LOAD BEARING AUTOCLAVED AERATED CONCRETE WALL IN INDUSTRIALISED BUILDING SYSTEMS CONSTRUCTION

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Finally, I have completed my final project and accomplished the mile stone. Here, I gratefully acknowledge to those who help me a lot in the journey of doing this project.

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As is customary, I will accept blame for errors of commission and omission. I hope that any errors that are discovered will be brought to my attention so that they may be corrected in future.

ABSTRACT

The Industrialised Building Systems (IBS) is a construction process that utilizes techniques, products, components, or building systems which involve prefabricated components and on-site installation. In order to implement IBS effectively, the understanding of new construction materials, such as Autoclaved Aerated Concrete (AAC) and technology are encouraged. The aim of this study is to verify that AAC load bearing wall is capable to adopt in IBS with its low compressive strength for low-rise construction. This study is to conduct a finite element analysis by using engineering software Staad-Pro on the different kind of AAC load bearing wall, which subjected to various opening in single and double storey building. The analysis is focus on the behavior of the AAC act as a load bearing wall. The stresses induced by different type of design criteria are determined. The accuracy of the finite element model is verified against theoretical result, which conducted by manual calculation. Besides that, manual calculation for reinforced AAC load bearing wall is carried out to compare with the non-reinforced AAC load bearing wall. The maximum capacity and bending moment of the both type of wall are determined. Reinforced AAC load bearing wall have higher resistance to bending moment but have no significant effect on the axial load capacity if compared with non-reinforced AAC load bearing wall. At the end of the study, it is found that AAC load bearing wall is able to sustain design load of single and double storey building.

ABSTRAK

Sistem Bangunan Berindustri (*Industrialised Building Systems* (IBS)) adalah satu proses pembinaan dengan menggunakan teknik, produk, komponen atau sistem binaan yang melibatkan pasang siap komponen dan pemasangan di tapak pembinaan. Untuk melaksanakan IBS dengan berkesan, pemahaman bahan bangunan baru, seperti Konkrit Berudara Autokraf (*Autoclaved Aerated Concrete* (AAC)), adalah amat digalakkan. Tujuan utama penyelidikan ini adalah untuk mengesahkan bahawa dinding AAC mampu digunakan dalam IBS dengan kekuatan mampatan yang rendah untuk pembinaan bangunan rendah. Penyelidikan ini menggunakan perisian kejuruteraan Staad-Pro yang berasaskan kaedah unsur terhingga untuk mempelajari perilaku pelbagai jenis dinding galas beban AAC yang mempunyai perbezaan bukaan ruang dalam satu dan dua tingkat bangunan. Nilai tekanan ditentukan dengan menggunakan pelbagai kriteria rekabentuk. Ketepatan model unsur terhingga disahkan dengan keputusan berdasarkan teori dan kiraan secara manual. Selain itu, kiraan secara manual untuk dinding galas beban AAC yang bertetulang dilakukan untuk membandingkan dengan dinding galas beban AAC yang tidak bertetulang. Keupayaan maksimum kedua-dua jenis dinding juga akan ditentukan. Dinding galas beban AAC yang bertetulang mempunyai rintangan terhadap momen lentur yang tinggi tetapi tiada kesan dalam beban paksi jika dibanding dengan dinding AAC tanpa tetulang. Di akhir kajian ini, adalah didapati bahawa dinding AAC sesuai dan berupaya untuk menahan beban dalam pembinaan rumah satu dan dua tingkat.

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LIST OF SYMBOLS

fk	–	Characteristic compressive strength
γm	–	Partial safety factor for material strength
fkx	–	Characteristic flexural strength masonry
F	–	Force
m	–	Mass
A	–	Acceleration
t	–	Thickness of wall
β	–	Capacity reduction factor
ex-	–	Eccentricity of applied load
heff	–	Effective height
r	–	Radius of gyration
I	–	Moment of inertia
fkx par	–	Characteristic flexural strength parallel to the bed joints
fkx perp	–	Characteristic flexural strength perpendicular to the bed joints
Z	–	Elastic modulus
punit	–	Compressive strength of unit
Wk	–	Characteristic wind load
Gk	–	Characteristic dead load
Qk	–	Characteristic imposed load
γmf	–	Partial safety factor for masonry in flexure
SRall	–	Allowable slenderness ratio
Φ	–	Diameter
E	–	Modulus of Elasticity

