DISTRIBUTION OF UNBONDED PRESTRESS IN STRUCTURAL SYSTEM FOR BRICK WALL

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CERTIFICATION OF APPROVAL

Distribution of Unbonded Pretress Structural System for Brick Wall

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the reference and acknowledgments and that the original work again contained herein have not been undertaken or done by unspecified sources or persons.

Zacharia Thomas Tingui Bandu

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ABSTRACT

Sustainability is a term used to describe Green House System. As an effort to promote sustainable development, a group of researchers came up with a new innovative structural system called Dry Masonry Brick House System (DBHS) that encompasses the 3R: Reduce, Reuse and Recycle. To adapt this structural building system in Malaysia there must be changes in standard and specifications in order to suit Malaysian climate. This final year project examined work done by other researchers before amending the specifications. Similar tests were conducted in areas related to tensile strength analysis & compressive strength distribution in unbounded brick wall system and to further compare the strength to the conventional mortar brick wall.

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LIST OF SYMBOLS

P	-	Compressive Strength
x	-	Specimens data
n	-	Number of specimens tested
x_0	-	Average compressive strength of the specimens
w	-	Width of the class interval
Fi	-	Number of observation fallen in the i^{th} class interval
Di	-	Deviation
y	-	Mean
σ	-	Standard Deviation
f_k	-	Characteristic compressive strength of bricks.
t	-	Thickness

CHAPTER 1: INTRODUCTION

1.1 Background

The current surging urbanization and population explosion in areas like Kuala Lumpur, shah Alam among others has translated in to the increase in generation rate of municipal solid waste and its composition alike. Most of the municipal solid wastes are disposed at landfill or dumpsite and only a small amount to incinerators. The Solid Waste and Public Cleansing Management Act 2007 define solid waste as controlled solid wastes which includes commercial solid waste, household solids waste, institutional solids wastes and public solid wastes.

Municipal solid is divided into four categories, which are biodegradable waste, recycled material, construction and demolition waste and hazardous waste. The 9th Malaysia plan reported that the average per capita generation has increased from 0.67 kg/person/day in 2001 to 0.8 kg/person/day in 2005 [RMK9]. Nazeri [2002] stated that the waste generation in peninsular Malaysia has increased from 16,200 tonnes per day to 19,100 tonnes per day. By 2025 solid waste is expected to increase four times with increasing 72% of generation rate. Reduction in solid waste generation is seen crucial to help reduce environmental impacts and help sustain its wellbeing.

As a mitigation to counter balance and reduce the generation of solid waste to a reasonable and acceptable level, one new structural building system better known as Dry-masonry Brick House System (DBHS) has been proposed. The research into DBHS is being done by a group of researchers lead by Prof. Yasunori Matsufuji of Khusyu University. The new structural system DBHS can be constructed using the construction method “Steel Reinforcement Brick Based on Distribution of unbounded Pre stress Theory” (SRB-DUP). In order to hold the layers of bricks in place, a mortar is not used, as is the case in normal construction method instead steel nuts, round and spring washer are used.

Through perfecting and adapting the new structural system, the generation of municipal solid waste from construction and demolition in Malaysia can be brought to its minimal.

DBHS is not only considered as the cleanest method of construction and housing but it also promotes sustainability in term of reduction-reuse and recycles. Structure that utilizes DBHS can easily be dismantled. It is noticed that 98.32% of brick can be dismantle safely and reused and 1.66% can be recycled. Other steel parts such as steel rod, steel bolts, nuts and plates are found to be 100% reusable.

1.2. Problem statement

Dry-masonry brick house system DBHS being a recent advance in a method of construction has only been applied in housing system in Japan. Due to its invention in japan, the entire standard and specification conform only to Japan.

Malaysia being one of south East Asian countries that lies outside the earthquake prone zone makes its design to adapt a least factor of safety of only 1.5 unlike japan that uses 3.0 factor of safety. Because of that reason couple with other factors such as climatic condition it is impossible to adapt the DBHS in Malaysia before necessary modification is done to suit Malaysia standard and specification.

1.3. Objective

This research will focus on the suitable DBHS design method that can be adapted by Malaysia to avert over design.

- To analyze and choose the appropriate size (diameter and length) of bolts and steel rode which acts as a vertical reinforcement members in Dry Masonry Brick House System (DBHS). The process will take into the consideration the British code 4190 as the commonly standard and specification used in Malaysia for tensile strength analysis.

- ♦ Modify the fastening composition of the DBHS to comply with the new verified dimensions of vertical reinforcement and bricks arrangement.
- ♦ The strength of the unbounded brick wall under loading condition.
- ♦ Distribution of pre stress within the DBHS.

1.4. Scope of study

To provide an appropriate size of steel rode and bolts necessary to be utilized as a vertical reinforcement in Dry Masonry Brick wall System (DBHS), bolts of varying sizes and the diameter will be tested using the tensile strength test analysis using a Universal Testing Machine (UTM).

CHAPTER 2: LITERATURE REVIEW

2.1 Sustainable/Green Development

By definition Sustainable/Green Development refers to a mode of human development in which resource use aims to meet human needs while ensuring the sustainability of natural systems and the environment. Although new technologies are constantly being developed to complement current practices in creating sustainable or greener structures, the common objective is that green buildings are designed to reduce the overall impact of the built environment on human health and the natural environment. In other word sustainable development is the development that is considered to be economically affordable, socially acceptable and environmentally effective (Dharmija, 2006).

In realizing the attainability of greener/sustainable structures, it requires a collective effort to ensure that materials used are equivalent to the capacity that can be provided by nature. Construction activities are regarded as one of biggest contributor to the waste generation and most importantly resource usage. The fit-out, operation and ultimate demolition is considered a huge factor that contribute to human impact on the environment, the impact could be both direct or indirectly. The impact on the environment in turn affects the wellbeing of individual, society, community and organizations.

To meet and avail solutions to the challenges and obstacles people need to enhance quality of life for all by designing healthy buildings and environmentally fit for individuals and communities (Halliday, 2008). According to the author the following approach are necessary:

- Use resources effectively.
- Minimize pollution
- Create healthy Environment
- Enhance Biodiversity- avoid using materials from threatened species.

- Manage the process- require identifying appropriate targets, tools and benchmarking and managing delivery.

2.2 Masonry

Masonry is the building of structures from individual units laid in and bound together by mortar; the term *masonry* can also refer to the units themselves (McKenzie, 2004). In other hand Henry stated that masonry walls could either be external or internal or maybe load bearing. Masonry wall may also acts as the cladding of the building. Listed below are some of the advantages of masonry.

- Low Cost
- Excellent Durability
- Easy and Faster to build
- Fire protective
- Sound insulated
- Easy to be utilized in composite materials

The disadvantages of masonry are as listed below:

- Vulnerable to damaging environmental agents posed by extreme weather.
- Required strong foundation to avoid settling and cracking.

A compressive strength is a test to determine the capacity of a material or structure to withstand loads tending to reduce size. It can be measured by plotting applied force against deformation in a testing machine. Some material fracture at their compressive strength limit; others deform irreversibly, so a given amount of deformation may be considered as the limit for compressive load. Compressive strength is a key value for design of structures.

According to W.G Curtain (1997), masonry structures have strong compressive strength (vertical load) but proven weak under tensile strength (twisting or stretching). Bending tensile strength of masonry is often 5% of their compressive strength but could be reinforced to carry the tensile stress or pre stressed to eliminate them (Beck, 1998).

The variety of materials use in masonry has increased rapidly. However only two types of masonry existed and they are mainly wet masonry and dry masonry. Wet masonry is this type of masonry in which mortar is used to hold in the bricks in place (act as a binder), this type is the most used in construction sector. On the other hand dry masonry is considered to lack mortar as a binding agent. This paper will discuss the dry masonry in detail and how it withstands loading.

