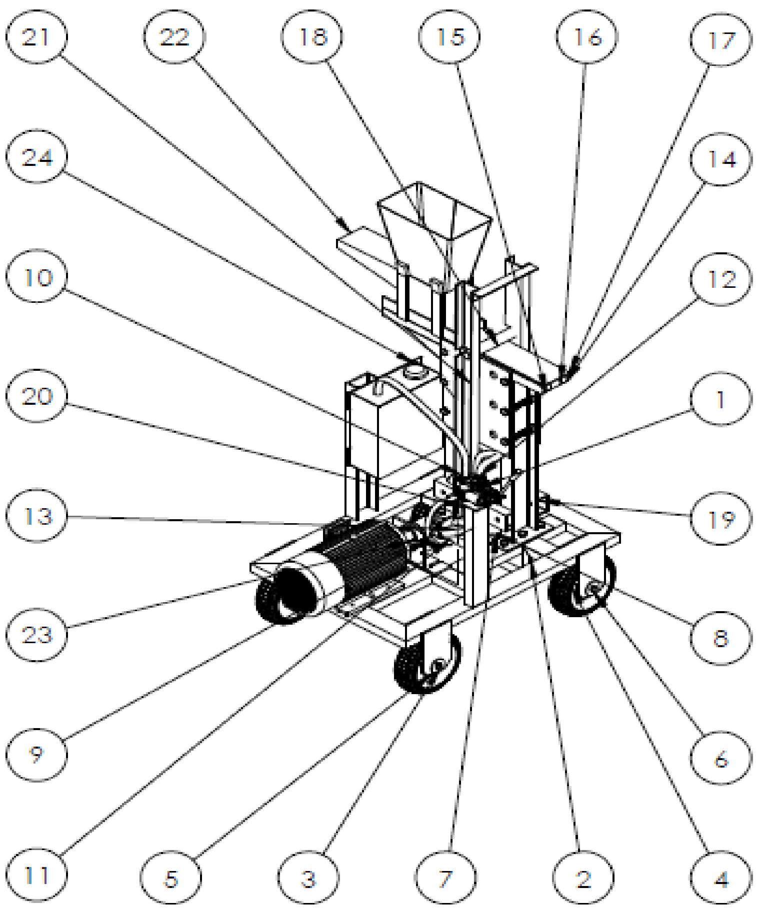
	Block Measurements							
ID No.	Lentgth(mm)	Height(mm)	Width(mm)	Weight(kg)	Area (mm2)	Max Load (kgf)	Strength (N/mm2)	lk Density(Kg/m
RATIO 1:8/PREASSURE 2MPa								
1	249.00	120	220	9.90	54,780.00	13,900.00	2.49	1,506.02
2	247.00	120	220	9.60	54,340.00	14,000.00	2.53	1,472.21
3	252.00	120	220	10.00	55,440.00	13,200.00	2.34	1,503.13
4	254.00	120	220	10.00	55,880.00	14,400.00	2.53	1,491.29
5	252.00	120	220	9.90	55,440.00	14,100.00	2.49	1,488.10
6	251.00	120	220	9.80	55,220.00	14,200.00	2.52	1,478.93
MEAN	**250.83**	**120**	**220**	**9.87**	**55,183.33**	**13,966.67**	**2.48**	**1,489.95**
SD	**2.48**	**0.00**	**0.00**	**0.15**	**546.32**	**413.12**	**0.07**	**13.22**
RATIO 1:8/PREASSURE 4MPa								
1	232.00	120	220	10.00	51,040.00	22,500.00	4.32	1,632.71
2	236.00	120	220	10.20	51,920.00	23,000.00	4.35	1,637.13
3	230.00	120	220	9.40	50,600.00	23,200.00	4.50	1,548.09
4	229.00	120	220	9.80	50,380.00	22,800.00	4.44	1,621.01
5	229.00	120	220	9.80	50,380.00	24,200.00	4.71	1,621.01
6	230.00	120	220	9.80	50,600.00	23,000.00	4.46	1,613.97
MEAN	**231.00**	**120**	**220**	**9.83**	**50,820.00**	**23,116.67**	**4.46**	**1,612.32**