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Industrial Revolution is a process of social and economic change for human society to transform from pre-industrial to a new industrial country. Industrialization in construction industry is part of a process in change and improvement management. The Industrialised Building Systems (IBS) is a construction process that utilizes techniques, products, components, or building systems which involve prefabricated components and on-site installation. Industrialization has demonstrated to reduce the costs, improve the quality and get complex products available at high quality of finishing to the vast majority of people. Indeed, Industrialized Building System (IBS) has been introduced to cope with a growing demand of affordable housing, solving issues associated with foreign workers and improving image, quality and productivity of construction related services in Malaysia. In order to implement IBS effectively, the understanding of new construction materials and technology are encouraged.

Autoclaved Aerated Concrete (AAC) is one of the relatively common construction materials in other country and gradually introduced in Malaysia. Autoclaved Aerated Concrete (AAC) is one of the component to be highly recommend for the IBS (Industrialized Building Systems) because it is lightweight, easy to construct, and economical to transport. Load bearing Autoclaved Aerated Concrete (AAC) Wall is a lightweight precast concrete wall which formed by AAC masonry block and plank/panel， with or without reinforcement. Autoclaved aerated concrete (AAC) is a lightweight concrete material that was developed in Sweden approximately 85 years ago and has been widely spread across countries such as USA, United Kingdom and Sweden.

1.2 Problem Statement

The development of lightweight, industrialized and sustainable housing system in Malaysia as per modular coordination system is a need of the day. The present modular coordination system usually focus on the use of cement or concrete blocks for the infill or to certain extent as load bearing walls which are heavy in weight. Autoclaved aerated concrete structural elements are widespread as lightweight, high performance construction material which can replace its counterpart conventional materials. However, these could not gain popular acceptance here due to the limitation of the manufacturing facilities, which induce to suffering of higher initial cost. Both the costs and availability of AAC are expected to improve as AAC manufacturers invest in additional plants.

Moreover, building with AAC has a learning curve both with respect to the construction community as well as with local governments. Few contractors are a currently familiar with the product, and trained masons must adjust to using thin-set mortar as opposed to traditional cement-based mortar, which requires less precision in its application. Local building departments, design review boards, and planning commissions are also largely unfamiliar with AAC and must be educated with respect to the products ability to satisfy local building codes. In this literature, only 2-storey of building is considered for the construction of AAC wall due to its low compressive strength. However, AAC in IBS is ideally an approach to solve the problem of highly demand housing in Malaysia.

1.3 Aim and Objectives of the Study

The main aim of this research investigation is to study the behavior and properties of AAC material and adopt the software to run the analysis and design of the AAC wall as a load bearing wall in the structure.

Towards achieving the above mentioned aim, the related objectives associated were identified as follows:

(i) To study the behavior of autoclaved aerated concrete in term of flexure, and compression.
(ii) Finite element analysis for the load bearing AAC wall by using software of StaadPro.
(iii) Analysis for the various type of AAC wall panel with opening and without opening, with reinforcement and without reinforcement.

1.4 Scope of Study

Analysis was carried out on a scaled model of single and double storey building. The software used to analysis the models was StaadPro which based on the finite element method of frame analysis. All the material properties assigned are taken from the standard table by manufacturer. The load applied was also based on the BS 8110. Results obtained from the analysis were being used in the design of AAC members subjected to flexure and compression.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The world is witnessing a revolution in construction practices along with a new phase of development fuelled by the rapid economic growth and the high rate of urbanization. Construction provides the direct means for the development, expansion, improvement and maintenance of urban settlements (Suresh, 2004). The construction industry is entering in an era of globalization where the utilization of the latest technology and material shall no longer recognize national borders (Abang, 1999).
Thus, the construction industry must keep up with the advanced technology and systems to cope with the modern trends and demands. The growing need for affordable houses is a much discussed subject because due to spiraling construction cost, housing today is not an affordable proposition for the common people even on the international scene. Malaysia also is not spared from the problem of inadequate housing. There is still a very high demand for affordable houses in the country (Mahyuddin and Wahab, 1994; Abang, 1995; Waleed et al., 2004). Especially in the case of developing countries, the gap between demand and supply of adequate housing is continuously increasing (Shaikh, 1999; Arif et al., 2001; Waleed et al., 2004). The duration of construction is vital in this regard. In order to minimize the time span of the construction, prefabrication is generally preferred.