2.2.1 Dry Masonry Brick House (DBHS)

Dry Masonry Brick House is a recent development in construction that SOLELY emphasized on the dry masonry. The method of construction is based on the theory "SRB-DUP". This system of construction suggested that materials of different type should not be bonded. Yamaguchi et all (2007) claimed that, it would be easier to reuse materials if different materials were not bonded together. The highlighted that by doing so it help design for deconstruction. To make sure the layers of bricks in masonry is hold in place, normally steel nuts, round and spring washers are used. Due to the kind of binding used in the dry masonry, the structure will utilize the friction resistant stress transfer mechanism. The term unbounded it is used to single out the behavior of pre stress distribution. It shows that pre stress act at each connection point of vertical reinforcing element in a distributed manner (Fig).

The main reason for DBHS is to promote sustainability system, which will translate into high Life Cycle Assessment (LCA), and Low Cycle Cost (LCC), (Khamidi, 2004).

Moreover DBHS promotes ability to reduce, reuse and recycle apart from it being the new system of construction in the market. As noted by the researcher during the deconstruction phase 98.34% of brick are reusable and 1.66% are recyclable. The remaining part is considered 100% reusable.

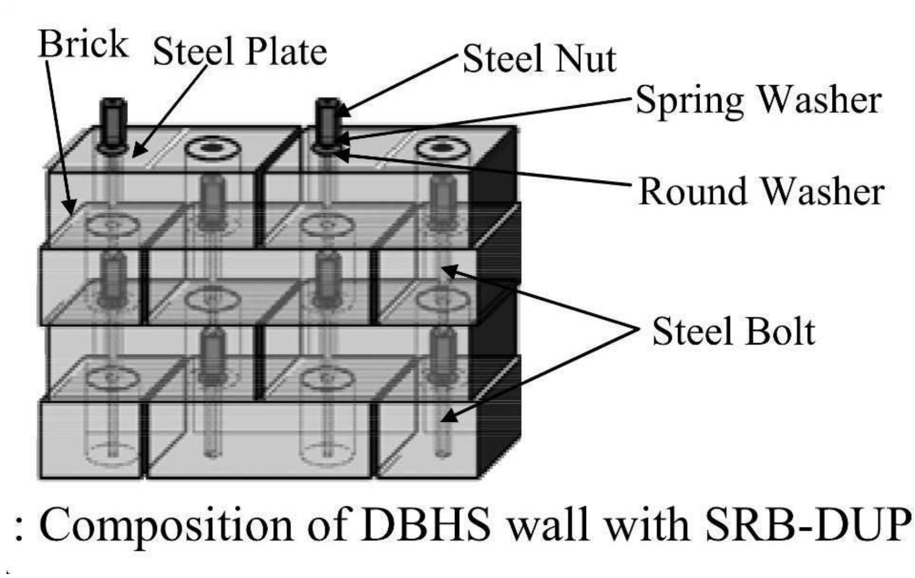


Figure 2.0: Structural Composition of DBHS Wall with SBR-DUP Method
(Khamide F, 2004)

2.2.1.1 Advantages of DBHS

- Can be dismantled easily and effectively instead of demolition.
- Time effectiveness hence reduces sky rocketing construction cost.
- Environmentally Friendly and promotes the idea of 3R.
  Reduce, Reuse and Recycle

2.2.1.2 Construction and Demolition Waste(C&DW) Minimization

According to the research by Khamidi el.al (2004), Dry Masonry Brick House System aim to promote sustainable system of construction that will be able to achieve High Life Cycle (LCA) and Low Life Cycle (LCC). It is believed that with DBHS is by no mean a system of construction that is environmentally friendly.

As believed by many, the process of construction and demolition is considered as one of the main source of waste generation; however DBHS is the ultimate solution to such issues. DBHS is a building system that incorporates DFD (Design for Dismantling) and DFR (Design for Recycling) in its design stage. By no doubt adaptation of the DBHS will only provide a remedy that may well solve the problems devouring the construction industries for years.

As mentioned earlier, significant reduction in the waste generated from the process of construction and demolition is eminent due the fact that 98.34% of the building blocks/brick used in the construction is usable with 1.66% consider recyclable. The remaining part utilized are considered 100% reusable due to its ability to easily be separated after the demolition process.

2.2.2 Types of Masonry Wall

Masonry wall are divided as listed below:

i. Pre stressed Masonry walls.
ii. Reinforced Masonry Walls.
iii. Unreinforced Masonry Walls.

Pre stressed/Reinforced Masonry

Define as the application of compressive stresses to masonry members, pre stress/reinforcement is basically the same concept only differs in the fact that pre stress is done before erecting the structure while reinforcement is done during the construction phase. Based on M.M Lwin (2001), pre stressed masonry and reinforced masonry differs in two aspects, the type of reinforcement steel and the way the reinforcing steel is stressed.

Advantages of Pre stress and Reinforcement

According to M.M Lwin el al (2001), for pretension, the tendons are tension with anchors outside the concrete/masonry members before the casting while for post tensioning, the tendons are tensioned with tendon outside the concrete/masonry, normally done when a masonry has developed a required strength. Due to its simplicity, post tension method is always used for pre stress masonry.

2.2.2.2 Unreinforced masonry

Unreinforced masonry is the type of masonry that doesn't utilized steel reinforcement. However it uses mortar as the binder to hold the subsequent bricks together.

Based on Chaimoon et all (2006), the lateral and vertical loads lead to tension and shear combined with compression within the walls. Fracture and failure of masonry wall under shear compression is intricate because of c2.omplex interaction of shear failure along the mortar joints and compression often at the toe of the wall.

2.3 Brick

According to Lynch, a brick is walling unit not exceeding 337.5mm in length, 225mm in width and 337.5mm in height. Generally the form can be defined as a rectangular prism of a size that can be handled conveniently with one hand.

Bricks availed certain benefits as per construction, some are as listed below:

i. Provide a boundary wall to a property.
ii. Provide Security.
iii. Modish privacy wall.
iv. Acts as blockage to noise pollution emanating from busy street.

2.3.1 Types of Bricks

There are three types of bricks used in construction and they are:

Clay bricks

Clay brick are produced in variety of colors depending on the mineral composition and the firing temperature, most commonly in the shades of red.

Facing brick in one hand are mostly yellow, buff and brown and with roughened surface texture (Hendry, 2000).

According to Hendry the density for a clay brick is 2t/cubic meter. However the weight of brick is more important in construction, it is a function of size, shape and type. Certain clay bricks that have a water absorption capacity of 4.5% to 7% are used as damp proof course material. Highly absorptive clay brick may absorb water from the mortar thus posed a risk of incomplete hydration of cement. Such phenomena caused weakness of the wall, which in turn affects the overall structure.

Concrete brick

Mainly three types of concrete brick and they are:

1. *Facing brick*

   Facing brick has strength of 20N/square meter and is used to provide attractiveness for all form of construction, being internal or external. They are available in wide range of colors.

2. *Engineering brick*

   Engineering brick has strength of 40N/square meter and is particularly suitable for aggressive environment where resistance due to sulphate and low water absorption are paramount.

3. *Common brick*

   Common brick is manufactured in variety of strength, density and cementations content to satisfy the structural and durably requirement of BS 5628: Part 3.

