CERTIFICATION OF APPROVAL

SCALED DYNAMIC TESTING ON LIGHTWEIGHT CONCRETE FOR WAVE SUPPRESSING SYSTEM

BY

MOHD ABSHAR B MOHD NOR

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Civil Engineering)

JUNE 2006

Approved by,

____

(Associate Professor Ir. Dr. Muhd Fadhil Nuruddin)

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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 references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Mohd Abshar B Mohd Nor

ABSTRACT

The Wave Suppression System (WSS) invented by Mohammad Firdaus Hashim has shown promising results, and UTP is keen to further develop the invention to the point of making it commercially usable and viable. This project serves as part of UTP's effort to make the WSS workable, viable and durable for commercial use.

The project focuses on trying to determine the durability of the ALC used in the WSS by conducting a series of tests which best simulates the dynamic wave forces to a scaled model. There will be two main test; maximum strength and cyclic loading resistance.

The former results are significant in two ways; they provide a reference load to the second tests and providing maximum strength value for WSS designers to relate with the return period of certain wave heights. The return period of a wave height that is equal to the WSS maximum strength shall serve as the lifespan of the WSS in terms of years. If the maximum strength is equivalent to a 10 m wave height, and the targeted coast area has a hypothetical 20 years return period for 10 m waves, the WSS will theoretically last for 20 years.

However, even low wave heights, which equal low forces, which continuously hit the WSS of long period of time may cause the WSS to fail due to fatigue crack propagation. This is why the second test is employed to determine its resistance for cyclic loading. The test will give the maximum number of cycles the WSS can withstand before failure at a variety of frequencies arbitrarily set to the most common wave periods. The load shall be varied in terms of percentage of the maximum load.

It must be noted that in order to compare the results with the actual wave forces, dynamic similarity must be achieved as close as possible between the intended full scale prototype and the scaled model. The dynamic similarity is reasonably achieved

by correcting the results with the appropriate scale factor. The corrected results will then be used as a basis for comparison with actual wave periods.

The experiments results expose the ALC weakness, which is low maximum strength and low resistance to cyclic loading. Even under the most favourable coastal circumstances the ALC will struggle to last for more than 6 months.

ACKNOWLEDGEMENT

For the completion of this project, I would like to thank and acknowledge the following individuals for their support and assistance. Without their guidance and generosity, this project would not have been possible. Many of the individuals involved in this project are related subject matter experts and have been more than willing to share their experiences and expertise to allow myself and the other students working on this project to better our understanding of the subject matter.

First and foremost, I would like to thank my supervisor Associate Professor Ir Dr Muhd Fadhil Nuruddin, Head of Civil Engineering Programme, Universiti Teknologi PERTRONAS. His comments and guidance were very useful, and the opportunity he had given me to be at the ITPA R&D EXPO at PWTC was a really invaluable experience. My thanks also to Miss Zahiraniza Binti Mustaffa for her kindness in lending her expertice to help me with my project related poblems.

I would like to express my gratitude to Mr Teh Hee Min, Lecturer of Civil Dept for his guidance, patience, opinions and advices he had given me. His sincere help is most helpful in helping me grasp the principle behind hydrodynamics, and coastal engineeering.