SD	**2.68**	**0.00**	**0.00**	**0.27**	**590.32**	**581.09**	**0.14**	**32.59**
RATIO 1:8/PREASSURE 6MPa								
1	222.00	120	220	9.80	48,840.00	26,600.00	5.34	1,672.13
2	227.00	120	220	10.10	49,940.00	25,400.00	4.99	1,685.36
3	227.00	120	220	10.10	49,940.00	25,400.00	4.99	1,685.36
4	230.00	120	220	10.30	50,600.00	26,000.00	5.04	1,696.31
5	230.00	120	220	9.80	50,600.00	27,000.00	5.23	1,613.97
6	230.00	120	220	10.00	50,600.00	25,000.00	4.85	1,646.90
MEAN	**227.67**	**120**	**220**	**10.02**	**50,086.67**	**25,900.00**	**5.07**	1,666.67
SD	**3.14**	**0.00**	**0.00**	**0.19**	**691.05**	**777.17**	**0.18**	**30.90**
RATIO 1:8/PREASSURE 8MPa								
1	219.00	120	220	9.80	48,180.00	36,000.00	7.33	1,695.03
2	219.00	120	220	9.80	48,180.00	34,200.00	6.96	1,695.03
3	220.00	120	220	10.00	48,400.00	33,600.00	6.81	1,721.76
4	218.00	120	220	10.00	47,960.00	29,400.00	6.01	1,737.56
5	215.00	120	220	9.90	47,300.00	28,400.00	5.89	1,744.19
6	215.00	120	220	9.80	47,300.00	29,800.00	6.18	1,726.57
MEAN	**217.67**	**120**	**220**	**9.88**	**47,886.67**	**31,900.00**	**6.53**	1,720.02
SD	**2.16**	**0**	**0**	**0.10**	**475.25**	**3,095.16**	**0.58**	**20.91**