Calcium Silicate brick

This very type of brick is designed by BS 187:1979 according to their compressive strength and appearance into the classes. Below are the few advantages of a silicate brick;

i. Consistent Structure- No soluble salts within the brick.
ii. Size – regularity of dimensions in size and shape of the bricks gives enhanced consistency of laying.
iii. The light reflective qualities added to dimensional accuracy, gives appeal for decorative internal brickwork.
iv. The inherent property gives global attributes for use in hot and cold climate.
v. A comprehensive range of colors is available which can be adjusted in tone to match any color shade the client requested.

2.4. Walls

"Walls are the vertical construction of building that enclose, separate and project its interior spaces. They maybe load bearing structures of homogenous or composite structure designed to support imposed loads from floors and roof, or consist of a framework of columns and beams with nonstructural attached to them".[Ching et al(2000)]

Ching also stated that, exterior wall construction must be able to withstand horizontal wind loading to support vertical loads and if rigid enough they can serve as shear wall and transfer lateral wind and seismic forces to the ground foundation.

2.4.1 Types of wall systems

2.4.1.1 Structural frames

Structural frames are structures that can support and accept variety of non-bearing or curtain wall system. Structural frames for wall system consist of:

i. Concrete Frames (rigid frames)- can be characterize as non-combustible (fire-resistive construction)
ii. Noncombustible steel frames- may utilize moment connection and necessitate fireproofing to characterize as fire resistive construction.

iii. Timber Frames- diagonal bracing or shear planes are required for lateral stability and can characterize as heavy timber construction if used with noncombustible , for resistive exterior walls and if members meet the minimum size requirements specified in the building code of construction.

iv. Steel and Concrete Frame- able to span greater distance and carry heavy load than timber structure.

2.4.2 Concrete Masonry bearing walls

Concert and masonry walls are strong in compression and are normally required for reinforcing to handle tensile stresses. It can be characterize as noncombustible construction and based on their load carrying capacity. The critical factor in wall design and construction are height to width ratio, provision for lateral stability and proper placement of expansion joint.

2.4.1.3 Metal and wood stud walls.

According to ching et all (2000) state that

i. Stud carries vertical load while sheathing or bracing stiffen the plane of the wall.

ii. Cavity I e wall frame can be accommodate thermal insulation, vapor retarder and mechanical distribution and outlet of mechanical and electrical services

iii. Stud framing can accept variety of interior and exterior wall finishes.

iv. Stud wall are flexible in form due to the workability of relatively small pieces and he various means of fastening available.

2.5 Municipal solid waste

According to the Volume 40 of the US Code of federation regulations (40 CFR 240.101) DEFINES Solid waste as:

"Garbage, refuse, sludge and other discarded solid material resulting from industrial, commercial operations and from community activities. It does not include solid or dissolved material in domestic sewage or other significant pollutant in water resources, such as silt, dissolved or suspended solid in industrial waste water effluents, dissolved material in irrigation return flows or other common water pollutants."

Municipal solid waste or MSW and sometimes known as domestic waste is generated within the community from several sources and not simply by individual consumer or household. MSW originate from residential, commercial, institutional and municipal sources. The schematic diagram depicting the contribution of waste from each contributor. Adapted from local government department ministry of housing and local government.

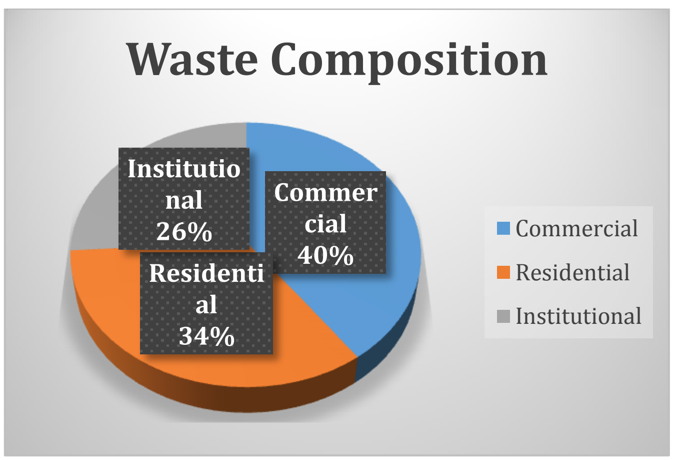


Chart 2.0 Waste Compositions in KL, 2002.

Municipal solid waste can be divided into 4 major categories which are:

- Biodegradable waste
- Recyclable material
- Construction and demolition waste
- Hazardous waste

2.5.1 Biodegradable waste

Biodegradable waste originates from plants and animals and can be broken down by other living organisms. Biodegradable waste can be commonly found in municipal solid was as green waste, food waste, paper waste and biodegradable plastic. Other biodegradable waste includes human waste, manure, and sewage and slaughter house waste.

2.5.2 Recyclable material

Recyclable materials are material that can be processed into new products and it includes many kinds of glass, paper, metal, plastic, textiles and electronics. Recyclable materials nowadays bear the logo as shown below.

Figure 2.1 Recyclable Logo

2.5.3 Construction and demolition waste

Construction and demolition (C&D) waste material produced during construction, renovation, or demolition of structures. Structure includes residential and non-residential buildings as well as roads and bridges. Components of C&D include concrete, asphalt, wood, metals, gypsum wallboard and roofing. Land clearing debris such as tree stumps, rocks and soil are also included on C&D waste.

2.5.4 Hazardous waste

According to the resource conservation and recovery act (RCRA), hazardous waste mentioned as: “Any waste or combination of waste which pose a substantial present or potential hazard to human health or living organism because such was are non-degradable or persistent in nature or because they can be biologically magnified, or because they can be lethal, or because they may otherwise cause of tend to cause detrimental effect.”

The characteristic of hazardous waste are:

- Ignitability
- Corrosively
- Reactivity
- Toxicity

Examples of hazardous waste are residues from solvent manufacture, electroplating, metal treating, wood preserving and petroleum refining.

2.6 Compressive strength Test

Compressive strength is the capacity of a material or structure to withstand loads tending to reduce size. It can be measured by plotting applied force against deformation in a testing machine. Some material fracture at their compressive strength limit; others deform irreversibly, so a given amount of deformation may be considered as the limit for compressive load. Compressive strength is a key value for design of structures.

Compressive strength is often measured on a universal testing machine; these range from very small table top systems to ones with over 53 MN capacity.[1] Measurements of compressive strength are affected by the specific test method and conditions of measurement. Compressive strengths are usually reported in relationship to a specific technical standard

2.7 Stress Strain Diagram

According to Beer et al, (2006) state that, stress-strain diagram representing the relation between stress and strains in a given material are important characteristic of the material. To obtain the stress diagram of a material, a tensile test usually be conducted.

"Stress-strain diagrams of various material vary widely and different tensile tests conducted on the same material may yield different results, depending upon the temperature of the specimen and the speed of loading" [Beer et al (2006)]

Stress is defined as pressure per unit area (P/A). Where P is tension load and A is the tension area. However if the applied tension doesn't exceed the proportional limit of a material then Hooke's Law should be applied.

$$\boldsymbol{Stress} = \varepsilon \boldsymbol{E}$$

Where:
Ɛ= strain
E= modulus of elasticity
However;

$$\varepsilon = \boldsymbol{\delta / L}$$

Where:
Ɛ = strain
δ = elongation of material
L = Total length of material

There are various groups of materials but they can be divided into two broad categories based on their characteristics, ductile materials and brittle materials.
Ductile materials are characterized by their ability to yield at normal temperatures. Ductile material inclusive of structural steel as well as many alloys of other materials. In materials before rupture. Different type of materials will have different yield characteristic although having similar categories depend on the gage length and cross sectional area of the specimen.