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LIST OF ABBREVIATIONS

WSS – Wave Suppressing System

UTP – Universiti Teknologi PETRONAS

PETRONAS – Petroliam Nasional Berhad

ALC – Autoclaved Lightweight Concrete

CSR – CSR Building Materials (M) Sdn Bhd

KN – KiloNewton

MPa – Mega Pascal

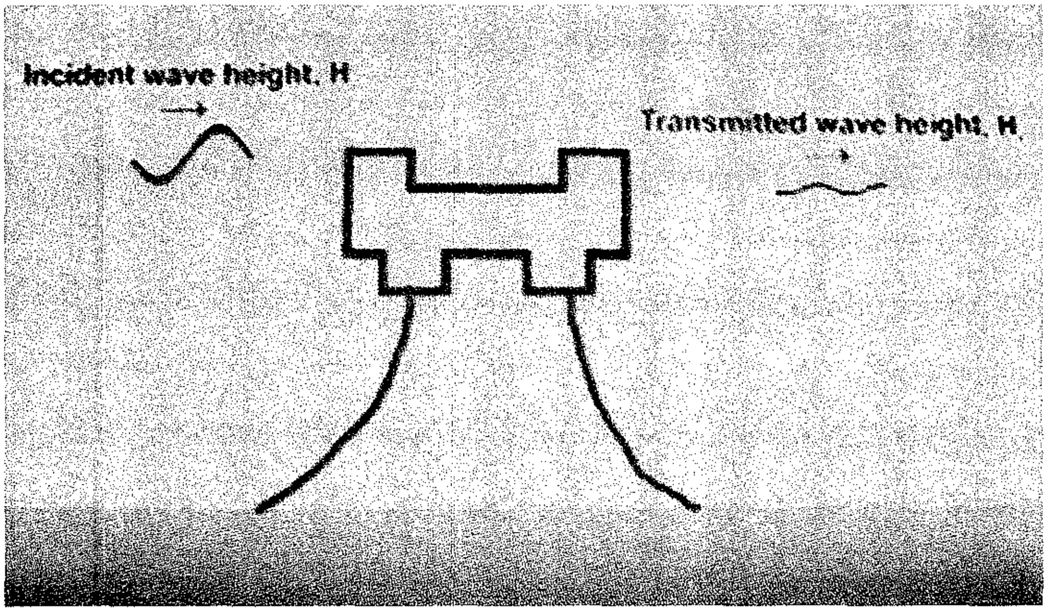
HZ – Hertz

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

The Wave Suppression System (WSS) was co-developed by third year student Mohd Firdaus, and lecturer in Civil Engineering Department in January 2004/2005 semester for former's Engineering Team Project course. Cut from a solid block of autoclaved lightweight concrete (ALC), the system proved to be so effective and innovative that it won second place in the ITEX award.

Figure 1.1



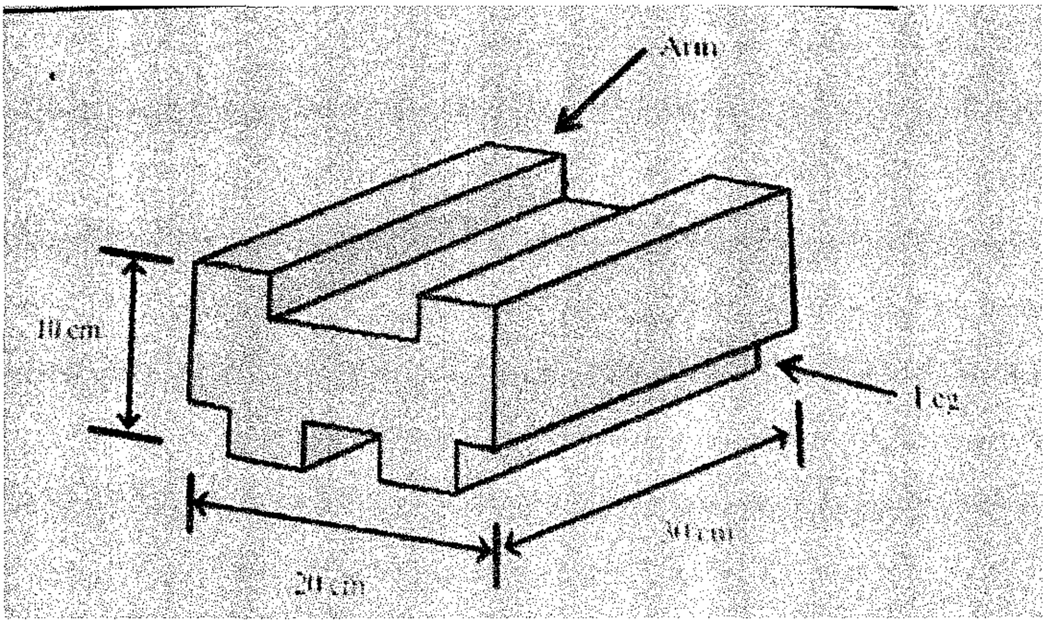


Figure 1.2

The WSS is in fact a floating breakwater, designed to dissipate the erosive force of wave energy with comparatively minimal cost and impact to the environment. UTP is keen to take this fruit of ingenuity and simplicity to another level, which is to make the WSS a workable and commercially viable product that can compete with the best existing wave suppressing systems in the world.

This is where this final year project comes to place, being a part of the development process for WSS. In real life conditions, the WSS will be subjected to the dynamic force of the waves, which will continuously pound the WSS at various frequencies and loadings.

For this particular project, we will be concentrating mainly on the WSS's ability to withstand the cyclic loading from waves using the current material, which is ALC. Even more specific and of greater use is how many cycles can the WSS, with the current material, withstand before failing, which will help WSS designers in predicting the lifespan of the WSS given the statistical wave data of that particular location.

1.2 PROBLEM STATEMENT

Currently, the resistance of the non-reinforced ALC used in the WSS to cyclic loading is unknown. Reliable estimate or reliable basis for estimation of cyclic loading resistance is crucial in determining the workability, reliability and longevity of the product.

It is also important to determine the suitability of the current material (ALC) for its intended purposes in the WSS. The ALC is expensive, thus its usage in the WSS must be justified and supported by empirical studies which verifies its strength and reliability.

1.2.1 Problem Identification

We identified 3 problems which shall be adressed during the course of this project.