Prefabricated structures are also preferred for rapid construction of tourism facilities such as, transportation utilities, communication units, hotels etc. In order to satisfy the ascending demand for rapid construction of the structures mentioned, the method of prefabrication is remarkably employed now days (Korkmaz and Tankut, 2005). Precast concrete members offer various advantages in service and quality over their cast-in-place correspondents; such as their higher allowance for quality control (Seckin and Fu, 1990; Soubra et al., 1991; Soubra et al., 1993), the ready supply of good quality aggregates, much higher strength due to better batching and quality control of the concrete achieved through the use of a specialized labour force under factory conditions and results in the reduced construction activities at the site (Korkmaz and Tankut, 2005). In this context, there is need for the adoption of cost-effective and environmentally appropriate technology and materials.

Recent years has seen a renewed interest in the development of precast composite structural elements by adopting the technique of lightweight concrete. Precast AAC elements present a series of possibilities for the solution of housing problems.

2.2 Autoclaved Aerated Concrete (AAC)

2.2.1 Introduction

Autoclaved aerated concrete (AAC) was developed by Swedish architect Johann Axel Eriksson in the early 20th century and patented in 1924. The material is a mixture of sand, lime, cement, gypsum, water and an expanding agent that is cured in a pressurized steam chamber, called an autoclave, producing a cellular lightweight material.

Comprised of all natural raw materials, AAC is used in a wide range of commercial, industrial, and residential applications and has been in use in Europe for over 70 years, the Middle East for the past 40 years, and South America and Australia for approximately 20 years. According to one manufacturer, AAC now accounts for over 40% of all construction in the United Kingdom and more than 60%

of construction in Germany. More AAC is produced worldwide than any other building material with the exception of regular concrete. It has only recently been introduced in the Malaysia.

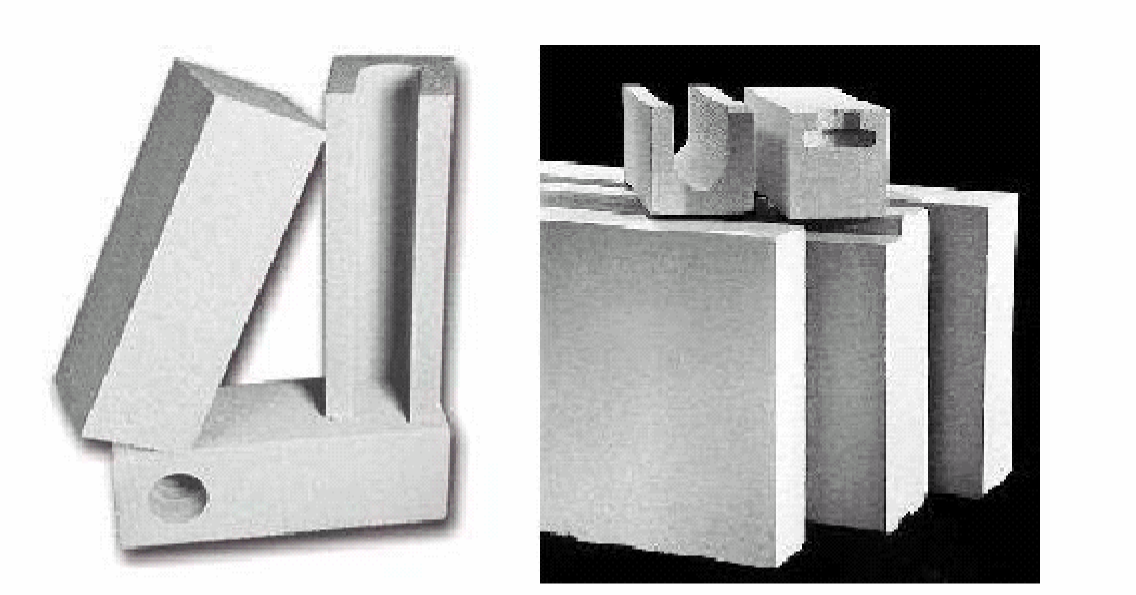

Figure 2.1 AAC Mansory Block and Plank/Panels

2.2.2 Manufacturing Process

The production of Autoclaved Aerated Concrete (AAC) is similar in nature to the production of clay masonry units or even precast concrete. The materials used in AAC are similar to the concrete normally used in structural components. The manufacturing process of AAC can be likened to the process of baking bread, and can be summarized into five main steps:

i) Assembling and mixing of the raw materials.
ii) Adding of the expansion agent.
iii) Expansion, shaping, pre-curing., and cutting.
iv) Final curing utilizing an autoclave.
v) Packaging and shipping.