C5: 10% Cement Composition.

	Block Measurements							
ID No.	Lentgth(mm)	Height(mm)	Width(mm)	Weight(kg)	Area (mm2)	Max Load (kgf)	Strength (N/mm2)	Bulk Density(Kg/m3)
RATIO 1:10/PREASSURE 2MPa								
1	265.00	120	220	10.20	58,300.00	11,000.00	1.85	1,457.98
2	265.00	120	220	10.20	58,300.00	11,800.00	1.99	1,457.98
3	270.00	120	220	10.20	59,400.00	10,000.00	1.65	1,430.98
4	265.00	120	220	10.40	58,300.00	10,400.00	1.75	1,486.56
5	270.00	120	220	10.50	59,400.00	10,000.00	1.65	1,473.06
6	268.00	120	220	10.50	58,960.00	10,400.00	1.73	1,484.06
MEAN	**267.17**	**120**	**220**	**10.33**	**58,776.67**	**10,600.00**	**1.77**	**1,465.10**
SD	**2.48**	**0.00**	**0.00**	**0.15**	**546.32**	**692.82**	**0.13**	**20.73**
RATIO 1:10/PREASSURE 4MPa								
1	237.00	120	220	10.10	52,140.00	24,800.00	4.67	1,614.24
2	240.00	120	220	10.00	52,800.00	21,000.00	3.90	1,578.28
3	245.00	120	220	10.20	53,900.00	19,600.00	3.57	1,576.99
4	240.00	120	220	10.10	52,800.00	20,000.00	3.72	1,594.07
5	240.00	120	220	10.20	52,800.00	19,800.00	3.68	1,609.85
6	240.00	120	220	10.10	52,800.00	19,800.00	3.68	1,594.07
MEAN	**240.33**	**120**	**220**	**10.12**	**52,873.33**	**20,833.33**	**3.87**	**1,594.58**
SD	**2.58**	**0.00**	**0.00**	**0.08**	**568.04**	**2,005.66**	**0.41**	**15.46**
RATIO 1:10/PREASSURE 6MPa								
1	235.00	120	220	10.20	51,700.00	23,400.00	4.44	1,644.10
2	230.00	120	220	10.10	50,600.00	21,000.00	4.07	1,663.37
3	235.00	120	220	10.30	51,700.00	26,000.00	4.93	1,660.22
4	235.00	120	220	10.20	51,700.00	22,600.00	4.29	1,644.10
5	235.00	120	220	10.30	51,700.00	22,400.00	4.25	1,660.22
6	235.00	120	220	10.20	51,700.00	23,000.00	4.36	1,644.10
MEAN	**234.17**	**120**	**220**	**10.22**	**51,516.67**	**23,066.67**	**4.39**	**1,652.69**
SD	**2.04**	**0.00**	**0.00**	**0.08**	**449.07**	**1,652.47**	**0.29**	**9.47**
RATIO 1:10/PREASSURE 8MPa								
1	225.00	120	220	10.40	49,500.00	22,400.00	4.44	1,750.84
2	230.00	120	220	10.50	50,600.00	28,000.00	5.43	1,729.25
3	225.00	120	220	10.30	49,500.00	25,200.00	4.99	1,734.01
4	225.00	120	220	10.40	49,500.00	27,200.00	5.39	1,750.84
5	228.00	120	220	10.10	50,160.00	22,600.00	4.42	1,677.96
6	225.00	120	220	10.30	49,500.00	26,900.00	5.33	1,734.01
MEAN	**226.33**	**120**	**220**	**10.33**	**49,793.33**	**25,383.33**	**5.00**	**1,729.48**
SD	**2.16**	**0**	**0**	**0.14**	**475.25**	**2,413.64**	**0.47**	**26.86**