1. Identifying the dominant resultant wave force.
   From our literature review, we come to the conclusion that only the net horizontal force shall be simulated.
2. Finding ways to simulate the dynamic nature of wave forces.
   We shall simulate the wave effect by applying cyclic load using the dynamic actuator. The decision to apply cyclic loading is supported in the literature review which points out that in the Airy Wave Theory, waves are sinusoidal in nature.
3. Finding the correct scale ratio to relate with full size wave load. Since it's a scaled model, we need to find the correct scale ratio for every parameter. Our literature review shows that the undistorted froudian scale ratio is adequate for our experiments.

1.2.2 Significance of the Project

The prospect of WSS to be commercialised lies in three factors; the workability of the design shape, the reliability of actual product in real conditions and the product cost. This Final Year Project will address the second prospect, which is currently unknown.

From our literature research, there are two circumstances which will result in failure of the WSS. First is when the wave hitting the WSS is carrying more load than the WSS maximum strength. The second is in the event that even if the waves hitting the WSS is for lower than the maximum strength, the sinusoidal nature of wave load meant that the WSS will be receiving continuous repetitive pounding which will result in crack propagation and failure.

Our first experiment will determine the maximum strength, and relate it to the maximum wave height the WSS can withstand. This will enable the WSS designers to estimate the lifespan of the WSS based on the return period of the maximum wave height.

The next experiments will focus on applying cyclic loading to the WSS, which mimics the sinusoidal wave force loading. The maximum number of cycles will be related to how long the WSS can be used at a given wave height and wave period of a specific location.

1.3 OBJECTIVES AND SCOPE

The objectives and scope of the project will limit the study so as to feasibly complete this project within the given time period of two terms.

1.3.1 Objectives

- To establish the characteristic of the dynamic forces of waves acting upon the WSS by using the Dynamic Actuator.

- To develop a mathematical approach of relating the accumulated data gained from the conducted tests with the estimation of the WSS lifespan at a specific wave period.

1.3.2 Scope and Relevance to the Study

The scope of this study is limited to studying the durability of the ALC in the WSS when subjected to forces which simulates actual, dynamic wave conditions, which from our literature review had been determined to be in terms of maximum load and cyclic load.

The scope of this study also includes recommending solutions or better alternatives which will result in better durability performance, in the event that our tests results indicate that the ALC is not strong and reliable enough for use in WSS.

The scope of this study shall not include the effect of applied coatings on the strength of the WSS because:

- At the point of writing, the type of coating which will be applied has not been confirmed.
- At the point of writing, the thickness of the coating has not been confirmed, thus we cannot apply scaled coating thickness to the scale model.
- The coating will have very minimal effect on the strength.

This study is relevant not only in enabling WSS designers to predict the lifespan of the WSS as explained in 1.2.2 Significance of the Project, but also provide reference for the behaviour of ALC under cyclic loading for future studies.

1.3.3 Feasibility of the Study

This project is planned for the period of 2 semesters. For the first half of the semester, time will be spent on sourcing for references and studying the research materials. The second semester will be used to perform the required tests. Unfortunately, the dynamic actuator in UTP was unavailable for use due to reinstallation and software problems, and the problems will only be rectified in next semester.

The cost of material to be used in this project is free, courtesy of CSR Building Materials (M) Sdn. Bhd, who supplied us with the prefabricated ALC blocks for research purposes.

Ideally the test should be done in full scale for maximum accuracy and reliability of results, but unfortunately CSR is not willing to incur the huge cost of custom mold for our WSS, hence the scale model testing. If the scale model testing indicates favourable results, the next step would be acquiring sponsors to help us make full scale trial prototypes.

Another way is obtaining government grant, provided our request is supported by strong empirical evidence on the potential of the WSS.

CHAPTER 2
LITERATURE REVIEW

2.1 COASTAL DEFENCE PRINCIPLES

The WSS is essentially a coastal defence mechanism design to dissipate wave energy. Coastal defence is a general term used to cover all aspect of defence against coastal hazard. Two specific terms are used to distinguish between different types of hazards. The term **sea defence** is used to describe systems which are design to prevent flooding of coastal regions under extremes of wave and water levels. By contrast, the term **coastal protection** is reserved to describe mechanisms designed to protect an existing coastline from erosion, which is what the WSS is designed for.

There are two approaches in designing coastal defence systems. The first is referred to as **soft engineering** which aims to work in sympathy with the natural processes by mimicking natural defence mechanisms. Such an approach has the potential for very low cost whilst minimising the environmental impact and creating environmental opportunities. The second is referred to **hard engineering**, whereby structures are constructed on coastline to resist the energy of waves and tides. The WSS obviously belongs to the former category, which narrows down our literature research to the hydrodynamics of that category only.

2.2 WAVE THEORIES

As the WSS will be subjected to wave forces, our testing shall in the most accurate way possible simulate the actual condition at sea. To simulate the actual wave forces on the scale model, it is imperative for us to understand the very nature of waves.