Brittle materials which comprise cast iron, glass and stone are characterized by the fact the rupture occurs without any noticeable prior to change in the rate of elongation. Thus for the brittle materials there is no difference between ultimate strength and the breaking strength. Also, the strain at the time of rupture is much smaller for brittle material.
For this project, only the ductile materials (steel bolts) was tested for tensile strength analysis.

Table 2.0 Distinguishing characteristics of brittle versus ductile behavior depending on the scale of observation.

Scale of observation	Brittle	Ductile
Structural engineer	Applied stress at failure is less than the yield strength	Applied stress at the failure is greater than the yield stress
By eye (1x)	No necking, shiny, facets, crystalline and granular	Necked, fibrous, woody
Macro scale (<50x)	“Low” RA or ductility	Medium to high reduction area
Micro-scale, scanning	Brittle	Ductile

election microscopy (100-10,000x)	Micro process, cleavage inter granular	Micro process, micro void coalescence
Transmission election microscopy (>10,000x)	May have a large level local plasticity	High amount of plasticity globally

2.7.1 Tensile strength

Tensile strength or ultimate tensile strength (UTS) measures the forces required to pull something such as rope, wire or structural beam to the point where it breaks. The ultimate tensile strength happens before the object failure. Tensile strength is important for deign characteristic because it will be used for quality control in production, for ranking performance of structural materials, for evaluation of newly developed alloys and for dealing with the statistic requirement of design.

2.7.2 Tensile Strength Test

Tensile strength test is commonly used to determine the maximum load of the tensile

Strength that a material or product can withstand. To determine ultimate tensile strength for steel bolts, direct tension test can be done.

Besides that, tensile strength test can be used to determine other mechanical properties:

- Elasticity deformation properties.
- Yield strength.
- Ductility properties.
- Strain hardening characteristics.

[ASTM E8]

In a tensile test, the test specimen is will be placed in the testing machine (refer to the appendices) which used to applied distributed load. For ductile materials, after a critical value σy of the stress has been reached, the specimen will undergo a large deformation with a relatively small increase in the applied load.

2.8 Steel Structures

Steel structures are composed of elements which are rolled to a basic cross sectional in a mill, and worked to the desired size. According to Dunggal, 2000, state, for building a steel structure. The designer is normally compelled to use standard rolled section.

Fortunately, the variety of steel sections available is so great that any desired structural effect can be achieved in steel.

The advantages of steel as a structural material are:

- Have high strength per unit weight
- Light can be conveniently handled and transported.
- Have a long life.
- Properties mostly don't change with time.
- Ductile material doesn't fail suddenly.
- Addition and alteration can be made easily.st all buildings materials.
- Can be erected at the faster rate.
- Have the highest scrap value among.

However steel also have their own disadvantages as a structural material and they are as listed below:

- Corrosion - when exposed to nature and required frequent painting.
- Need fire proof treatment - increase cost.

2.8.1 Steel bolts

According to Dunggal, 2000, it is stated a bolt may be defined as a metal pin with a head at one end and a shank threaded at the end to receive a nut. Steel washer will be used under the bolt as well as the nut to help distribute the pressure on the bolted wall and to prevent the threaded portion of the bolt bearing on the connecting pieces.

For this specific project stud bolt will be used. Stud bolt is a round metal bar screwed at the both ends or fully screwed.

Even though bolts are commonly used but there are objection associated with it usage, below are some few of the limitations.

- High cost.
- Tensile strength of the bolt is reduced because of area reduction.
- When subjected to vibration may fail.

For this project, stud bolt are been chosen as a vertical reinforcement member for Dry-Masonry Brick System because stud bolt can improve stress concentration factors, reduces local material variations, lower cost especially for high duty applications, less clearance required on holes allowing more accurate assemble and stud with two nuts can be tightened from either side of the joint.

In other hand, stud bolts have its disadvantages, below are two prominent ones:

- More nuts loosen with time.
- Acts as weak link in a joint.

2.8.2 Bolts Connection

Bolts is one of vertical reinforcement members in Dry- masonry brick house system (DBHS). Bolt usually attached together with nuts and washer. The kind of bolt connection can be divided into two.

I. None preloaded.

II. Preloaded.

Based on the observation made by Dunggal, 2000, the advantages of bolted connection are:

- The erection of structure can be speeded up.
- Less skilled people can performed the work.

CHAPTER 3: METHODOLOY

3.1 General

This research was carried out with the purpose of having a detailed understanding of the effect and response of unbounded brick specimen to compressive strength and with the aim of finding the stress distribution within the brick segment. To achieve the objectives stated previously, several laboratory testing were conducted. By using appropriate apparatus and methods, testing was conducted on steel rode, brick and as well as the brickwork model or better known as brick prism. The testing method was solely based on the standard guides of the code of practice. All the testing was done in the concrete technology laboratory, Civil Engineering department. Universiti Teknologi PETRONAS.

3.2 Hazard Analysis

Hazard analysis is define as the identification of hazards and their causes. The term hazard analysis is useful because it encapsulates, in a less ambiguous manner, the two distinct but complementary activities described in ISO/IEC 14971 hazard identification process. A hazard is a condition or a combination of condition that if let uncorrected may lead to an accident, illness or property damage. All these hazard will cause deaf, irritation and more disease.

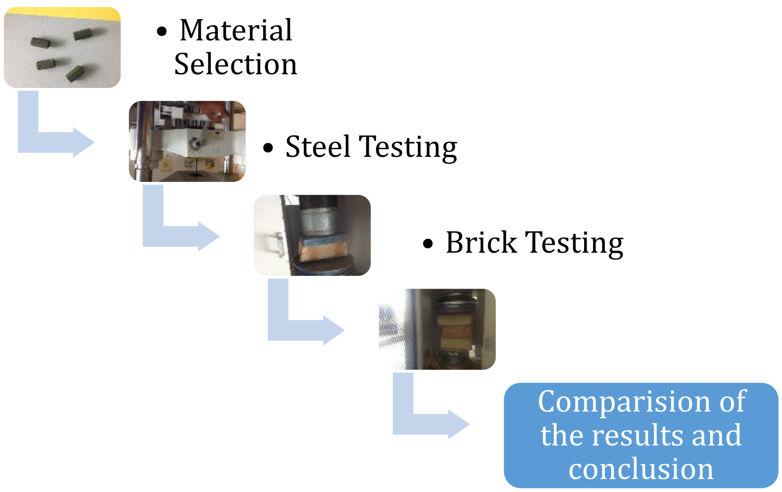
Hazard might come in several ways for instance through physical, chemical and biological. During compressive test and tensile test for the brick specimen and steel rod in the civil lab, the probability of hazard happening is high. It is doomed to happen if:

- Digressing from the procedures needed to guard the equipment.
- Improper personal protective equipment (PPE).
- Avoidance of using laboratory rules and regulations.

In order to avoid the potential hazard that might arise from the tensile strength test the below suggestions must be followed through experiment.

- ➢ Wear appropriate PPE.
- ➢ Adhere to the laboratory rules and regulations.
- ➢ Availability of a laboratory technician during conduction of the experiment.

The sequence of work was as shown below.



3.3 Required Materials

In this research the required materials for the brickwork are the brick predominantly made up of inside and the cover. The inside part is made up of normally oven backed common clay bricks and the outside is cover using cement, lime and sand mix. The design proportion of the cement, lime and sand was chosen based on BS 5628-1-2005. Additionally materials used are the washers, steel plate, steel rode and the bolts. The figures below shows in detailed all the materials used in this experiment.