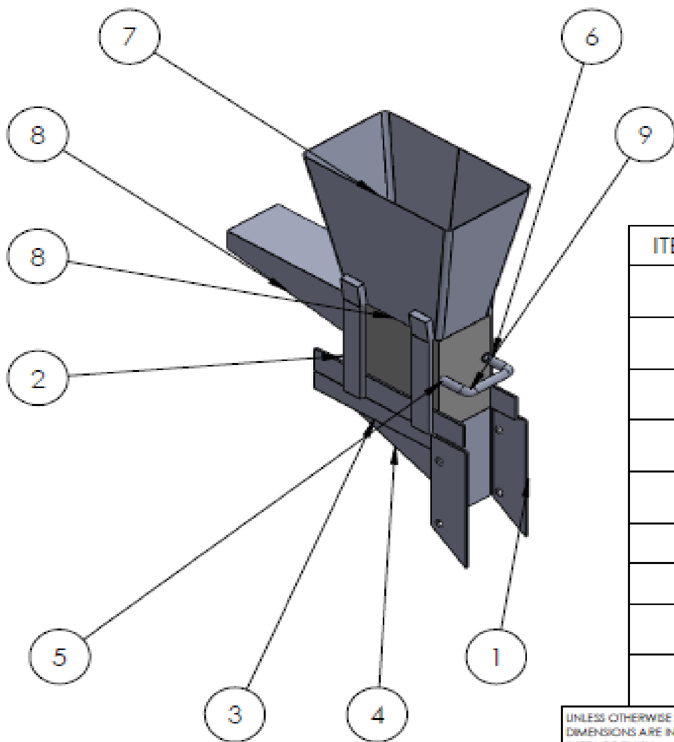
APPENDIX D: HISSB MAKING MACHINE DESIGN DRAWINGS AND MODELS

D1: HISSB Making Machine General Arrangement



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	HISSB_MACHINE SUB-ASSY2		1
2	HISSB_CYLINDER MAIN SUPPORT FRAME		1
3	HISSB_STUB SHAFT		4
4	HISSB_TROLLEY WHEELS		4
5	Black washer BS 4320 - M20 (Form G)	HISSB_PLAIN WASHER	4
6	external circlip_bsi		4
7	HISSB_MAIN CYLINDER BRACKET		1
8	HISSB CYLINDER		1
9	HSSB_PUMP AND BRACKET ASSY		1
10	HISSB_TUBE1		1
11	HISSB_TUBE2		1
12	HISSB_TUBE3		1
13	HISSB_TUBE4		1
14	HISSB BAR		2
15	HISSB HINGE BUSHE2		2
16	HISSB HINGE PIN2		1
17	HISSB LID2		1
18	HISSB MAIN PIN		1
19	HISSB HUB		2
20	HISSB PIN R		2
21	HISSB LEVER SUBASSEMBLY2		1
22	HISSB HOPPER CONVEYOR ASSEMBLY 2		1
23	HISSB_INDUCTION MOTOR		1
24	HISSB_RESERVOIR LID		1

D2: HOPPER AND SOIL CONVEYOR ASSEMBLY



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	HISSB HOPPER SUPPORT BRACKET	MOUNTING	1
2	HISSB CONVEYOR BASE	SUPPORT/BOTTOM COVER	1
3	HISSB CONVEYOR BASE SUPPORT	CONVEYOR SUPPORT	2
4	HISSB CONVEYOR WEB BRACKET	STRENGTH CONVEYOR	2
5	HISSB CONVEYOR SIDE BAR	CONVEYOR RAIL GUIDE	2
6	HISSB HOPPER STAND	HOPPER SUPPORT	4
7	HISSB HOPPER	SOIL MIXTURE HOLDING	1
8	HISSB HOPPER ASSEMBLY	HOPPER BOTTOM COVER	1
9	HISSB_CONVEYOR HANDLE	CONVEYOR MOVEMENT	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	O.S		
CHK'D	J.M.C		
APPV'D	C.GC		
MFG			
Q.A			

TITLE

HOPPER AND SOIL CONVEYOR ASSEMBLY

MATERIAL: MILD STEEL

DWG NO. 002/19.