Different wave theories are used to predict and describe wave shape and wave behavior. For the WSS, we will use only the Airy Waves theory, which in our opinion is the most applicable.

2.2.1 Airy Wave theory: sinusoidal waves

The airy wave theory is the most accurate for low amplitude waves in deep water. This theory simplifies the wave into a sinusoidal form, although it has to be noted that this theory is less accurate for predicting wave behavior in shallow water, where it is less likely to conform the theoretical sinusoidal shape.
It is also the most commonly used wave theory because it is the least mathematically complex and does not take into account the effects of wave height in determining wave velocity.

This is the theory which will give the most accurate representation of the actual wave hydrodynamics being exerted to our WSS model, and as such we shall use this theory to simulate the wave forces acting upon our scale model.

2.2.2 Stokes Wave theory: trochoidal waves

Stoked wave theory can be used for deep-, intermediate- and shallow-water waves.
It takes into account the effects of wave height on velocity and more accurately describes orbital velocity asymmetries present in the waves.

Although more accurate, it is mathematically far more complex and needs too many variables which are location specific and therefore not suitable for us to make a general representation which should apply in a various conditions.

2.2.3 Solitary wave theory: Solitary waves

The solitary wave theory takes into account an isolated crest moving in shallow water. The waves are assumed to be none oscillatory progressive waves (translatory), which are best used only to describe shallow-water waves. There is a possibility of the WSS to be used in shallow water locations, but as for now it is beyond our scope to apply two wave theories into our wave simulation, and thus we chose the more simple and most applicable airy wave theory.

2.3 WAVES GENERATION AND CLASSIFICATION

Ocean waves are undulations in the water's surface resulting from the transfer and movement of energy. The disturbance is propagated by the interactions of **disturbing** (e.g. wind) and **restoring** (e.g. gravity) forces. The energy in most ocean waves originates from the wind blowing across the water's surface. Large tsunami or seismic sea waves are generated by earthquakes, space debris, volcanic eruptions or large marine landslides. On the other hand, tides, largest of all ocean waves result from the combined gravitational force exerted on the oceans by the sun and the moon.

Waves can be classified according to whether the waves pass through the body of a material or move along an interface. Water waves are Rayleigh-type surface waves characterized by an orbital motion.

Wind is the most common disturbing force. Wind waves can be subdivided into capillary and gravity waves. An example of capillary waves (surface tension is the main restoring force) are the tiny ripples such as can be seen when blowing on a hot liquid to cool it. Gravity waves (gravity is the main restoring force) are much larger waves such as you see when going to the beach, taking a boat ride, or going swimming.

As the wind blows over the ocean surface, the pressure and stress deform the ocean surface into small rounded waves. These are called capillary waves because the dominant force that works to destory them and smooth the ocean surface is surface tension. Capillary waves characteristically have rounded crests and V-shape troughs.

As capillary wave development increases, the sea surface takes on a rougher character which allows the wind and ocean surface to interact more efficiently. As more energy is transferred to the ocean, gravity waves help in development with a shape more like that of a sine curve. The force of gravity then becomes the dominant restoring force. As additional energy is gained, the wave height increases more rapidly than wavelength, and the crests become pointed, while the troughs are rounded. Associated with increased height is an increased velocity, since energy imparted by wind increases the magnitude of both of these characteristics. When the wave velocity reaches that of the wind, neither of these characteristics can change because there is no net energy exchange, and the wave is at its maximum height.

Actually, all wind waves are covered with the smaller capillary waves, we simply don't perceive them. Which brings to the biggest waves of all; tides. Transtidal waves are generated by the pull of the moon and the sun as the disturbing force. Their major restoring force is Coriolis force due to the spinning of the earth. While capillary waves are often too small to notice, tides are generally too large, having a wavelength of up to one half the earth's circumference

For this project, we are only concerned with the forces of gravity waves, as the capillary waves are assumed negligible.

2.4 WAVE PARAMETERS

2.4.1 Wave length

The wave length is a term used to describe the horizontal distance between successive wave crests. Generally, wave lengths are quite difficult to measure. Among techniques used to measure wave length is by taking photos from an aeroplane or helicopter, and graphically measuring the wave length from the aerial photos.