The image below depicts the manufacturing process beginning with the mixing of raw materials and ending with the shipping stage.

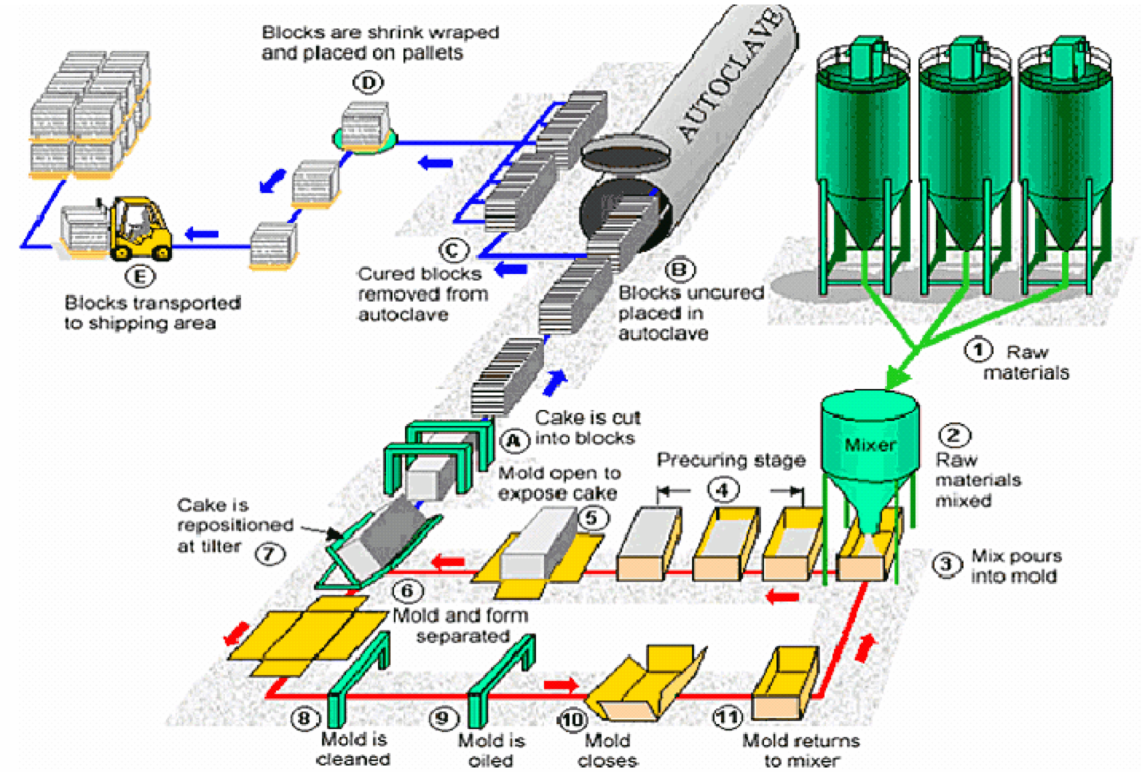

Figure 2.2 Manufacturing Process of AAC Masonry Units (www.aacstructures.com)

i) Assembling and mixing of the raw materials

The production of AAC starts with the raw materials of silica, cement, lime, and water. The silica, which is used for the aggregate, is made from finely ground quartz. Fine sand can be used in place of silica. Also, fly ash, slag, or mine tailings which are the ground up remains from mining operations, can be used as aggregate in combination with the silica. These materials are the fine aggregate of the concrete mix. The aggregate needs to be a fine gradation, not course or large material because a larger aggregate interferes with the internal structure created by the microscopic bubbles produced in step 2. Portland cement is used, just as it is used in normal concrete mixes. Portland cement is the binding agent which holds the aggregate together. It reacts with water in a process called hydration and then hardens, bonding all the aggregates together to form a solid material. All these mixed together with water form the base AAC mixture. The raw components are then mixed together with water in a large container.