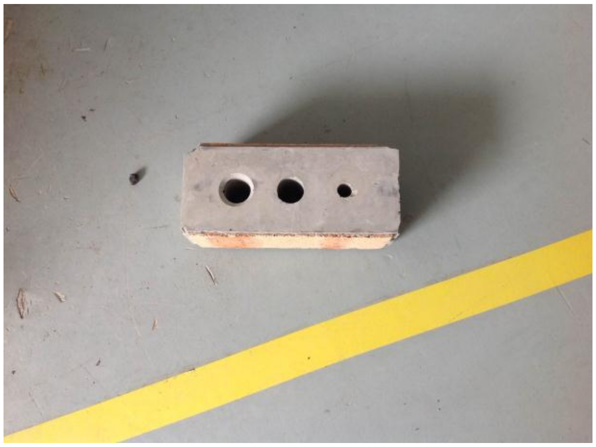


Figure 3.0 Sample of brick used for the construction of the specimen.

Figure 3.1 Bolts used for fastening brick specimen.

Figure 3.2 Washers to support the tightening of the bolts.

Figure 3.3 steel rods for fastening inner brick layers.

Figure 3.4 Steel rod for fastening bottom and upper brick layers.

Figure 3.5 Steel plates used as a cover.

3.4 Test on the materials

Prior to the test on the specimen a set of test is performed on the materials in order to determine the characteristics of the material that was to be used. The aim was to obtain the behavior of the materials independently so as to compare with the overall specimens. Several testing was thus conducted on the steel rods, bolts and the sample of a brick.

3.4.1 Test on brick

Several tests known common test are used to determine or obtain various properties of the bricks. However in this research test was done on one brick sample. The dimensions of the brick were measured and compressive strength was also determined. The procedure for the testing of the brick sample was based on British Standard Specifications for Clay Brick, BS3921:1985.

3.4.1.1 Measurement of Dimensions

For the bricks' dimensions measurement, the procedure followed was in line with BS 3921:1985. The required apparatus in the test was the ordinary measuring tape.

In this test a total of 9 bricks were selected randomly from the brick stack. Any blister, small projections or loose particles of cement past of clay that adhered to each brick had to

be removed to ensure correct reading. The bricks were then placed in contact with each other in straight line upon a level surface. The method of arranging he brick depended on which dimension to be measured; length, width or height. The figure below shows how arrangement of bricks with respect to the dimension to be measured.

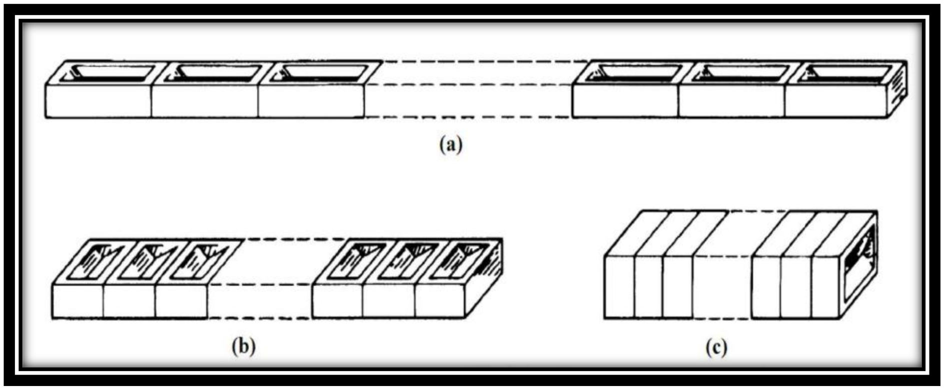


Figure 3.6 Arrangement of brick for the measurement of length, width and height.

The overall dimension (length, width and height) was measured to the nearest millimeter using measuring tape. Each result was recorded and compared with the dimensional deviations stated in British code, BS 3921:1985. The mean average was calculated using the arithmetic mean formula as shown below.

$$\mathbf{A = 1/n \sum_{i=1}^{n} Xi}$$

Where A = Average (or Arithmetic mean)

n = the number of Bricks measured.

Xi= value of each individual brick measured.

3.4.1.2 Assembling of a brick prism

After testing of the materials, the properties of the material obtained can be used to determine the volume of specimen required. A total of three specimens were constructed for the testing. For all the specimen steel bolts were used to hold the brick together by allowing the steel rod through the pre made hole in a brick demonstrating the idea of unbounded brick wall. The steel plate was used as a cover and in addition to the bolts and washers is used to ensure the fastening of the specimen. The fastening was done using the crescent wrench.

Figure 3.7 Crescent Wrench used for tightening the bolts.

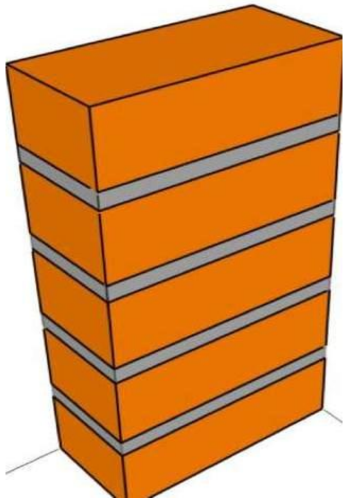


Figure 3.8 Model of 3 bricks prism specimen

3.4.1.3 Compressive strength test on the brick

The test was performed based on the code of practice stipulated in the British Standard Specification for Clay Brick, BS 3921:1985. The machine utilized was the compression testing machine.

Figure 3.9 Shows the compressive strength test conducted on brick samples

3.4.2 Compressive strength test on prism specimen.

The test was carried out in line with code of practice for Use on Masonry, BS 5628-1:1992. The required apparatus is the compression testing machine again.

3.4.2.1 Determination of Compressive strength

The compressive strength test for the brick and the brick specimens was done based on the procedure provided in BS 3921:1985. The required apparatus was the compression machine.

It was ensured that the compression machine's bearing surface of all the platens were wiped clean. The test started by randomly choosing a one brick sample in order to determine its compressive strength. Any loose grit or other material was ensured removed from the surface of the brick. The brick is then placed under the compressive machine and the 3.0KN/sec load was applied and the rate was maintained till the failure was observed in the sample. Failure occurred when the indicator needle fall back or when the specimen

Experienced explosive collapse. The maximum load (in KN) sustained or carried by the specimen subjected to the test was recorded.

To obtain the compressive strength of both the brick sample and the brick wallet specimen, the maximum load obtained from the compressive strength test was divided by the area of the bed face determined earlier. The strength obtained was then recorded to the nearest in N/mm^2 to the nearest 0.1 N/mm^2. Finally, the compressive strength of a brick sample and the three specimens was then calculated by taking the average (in case of specimen) of the strengths of the three specimen tested to the nearest 0.1 N/mm^2. The figure below shows the compressive strength test machine.

Meanwhile compressive strength test is calculated as shown below and is the product of dividing the applied load in (N) and Area of bed face in (mm^2).

$$\textbf{Compressive strength } (\mathrm{N}mm^2) = \frac{\textit{Applied Load } (N)}{\textit{Area of Bed Face } (mm^2)}$$

Figure 4.0 Compressive Strength Machine.

3.4.3 Tensile Strength Test for steel rod

For tensile strength a computer control is recommended because it is automatic and can record data more accurately during the test.

Procedure for Tensile Test using computer control as below:

1. Measure the span of the specimens three times and take the average.
2. Connect the extensometer to the HSC strain conditioner. The extensometer is interfaced with strain conditioner which is interfaced with the UTM.
3. Turn the UTM console first and then HSC strain conditioner.
4. Adjust both the load display and extension display to zero.