Due to the high cost of the above, wave length is most commonly calculated from wave period (T)

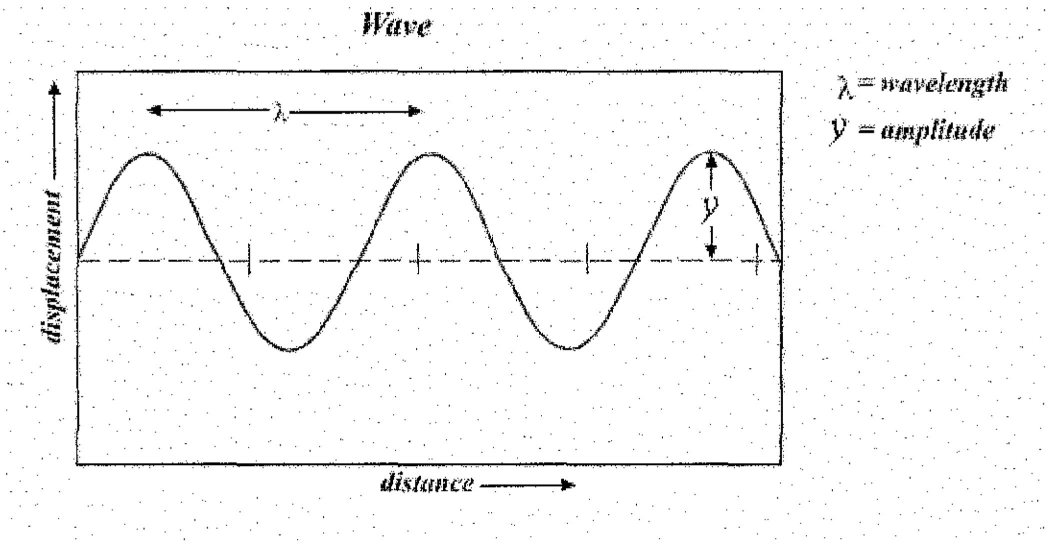
$$L = \frac{gT^2}{2\pi} \tanh r$$

Note: when d/L>.5, as for deepwater waves, tanhr approaches (2'd)/L, and when d/L<.5, as for shallow water waves, tanhr approaches 1

2.4.2 Amplitude

Amplitude is a nonnegative scalar measure of a wave's magnitude of oscillation, that is, magnitude of the maximum disturbance in the medium during one wave cycle.

In the following diagram,



the displacement y is the amplitude of the wave.

In ocean waves, the amplitude is the vertical distance between the crest or trough and the still-water level. (1/2H)

Wave amplitude is also more commonly known as wave height, and in deep water is equivalent to the diameter of the wave orbitals.

2.4.3 Period (T)

The period of a wave is the time the full wave takes to pass a given point. The period, T and the frequency f obey the following relation,

$$T = \frac{1}{f}$$

where f is the frequency of the wave, measured in inverse seconds (s-1 or hertz (Hz)) and T is the period, measured in seconds.

Since

$$v = f\lambda$$

where v is the wave speed, measured in metres/second (m/s) and λ is the wavelength, measured in metres (m), we have the following relation for T:

$$T = \frac{\lambda}{v}$$

As a matter of convenience, longer and slower waves, such as ocean surface waves, tend to be described by period rather than frequency.

It can also be described as the time (t) it takes for an entire wave (L) to pass a given point, T=L/t. In field measurement, the wave period is measured by timing the passage of 11 wave crests and divides by 10.

The wave period for the significant wave (highest 1/3) can be measured in the surf surf zone.

2.4.4 Frequency (F) - cycles or waves per unit time

Frequency is the measurement of the number of times that a repeated event occurs per unit of time. It is also defined as the rate of change of phase of a sinusoidal waveform.

To calculate the frequency of an event, the number of occurrences of the event within a fixed time interval are counted, and then divided by the length of the time interval.

In SI units, the result is measured in hertz (Hz), named after the German physicist Heinrich Rudolf Hertz. 1 Hz means that an event repeats once per second, 2 Hz is twice per second, and so on. This unit was originally called a cycle per second (cps), which is still used sometimes. Other units that are used to measure frequency include revolutions per minute (rpm) and radians per second (rad/s). Heart rate and musical tempo are measured in beats per minute (BPM).

An alternative method to calculate frequency is to measure the time between two consecutive occurrences of the event (the period) and then compute the frequency as the reciprocal of this time:

$$f = \frac{1}{T}$$

where T is the period. A more accurate measurement takes many cycles into account and averages the period between each.

Frequency has an inverse relationship to the concept of wavelength. The frequency f is equal to the speed v of the wave divided by the wavelength λ (lambda) of the wave:

$$f = \frac{v}{\lambda}$$

In the special case of electromagnetic waves moving through a vacuum, then v = c, where c is the speed of light in a vacuum, and this expression becomes:

$$f = \frac{c}{\lambda}$$

Note. When waves travel from one medium to another, their frequency remains exactly the same — only their wavelength and speed change.

2.5 FLOATING BREAKWATERS

The WSS is essentially a floating breakwater. An early and historical development in this area was the use of the "Bombardon" floating breakwater in World War II. Several of these steel structures in the shape of a Maltese Cross were arranged in two lines along the coast of France to aid the D-Day invasion in 1944. The controversial decision to use this floating breakwater was made after theoretical analyses and hydraulic model testing (Tsinker 1995). The "Bombardon" breakwater served its purpose to dissipate wave energy and provide shelter for invading troops during the critical initial stages of the invasion, until they failed due to an unexpected forty-year storm.