ii) Adding of the expansion agent

In making a loaf of bread, yeast is added to the dough mixture to make the bread rise. In a similar way, an expansion agent is added to the concrete mix to increase its volume. Yeast produces carbon dioxide which causes the dough to expand. In autoclaved aerated concrete, the expansion agent that is used is aluminum powder or paste. The aluminum reacts with the calcium hydroxide and water in the mixture creating millions of tiny hydrogen bubbles (Figure 1.2). This process can be shown by the following chemical equation (Pytlik & Saxena 1992):

$$2Al + 3Ca(OH)_2 + 6H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 6H_2O + 3H_2$$

Aluminum Powder + Hydrated Lime → Tricalcium Hydrate + Hydrogen

The hydrogen that is formed in this process bubbles up out of the mixture and is replaced by air. The hydrogen, which is a lighter gas, rises and is replaced by air which is a denser gas that gets into the mix as the hydrogen foams up out of the material. The aluminum expansion agent is thoroughly mixed into the batch so that it is evenly distributed during the mixing process. The creation of hydrogen bubbles causes the mix to expand, increasing the volume of the mixture approximately two to five times its normal volume. The volume increase is dependent upon the amount of aluminum powder/paste that is introduced to react with the calcium hydroxide in the mixture. The less expansion that is induced will produce a higher strength material (more dense) versus the maximum amount of expansion induced, which produces a lower strength material (less dense). The microscopic voids created by the gas bubbles give AAC its light weight and other beneficial material properties, such as its high thermal resistance properties.

Figure 2.3 Air voids in AAC (Tanner 2003)

iii) Expansion, shaping, pre-curing, and cutting.

After the addition of the expansion agent, the mix is poured into metal molds where it is allowed to expand. If a plank or panel is being cast, then steel reinforcement is placed in the mold prior to pouring the mix into the mold. The steel reinforcement is used to give tension strength to the lightweight concrete material. When the mix is poured into the forms, commonly 6m x 1.2m x 600mm thick (Pytlik & Saxena 1992), it first expands and then is allowed to procure for several hours. The pre-curing stage is to allow enough time such that the block can maintain its shape outside of its mold. The pre-cured block can then be cut, utilizing a device that uses thin wires, into the desired shapes. Standard AAC masonry can be found with nominal dimensions of 200mm deep by 24 inches long with varying thickness of 100mm to 300mm. The larger blocks are cut into solid masonry blocks similar to concrete masonry units (CMUs). Unlike CMU, AAC masonry units are cut from the larger block rather than being formed individually. The production of a plank, which can have reinforcement cast in, is not cut from a 6 large block. The waste that is produced from cuttings or any leftover bits can be reused in the original mixture as aggregate after being finely ground.

iv) Final curing utilizing an autoclave

An autoclave is “a strong, pressurized, steam-heated vessel.” This large steam-heated vessel is in effect a large pressure cooker by which the autoclaved aerated concrete is cured. Curing is the process by which the concrete mixture hardens through hydration (chemical process between cement and water) with the autoclave the blocks are cured with steam at high pressures. The pressure, temperature, and moisture are closely controlled for the twelve hours of curing time. The monitoring of proper pressure, temperature, and moisture allows for the optimum conditions for which hydration can occur. During this process the autoclave is heated to 374 degrees Fahrenheit and pressurized to 12 atmospheres of pressure, “quartz sand reacts with calcium hydroxide and evolves to calcium silica hydrate which account for the material's physical strength properties.” Basically, this step can be described as the actual baking portion like with bread.

v) Packaging and shipping

After approximately twelve hours of curing time (Pytlik & Saxena 1992), the cured blocks are removed from the autoclave, packaged, and shipped. Various literature states that after AAC is autoclaved it can be immediately shipped and used for construction, it is assumed that the cooling step is not expressed as a period of time where the material is set aside for the express purpose to cool down, but as the period of time when the material is being packaged. At this point in the process the autoclaved aerated concrete units are ready for use in the construction process.

Figure 2.4 Transportation of the AAC to jobsite