5. Fix the specimen in the gripers and re zero the load and extension display to zero.
6. Double click the UTM for windows on the computer desktop and type in test information.
7. Zero the extensometer by adjusting the zero knobs and attached the extensometer to the test specimen such that it firmly holds on to the sample.
8. Select the desired strain range (1:1) and zero the display on HSC strain conditioner.
9. Open set up and click “START TEST”.
10. Type in the measured height of the specimen in the space provided.
11. A graph will be drawn automatically on the monitor showing the load and strain relationship. Monitor the load and the specimen carefully before the specimen start to fracture due to the loading effect.
12. Watch carefully, where the specimen fails click “ACCEPT” at the end.
13. Use the UTM panel control to move the crosshead up to create enough space for specimen removal.
14. Remove the specimen from the machine.

Figure 4.1 Universal Testing Machine used for testing the steel rod

CHAPTER 4: RESULTS AND ANALYSIS

4.1 General

This chapter present the results obtained from the set of experiments done on both the material and the prism specimen. Analysis was done on the range of results obtained and the result was presented in a more appropriate formats such as tables, charts or statements. Comparison between the results was done and formula for calculating other parameter such as standard deviation is provided to be utilized by future researchers.

4.2 Test on Bricks

Measurement of the bricks' dimensions was done based on the procedures provided in the BS 3921:1985. The result of the measurement should comply with the limits stated in BS code of practice as stipulated in the clause above. The result for the measurement is tabulated as shown below.

Table 4.0 Dimension of the 14 bricks measured.

Dimension	Total Measurement for 14 Bricks (mm)	Mean Measurement of Single Brick (mm)
Length, L	3358.00	239.85
Width, W	1512.00	108.00
Height, H	1187.00	84.78

From the measurement done on the 24 bricks, the total length, width and height obtained were 3358mm, 1512mm and 1187mm. By taking the mean for the dimensions of a single brick, a brick was found to have 239.85mm in length, 108.00mm in width and 84.78mm in height.

4.2.1 Compressive strength test on Bricks

Compressive strength test done on the 5 sample of brick was in line with the procedure in BS 3921:1985. Table (4.1) shown below are the result recorded for the compressive strengths (or Stresses).

Table 4.1 Compressive strength and stress of tested bricks

Sample	Length (mm)	Width (mm)	Height (mm)	Bed Area (mm^2)	Maximum (Peak) Loading (KN)	Maximum Compressive Strength, P (N/mm^2)
1	240.0	108.0	85.0	25920.0	845.9	32.64
2	239.0	107.9	84.0	25788.1	836.0	32.42
3	240.0	107.0	84.0	25680.0	860.0	33.49
4	239.0	107.0	85.0	25573.0	840.8	32.87
5	239.0	108.0	85.0	25812.0	600.2	23.25

From the preceding table above, he highest and the lowest value obtained for the compressive strength were $32.87N/mm^2$ and $23.25N/mm^2$ respectively. Judging from the fact that the difference is quite far between the highest and the lowest result, it is anappropriate to take the mean of the the result as the characteristic compressive strength of the bricks. Shown below is the alternative statistical method adopted to calculate the representative compressive strength for the bricks. The result was thus using the following formula and the result tabulated in the table (4.2) below.

$$x_0 = \sum x_i / n_i$$

$$y = x_0 + w \left(\frac{\sum Fi\ D}{\sum F_i}\right)$$

$$\sigma = w \sqrt{\frac{\sum FiDi^2 - (\sum(FiDi)^2)/\sum Fi}{\sum Fi - 1}}$$

$$f_k = y - 1.645\sigma$$

Where,

x = Compressive strength of the specimens.

n = Number of model tested.

x_0 = Average compressive strength of the specimens.

w = Width of the class interval, selected as 2.5N/ mm^2

Fi = Number of observation fallen in the i^{th} class interval

Di = Deviation = 0, 1, 2….

y = Mean

σ = Standard Deviation

f_k = Characteristic compressive strength of bricks.

Table 4.2 Characteristic compressive strength calculation for bricks

No.	Class interval	Frequency Fi	Deviation Di	Fi Di	$FiDi^2$	Cumulative frequency
1	22.5-25.0	1	0	0	0	1
2	25.0-27.5	0	1	0	0	1
3	27.5-30.0	0	2	0	0	1
4	30.0-32.5	2	3	6	18	3
5	32.5-35.0	2	4	8	32	5
	$\sum =$	5		14	50	

$$x_0 = \sum x_i/n_i = \frac{154.67}{5} = 30.93 \text{ N/mm}^2$$

$$y = x_0 + w\left(\frac{\sum Fi\,D}{\sum F_i}\right) = 30.93 + 2.5\left(\frac{14}{5}\right) = 37.93 \text{ N/mm}^2$$

$$\sigma = w\sqrt{\frac{\sum FiDi^2 - (\sum(FiDi)^2)/\sum Fi}{\sum Fi - 1}} = 2.5\sqrt{\frac{50 - 14^2/5}{5-1}} = 4.12$$

$$f_k = y - 1.645\sigma = 37.93 - 1.645(4.12) = 31.15 \text{ N/mm}^2$$

Therefore, the characteristic compressive strength of the bricks was 31.15 N/mm^2. When compared the standard stipulated in the BS 3921: 1985, the result was less than 50N/mm^2. So the brick used in this research is categorized as common brick.

4.3 Tensile test on steel rod

Tensile strength test was done on three specimen of steel rode all having 10mm diameter and compared to another three specimen of steel rode having a 12mm diameter. The length for the steel rods tested were 162mm. below is the table of result for tensile strength test.

Table 4.3 The result obtained for Tensile Strength Test (10mm)

Sample No.	Diameter (mm)	Length (mm)	Maximum Load (mm)	Tensile Strength (N/ mm^2)
1	10	162	35.900	457.11
2	10	162	35.814	456.01
3	10	162	34.550	439.84

$$\text{Average Tensile Strength} = \frac{(457.900+456.01)}{(2)} = 456.995\ \text{N/mm}^2$$

Note: Result for sample 3 is omitted in the final averaging due to its irrelevancy to the preceding samples.

Graph 4.1 shows the stress-strain curve for 10mm steel rod.

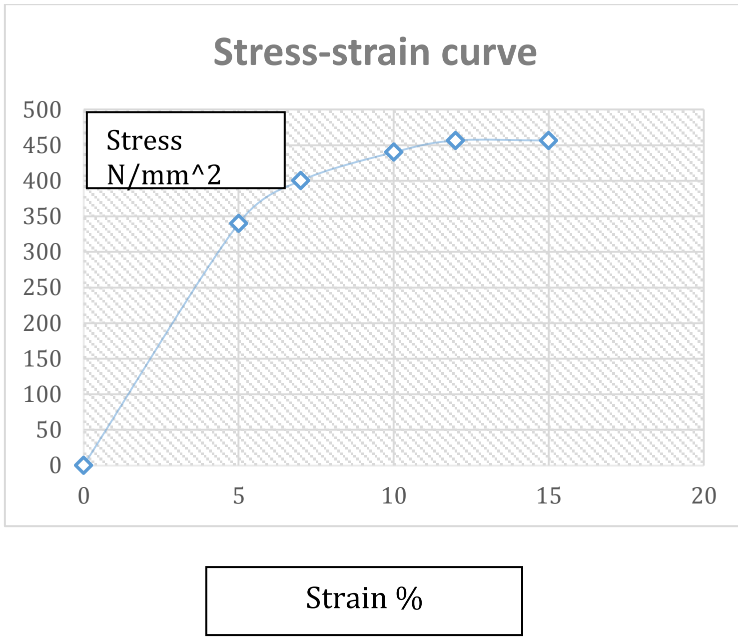


Table 4.4 Shows the tensile strength test (12mm)

Sample No.	Diameter (mm)	Length (mm)	Maximum Load (mm)	Tensile Strength (N/mm^2)
1	12	162	74.770	661.17
2	12	162	74.620	659.75
3	12	162	74.79	661.4

$$\text{Average Tensile Strength} = \frac{(661.17+659.75+661.4)}{(3)} = 660.77N/mm^2$$

4.4 Compressive strength test on Brick prism

Compressive strength test done on the 3 sample of bricks prism was in line with the procedure in BS 3921:1985. Table (4.5) shown below are the result recorded for the compressive strengths (or Stresses).