Over the years, many different types of floating breakwaters have been developed and many conclusions have been made. Some of the advantages of floating breakwaters include:

- Floating breakwaters are an economic alternative to fixed structures for use in deeper waters (depths greater than 20 feet) (McCartney 1985).

- Floating breakwaters can effectively attenuate moderate wave heights (less than about 6.5 feet) (Tsinker 1995).

- Poor soil conditions may make floating breakwaters the only option available (McCartney 1985).

- Floating breakwaters minimize the interference on water circulation and fish migration (McCartney 1985).

- If ice formation presents a problem, floating breakwaters can be removed from the site (McCartney 1985).

- Floating breakwaters are not obtrusive and can be more aesthetically pleasing than fixed structures (McCartney 1985).

- Floating breakwaters can easily be rearranged in a different layout or transported to another site for maximum efficiency (McCartney 1985).

2.5.1 Types of Floating Breakwater

The list of different types of breakwaters that have been modeled and/or constructed is quite long, but they can divided into four basic groups:

- Box
- Mat
- Pontoon
- Tethered float

Most box type breakwaters are reinforced concrete rectangular shaped modules. These structures have proved to be effective and have a 50 year design life. As our WSS is made of non reinforced ALC, this model cannot be used as comparison. The main disadvantages for these structures are that they are considerably more expensive than mat types and require higher maintenance. One restricting design parameter is the L/W (wavelength-to-breakwater width) ratio (McCartney 1985). As this value increases, the wave transmission coefficient, c_t, decreases. The wave transmission coefficient is the ratio between the wave height after the breakwater to the incident wave height.

Pontoon types include several different models, such as the ladder type, catamaran type, and the frame type. Pontoon types are generally less expensive than box types and have similar advantages and disadvantages of the box type. The L/W parameter must be controlled, as it was in the box type (McCartney 1985).
There are three types of tire mat breakwaters that have been used: Wave Maze, Goodyear, and Wave-Guard. The many advantages of the tire mat type breakwaters include low cost, simple construction, portability, low anchor loads, and greater effectiveness than box and pontoon types.

However, there are many serious limitations to the mat types, such as lack of buoyancy, 15-20 year design life, practical use for only moderate wave conditions (less than 3 feet high, 3-second periods), and easy accumulation of debris (McCartney 1985).

The last type of floating breakwater, the tethered float, can be considered most similar to our WSS, although at time of writing, the means of anchorage has not been finalised. Scaled prototypes of pile mooring and tethered version are currently being experimented. There is not a sufficient amount of prototype experience of these moored breakwaters to merit final conclusions.

2.5.2 Forces Acting Upon Floating Breakwater

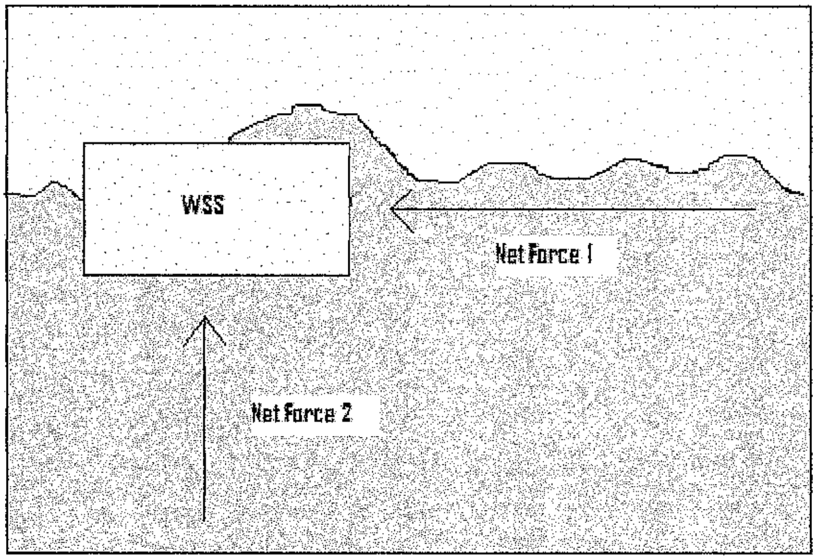


Figure 2.1

For this project, the net forces acting upon the WSS is only 2, as shown in the figure above. Net force 1 is due to the incident waves which we assume to be perpendicular and horizontal to the WSS. There will also by Net Force 2, an uplifting force caused by some of the incident wave going underneath the WSS colliding with reflected wave from the shoreline, creating a standing wave.