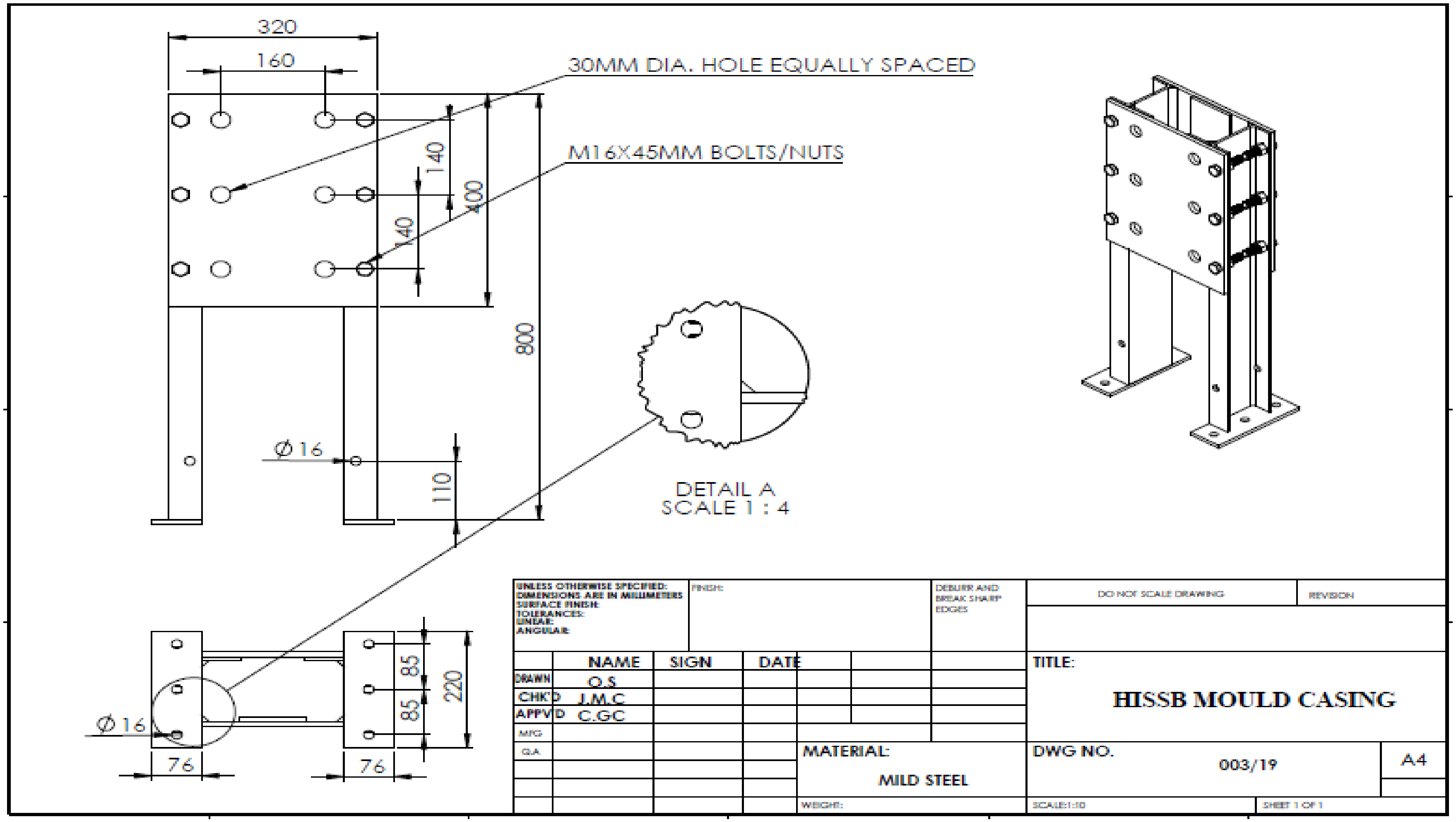
A4

WEIGHT:

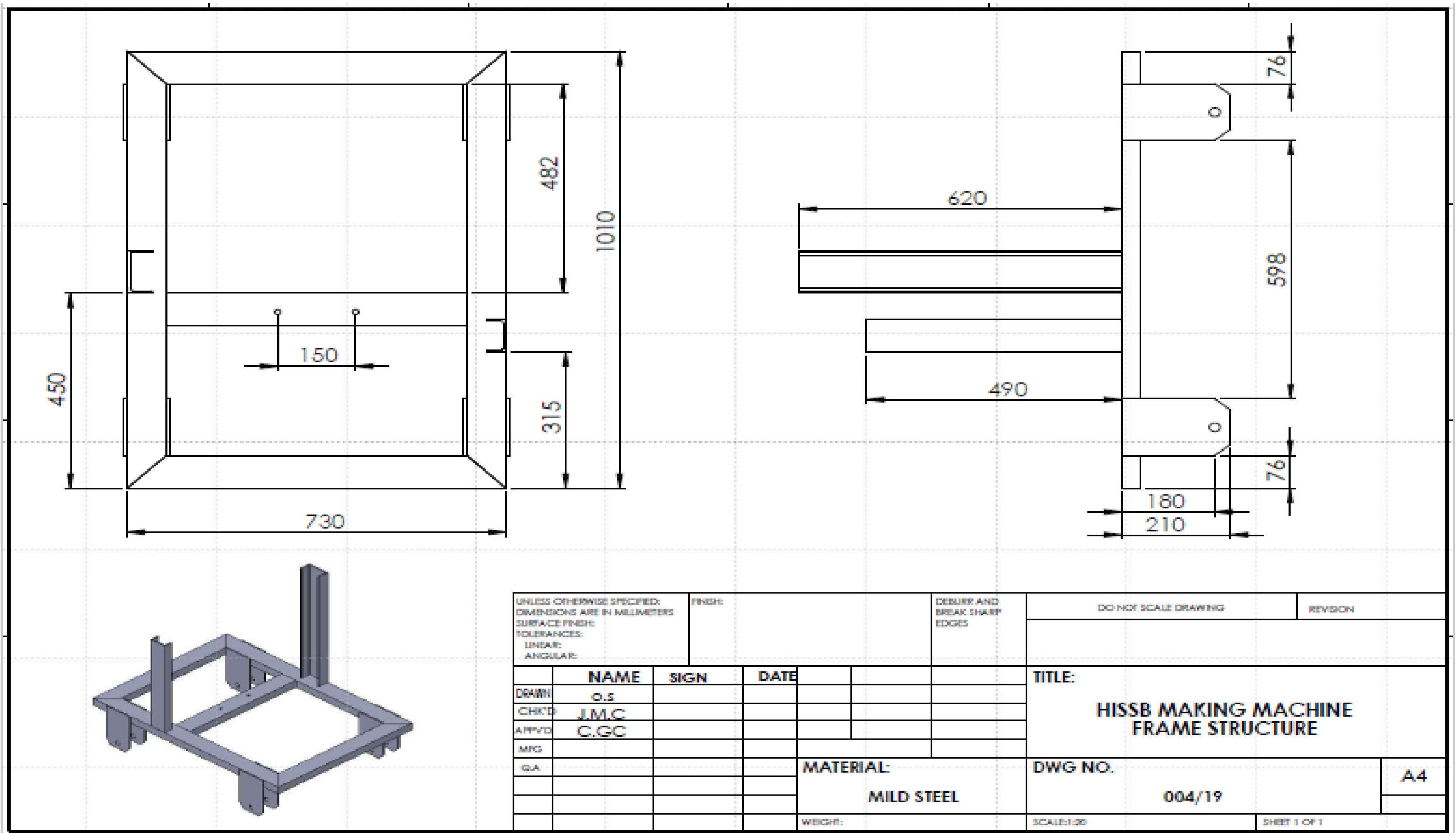
SCALE:1:10

SHEET 1 OF 1

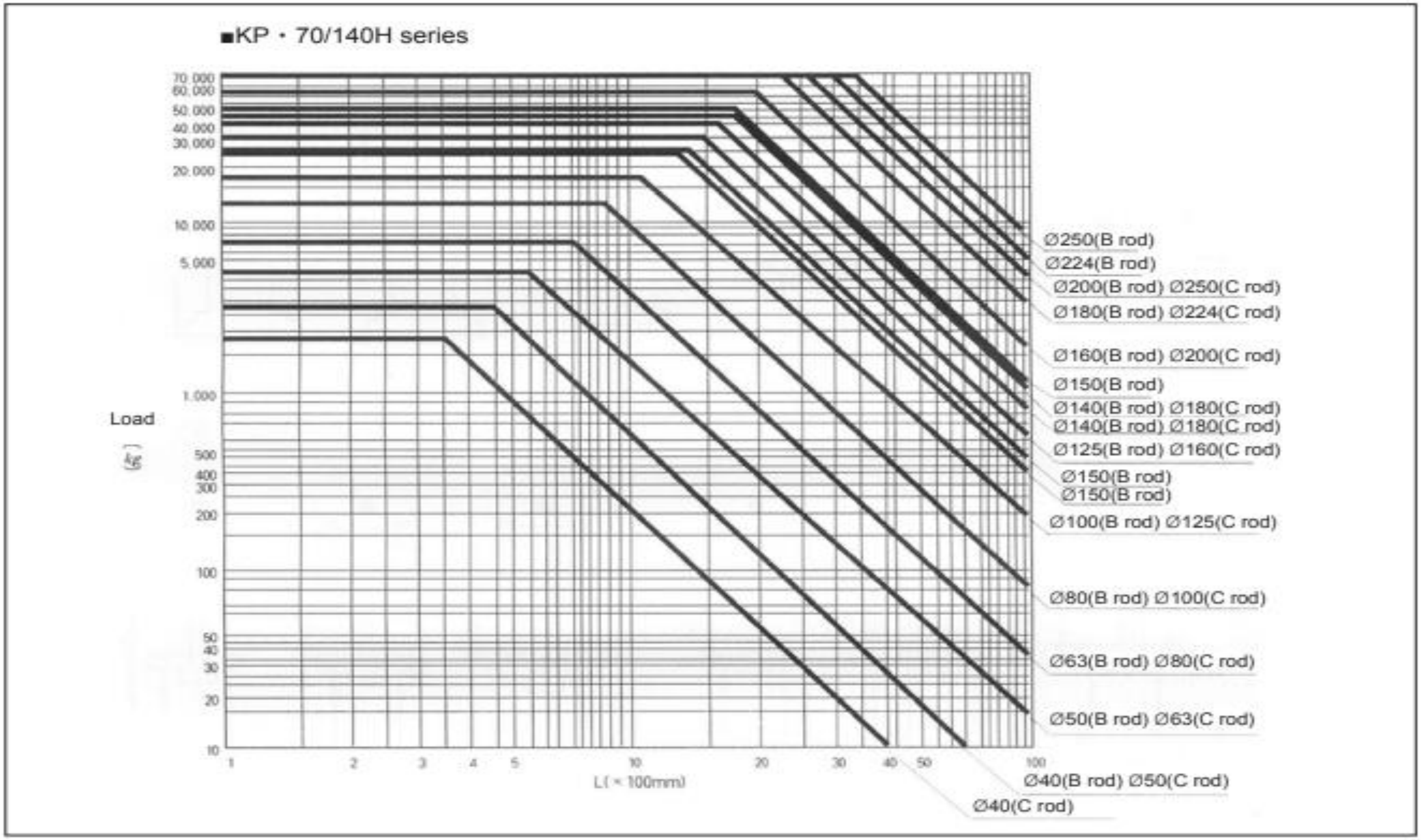
D3: MOULD CASING ASSEMBLY



D4: FRAME STRUCTURE ASSEMBLY



APPENDIX E: BUCKLING CHART OF CYLINDER RODS (www.kccpr.com)



APPENDIX F: ISSB MAKING MACHINE PRODUCTION RATES

Production Run No.	Production Rates (Sec)		
	OISSB	NISSB	HISSB
1.0	143	145	24
2.0	141	129	26
3.0	121	132	25
4.0	121	146	36
5.0	137	114	32
6.0	128	119	32
7.0	134	113	33
8.0	131	124	32
9.0	140	119	33
10.0	138	111	35
11.0	159	115	26
12.0	146	104	31
13.0	147	106	33
14.0	153	106	34
15.0	165	127	32
Mean Values	**140.27**	**120.67**	**30.93**
Standard Deviation	**12.66**	**13.16**	**3.79**

APPENDIX G: DESCRIPTIVE STATISTICS

G1: NISSB and HISSB Making machines

MACHINE		N	Mean	SD	SEM
NISSB		15	120.666	13.16	3.3984
HISSB		15	30.9333	3.79	0.9782
	Difference		89.7333		

G2: OISSB and HISSB Making machines

MACHINE		N	Mean	SD	SEM
OISSB		15	140.2000	12.5254	3.2341
HISSB		15	30.9333	3.79	0.9782
	Difference		89.7333		