Table 4.4 Shows the compressive strength test for brick prism

Sample	Length (mm)	Width (mm)	Height (mm)	Bed Area (mm^2)	Maximum (Peak) Loading (KN)	Maximum Compressive Strength, P (N/mm^2)
1	240.0	108.0	255.00	25920.00	870.20	33.57
2	239.1	107.8	254.00	25774.98	758.90	29.44
3	240.2	108.0	255.00	25941.60	823.90	31.76

Average Compressive Strength = $\frac{(33.57+31.76+29.44)}{3}$ = 31.59N/mm^2

4.5 Theoretical analysis

Based on the theory by Hendry (1981) on the brick bounded by mortar both elastic properties and strength of the brickwork can be calculated using the formulae as shown below.

$$\boldsymbol{\sigma_c} = \frac{\sigma'_b}{v_b + \left(\frac{v_m . m - v_b}{1 + r.m}\right)}$$

$$\boldsymbol{m} = \frac{\boldsymbol{E_b}}{\boldsymbol{E_m}},$$

$$\boldsymbol{r} = \frac{\boldsymbol{d}}{\boldsymbol{t}},$$

Whereas the parameters are as defined in the following table.

σ_c	=	brick strength in compression.
σ'_b	=	stress corresponding to tensile failure of the brick.
v_b	=	Poisson's ratios for brick
v_m	=	Poisson's ratios for mortar.
E_b	=	elastic modulus for brick.
E_m	=	elastic modulus for mortar.
d	=	depth of the brick.
t	=	thickness of the mortar joint.

Based on the researches by other researchers, some properties related to brick and mortar required for calculation of the compressive strength was found to be as listed below.

v_b = 0.1

v_m = 0.25

E_b = 37000 N/mm^2

E_m = 20000 N/mm^2

Other required relevant information was obtained from the result conducted in this research. The information obtained as listed below.

σ'_b = 31.15 N/mm²

d = 85.00 mm

However the thickness for the conventional mortar system is assumed as shown below since this research use unconventional unbounded method.

t = 7.0 mm, 10.0 mm and 15.0 mm

For each mortar thickness the strength of the brickwork was calculated.

t **=** 7.0mm

$$\boldsymbol{m} = \frac{\boldsymbol{E_b}}{\boldsymbol{E_m}}$$

$$= \frac{\mathbf{37000}}{\mathbf{20000}} = 1.85$$

$$\boldsymbol{r} = \frac{\boldsymbol{d}}{\boldsymbol{t}}$$

$$= \frac{\mathbf{85}}{\mathbf{7.0}} = 12.14$$

$$\boldsymbol{\sigma_c} = \frac{\sigma'_b}{v_b + (\frac{v_m . m - v_b}{1 + r . m})}$$

$$= \frac{30.15}{0.1 + \frac{(0.25)(1.85) - 0.1}{1 + (12.14)(1.85)}}$$

$$= 261.14 \text{ kN}$$

t = 10.0mm

$$\boldsymbol{r} = \frac{\boldsymbol{d}}{\boldsymbol{t}}$$

$$= \frac{\mathbf{85}}{\mathbf{10.0}} = 8.5$$

$$\boldsymbol{\sigma_c} = \frac{\sigma'_b}{v_b + (\frac{v_m.m - v_b}{1 + r.m})}$$

$$= \frac{30.15}{0.1+\frac{(0.25)(1.85)-0.1}{1+(8.5)(1.85)}}$$

$$= \quad 247.79\text{kN}$$

t = 15.00mm

$$\boldsymbol{r} = \frac{\boldsymbol{d}}{\boldsymbol{t}}$$

$$= \frac{\mathbf{85}}{\mathbf{15.0}} = 5.67$$

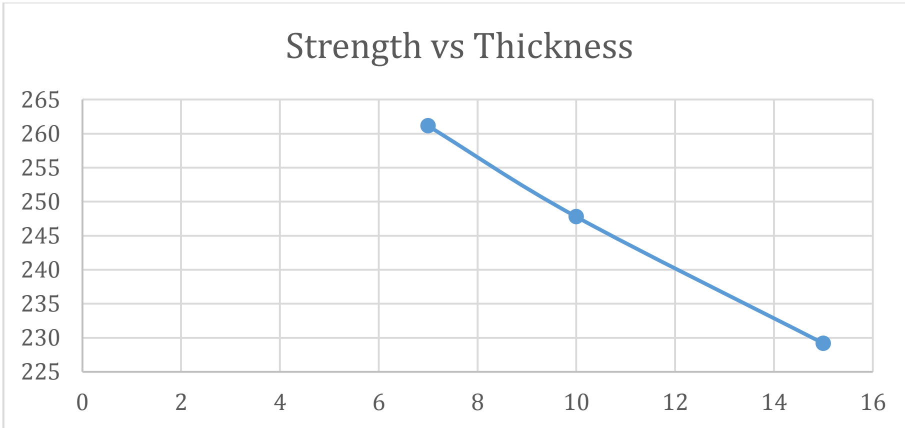
$$\boldsymbol{\sigma_c} = \frac{\sigma'_b}{v_b + (\frac{v_m.m - v_b}{1 + r.m})}$$

$$= \frac{30.15}{0.1+\frac{(0.25)(1.85)-0.1}{1+(5.67)(1.85)}}$$

$$= \quad 229.19\text{kN}$$

By using Hendry method proposed by Hendry (1981), the strength for the brickwork with mortar thickness 7.0mm, 10.0mm and 15.0mm was found to be 261.14kN, 247.79kN and 229.19kN respectively. The graph below explains how strength of brickwork increases with decrease in mortar thickness.

Graph 4.2 shows strength vs thickness of mortar.



4.6 Discussion and Comments

4.6.1 Test of Bricks

For a test conducted on the five bricks sample, several statements could be made based on the result obtained, observation done and conclusion drawn. First and for most from the initial measurement conducted on the bricks sample, it seem the brick used in this research didn't conform to the size limit as stated in BS 3921: 1985. The total dimension of the 9 bricks measured were 3358.00mm in length, 1512.00mm in width and 1187.00mm in height. Several factors might have contributed to the irrelevancy of the brick in comparison to the BS standard and that is being the quality of production in addition to the fact that the brick was shipped from Japan. Japan uses a different code of practice contrary to BS and that is the main reason as to why the brick exceeded the limits stated in BS beyond any doubting proportion.

During the compressive strength test on the bricks, failure could only be observed on the sides of the bricks. The side of the brick was broken off such that several layers could easily be peeled off. That kind of failure normally occurs due to development of tensile forces within the bricks when compressive forces were applied. The outer surface of the brick was noticed to be less retrained compared to the inner part of the bricks. So the surface failed by breaking free instead of normal cracking failure that occurs in retrained structures. Figure () shows the shape of the failed brick due to compression. The compressive strength of the brick was found to be 31.15 N/mm^2.

Figure 4.1 Shape of the failed brick after Compressive Strength Test

4.6.2 Tensile Strength Test on steel rod.

Based on the result for two set of diameters 10 and 12 mm respectively and of the same grade of steel, it was found that the tensile strength for steel with diameter 12mm was higher than the 10mm diameter steel. That simply implies that as diameter decreases tensile strength decreases as such, in other word the tensile strength is directly proportional to diameter of the steel.