If the WSS uses the pile mooring system, or cables which will allow the WSS vertical movement, we assume the uplifting force would be very negligible. Even if the uplifting force is more than we assume, it should be considerably lesser than the horizontal force (Net Force 1) from the incident wave to an extend that the WSS will fail due to the horizontal force first. Therefore, for our wave simulation we ignore the uplifting force.

2.6 FATIGUE CRACK PROPAGATION

It has been fund from experience that most common failures of engineering strcutures are associated with fatigue crack growth caused by **cyclic loading**. Engineering analysis of fatigue crack growth is frequently required for structural design, such as Damage Tolerance Tool (DTD), and residual life prediction when n unexpected fatigue crack is found in a component of engineering structure. For analysis, the fatigue life of concrete structures can be divided into 2 parts:

1. crack initiation phase
2. propagation phase

An experimental investigation by Tohoku Institute Of Technology, Sendai Japan, on the behaviour of plain concrete subjected to low number of cyclic loadings revealed that even a limited number of cyclic loadings degrades the elastic modulus to values of 5% to 22% lower than that obtained from monotonically loaded reference concrete specimens.

Experimental results indicated that the elastic modulus was more sensitive to small changes in small changes in the loading history than was the compressive strength. The test procedures conducted were taken and adapted for this project's testing methodology.

2.7 THEORY OF PHYSICAL MODELS

2.7.1 Similitude

If a scale model is constructed such that all lengths in the model are in the same ratio to those in the prototype, then geometric similarity is achieved. The geometric scale is defined as the ratio of any length in the prototype to that of the scaled model.

Scale ratios for area and volume follow directly from the length scale ratio. However, to achieve complete similarity between model and prototype also requires similarity of motions (e.g. similarities of velocities and accelerations) and similarity of forces, which is know as dynamic similarity and is of significance importance to this project because we are trying to simulate wave forces on a scale model.

The scale ratios of various parameters are available below.

			Scale Factors	
Group (1)	Quantity (2)	Dimension (engineering units) (3)	Exact Scaling (4)	Gravity Forces Neglected (5)
Loading	Force, Q	F	$S_E S_l^2$	$S_E S_l^2$
	Gravitational acceleration, g	LT^{-2}	1	1
	Time, t	T	$S_l^{1/2}$	S_t
Geometry	Linear dimension, l	L	S_l	S_l
	Displacement, δ	L	S_l	S_l
	Frequency, f	T^{-1}	$S_l^{-1/2}$	S_t^{-1}
Material properties	Modulus, E	FL^{-2}	S_E	S_E
	Stress, σ	FL^{-2}	S_E	S_E
	Poisson's ratio, ν		1	1
	Density, ρ	FL^{-3}	S_E/S_l	Neglected

$$S_l = \frac{lp}{lm}$$

$$S_e = \frac{e_p}{e_m} = 1$$

If we are doing simulation in a wave flume, we had to employ the distorted froudian ratio due to the same viscosity of water for both scaled model and prototype. By right the fluid in the scaled model wave flume should have a proportionately lesser viscosity than water. But since we are using the Dynamic Actuator, we shall ignore the more complicated distorted Froudian ratio.

CHAPTER 3
PROJECT METHODOLOGY

A flow chart illustrating the general flow process of the project is included as figure 2 in the appendix. The following are the major steps that will be undertaken. Note that this project planning will be carried through to the next semester until the completion of this project. The project timeline can also be referred to as figure 3 in the appendix. The progress to date of the project is also illustrated in the timeline.

3.1 READING MATERIAL / INFORMATION RESOURCE GATHERING

Most of the reading material that will be used in this research will be from books, journals or reliable internet sources.

3.2 DEVELOPING TESTING PROCEDURES

The test procedures in this project are adapted from the cyclic loading test by M. Saichi and H. Shinohe of Tohoku Institute Of Technology, Sendai Japan in their research papers titled ELASTIC MODULUS VARIATION OF CONCRETE SUBJECTED TO CYCLIC LOADINGS.

3.3 TESTING PROCEDURES

3.3.1 **Maximum strength test.**

A full scale model shall be shall be placed under the dynamic tester, and load is applied. The applied load will be increased until the model fails. This will determine the maximum amount of load the model can withstand.

The maximum load is critical in determining the lifespan of the structure. For example, lets say the model has been tested to be able to withstand up to 25N/mm2. Through calculation this equates a wave of 4 meters in height. If the structure is intended to be used in a specific location A, wave statistics for that area is studied to determine the return period of a 4m wave. The return period of the maximum wave height is the lifespan of the structure for that particular location.

Objective

To determine the maximum strength of the scale model.