Beside that the graph obtained showed the failure of 10mm diameter under 500N/mm^2 and 12mm diameter failure lies between 600 N/mm^2 and 700 N/mm^2. The results obtained from the test showed that 12mm diameter steel rod is suitable for use in DBHS compared to 10mm diameter steel rod due to its higher tensile strength. However 12mm diameter wasn't used in the experiment for the brick specimen due to the pre made diameter in the brick, as such 10mm diameter was used instead.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

4.1 General

Dry masonry brick house system is a new structural housing system adapted from Japan that promotes 3R. As mentioned earlier, to adopt this system in Malaysia it is required that proper modification is made to conform to the code of specifications and standards that suit Malaysia. That is to say it should adapt local building standard and specification such as Act 133 street, drainage and building 1974 and Uniform Building by Law (UBBL) 1984 and BS.

The vertical reinforcement members such as bolts and washers act as a resistant to the earthquake and wind loading. However as highlighted in the preceding paragraph, Malaysia lies outside the earthquake prone zone as such less focus will be given to earthquake loading. To ensure conformity two thing shall be taken care of;

- Brick wall configuration. (arrangement of bricks/blocks)
- Fastening level.
- Bolts and steel rod sizes.

Tensile strength test is required to ensure the success of the structure as a whole. It will be used to for the quality control in production, ranking performance of structural materials and evaluation for evaluation of the newly developed alloys and the new configuration.

In this Final Year Project, tensile strength test for the brick wall structure will utilize bolt of diameter 12mm. The 12mm bolts will be used for all the fastening of the brick layers at every two layers of bricks. This modification will produce s significance cost of construction.

4.2 Conclusion and recommendations

To conclude, achieving the main objectives as per requirement for Final Year Project has been achieved and that is being the non-trivial introduction of the research topic, the literature review and the methodology needed for the completion of the project on time. The tensile strength test done on the 10mm diameter steel rod was found to be 456.99N/mm^2. Compressive strength test on both brick and brick prism rendered similar result 31.15N/mm^2 and 31.59N/mm^2 respectively. Comparing the results obtained with the conventional method binding brick using mortar prove squarely that strength of brick increase with decrease in mortar thickness. It is recommended to investigate wind load and earthquake load on the brick prism in order to determine the effect of steel rod as a restraint binding bricks together since the compressive strength for both brick and brick prism was similar.

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British Code

APPENDICES

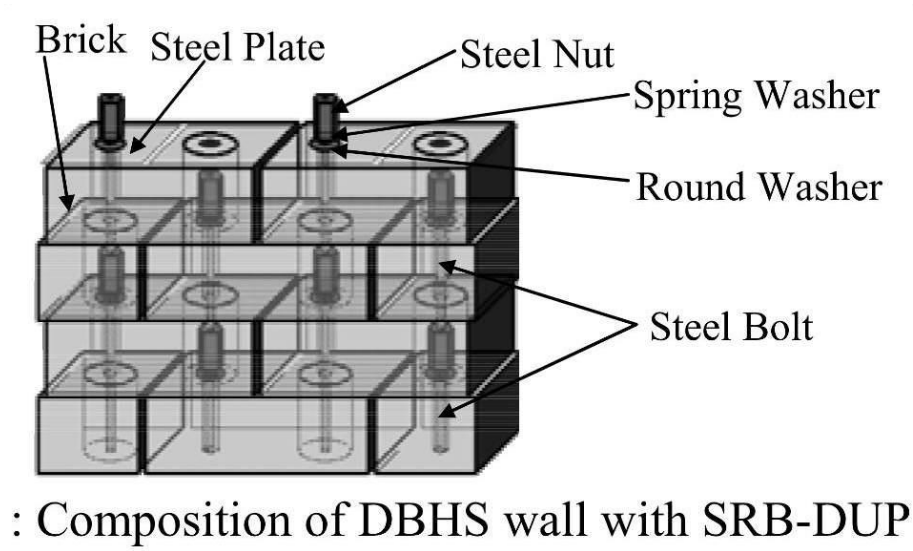

Figure 2.0: Structural Composition of DBHS Wall with SBR-DUP Method

(Khamide F, 2004)

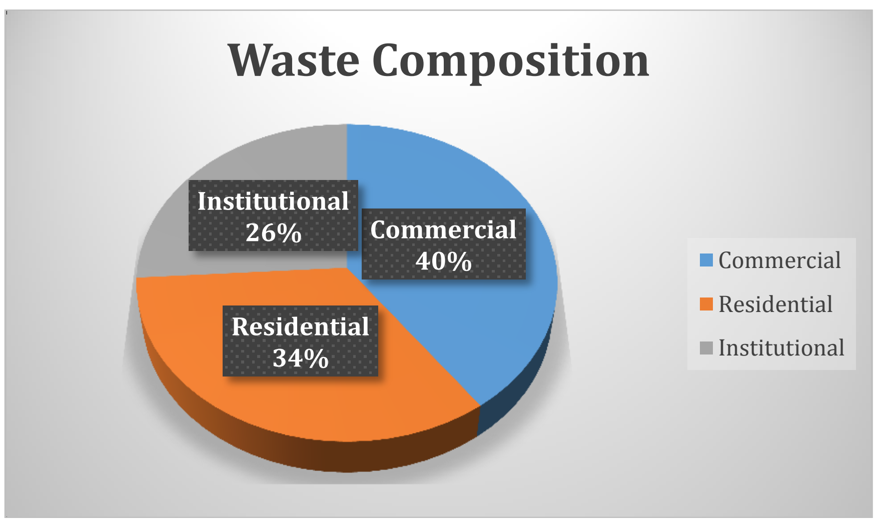

Chart 2.0 Waste Composition in KL, 2002.

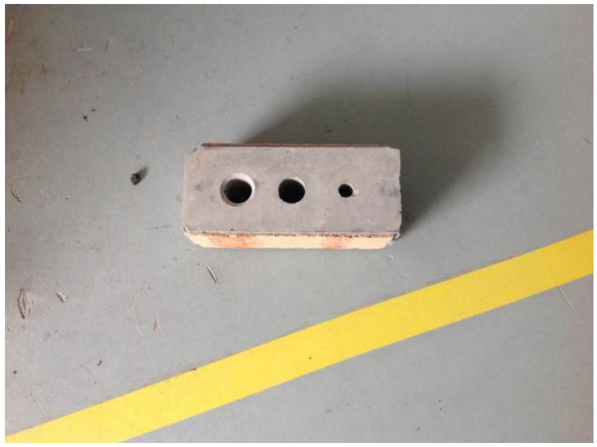

Figure 3.0 Sample of brick used for the construction of the specimen.

Figure 3.1 Bolts used for fastening brick specimen.

Figure 3.2 Washers to support the tightening of the bolts.

Figure 3.3 Steel rod for fastening inner brick layers.

Figure 3.4 Steel rod for fastening bottom and upper brick layers.

Figure 3.5 Steel plates used as a cover.

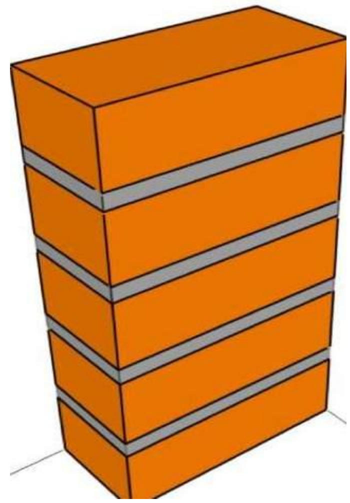

Figure 3.8 Model of 3 bricks prism specimen

Figure 3.9 Shows the compressive strength test conducted on brick samples