Equipment

Dynamic Actuator

Metal plate 1X

5 blocks of supplied autoclave lightweight concrete as specimens

Procedure

1. One piece of block shall be placed on the floor below the dynamic actuator.

2. A metal plate is fixed securely atop the specimen to ensure even load distribution.

3. The actuator is lowered down until it touches the block.

4. Using the computer software, the rate of loading is set at 2N per second.

5. The actuator is set to stop automatically at point of failure.

6. The specimen is loaded until to the point of failure.

7. Computer generated results shall be printed out and the force at point of failure is taken as maximum strength.

8. Step 1 to 7 is repeated for the 4 next specimens.

9. The average maximum strength from the 5 specimens is taken as the maximum strength.

10. Any value which is outside of a 90% confidence interval is considered erroneous, and the experiment shall be repeated with another specimen.

3.3.2 **Cyclic loading test**

Cyclic loading test will be conducted to mimic the effect of cyclical waves' impacts on the scale model. The test will be conducted on accelerated frequencies as opposed to the much longer actual wave periods due to time constraint as the dynamic actuator cannot be continuously operated for more than 24 hours. This forced us to make the assumption that the accelerated frequencies will not affect the scale model's actual resistant to actual wave frequencies.

Assumptions

1) The structure is static when being struck by the wave
2) Uplift force is negligible.

Objective

1. To determine the maximum number of cycles the scale model is able to withstand before failure at various loadings.

2. To develop the relationship between increased loadings and number of maximum cycles.

Equipment

Dynamic Actuator

Metal plate 1X

24 blocks of supplied autoclave lightweight concrete as specimens.

Procedure

1. One piece of block shall be placed on the floor below the dynamic actuator.

2. A metal plate is fixed securely atop and below the specimen to ensure even load distribution.

3. The actuator is lowered down until it touches the block.

4. Using the supplied software, the dynamic actuator is set at dynamic loading mode.

5. Frequency is set at 10 Hz

6. Level A loading is set at 0 KN
7. Level B loading is set at 90% of the maximum strength which was predetermined in the previous experiment.

8. The dynamic loading is set to automatically stop at the point of failure.

9. Computer generated results are printed, and number of cycles at failure is taken.

10. If the specimen did not fail after 4 million cycles, the dynamic loading is stop, and the specimen is loaded till failure.

11. Step 1 to 10 is repeated with 2 other specimens, and the average maximum cycles are taken.

12. Step 1-12 is repeated with 80%, 60%, 40%, 20%, 10% max strength.

13. A graph of max cycles versus percentage of maximum strength is plotted.

3.3.3 Corrected for Scale Values

Geomatric similitude is already achieved, as the supplied block is directly proportional to the planned prototype size.

Dynamic similarity is achieved by multiplying the force , frequency, dimension data with a scale factor:

			Scale Factors	
Group (1)	Quantity (2)	Dimension (engineering units) (3)	Exact Scaling (4)	Gravity Forces Neglected (5)
Loading	Force, Q	F	$S_E S_l^2$	$S_E S_l^2$
	Gravitational acceleration, g	LT^{-2}	1	1
	Time, t	T	$S_l^{1/2}$	S_l
Geometry	Linear dimension, l	L	S_l	S_l
	Displacement, δ	L	S_l	S_l
	Frequency, f	T^{-1}	$S_l^{-1/2}$	S_l^{-1}
Material properties	Modulus, E	FL^{-2}	S_E	S_E
	Stress, σ	FL^{-2}	S_E	S_E
	Poisson's ratio, ν		1	1
	Density, ρ	FL^{-3}	S_E/S_l	Neglected

3.4 RESULT EVALUATION AND DISCUSSION

The result will be evaluated, the durability of the ALC will be determined, the results accuracy shall be inspected for errors and anomalies, and relevancy and significance of the available data shall be discussed in further detail.

3.5 TOOLS REQUIRED

Only the Dynamic Actuator and a metal plate plus fixing bolts would be required for the whole experiment. However, as the dynamic actuator cannot be used for this semester as well, we had to use the smaller and unreliable Universal Dynamic Tester.

40 blocks of ALC will be required for the experiment, with allowance for errors taken into consideration.

3.6 CONCLUSION AND RECOMMENDATION

CHAPTER 4
RESULTS AND DISCUSSION

4.1 RESULTS

4.1.1 Maximum Compressive Strength Test (Experiment 1)

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average**
Force (kN)	57.44	[redacted]		57.34	57.88	57.55333
Pressure* (Mpa)	2.872	[redacted]		2.867	2.894	2.877667

*area of model surface subjected to pressure = 0.02m2

** Sample 2 and 3 were assumed to be erroneous, therefore were taken out from the average calculation

From this results the maximum force and pressure of the sample are set to 57kN and 2.85 Mpa respectively

4.1.2 Cyclic Loading Test (Experiment 2)

90% strength, 10Hz

	Sample 1	Sample 2	Sample 3	Average
Max no. of cycles before failure	1	1	5	2.333333
Total duration of experiment (hours)	0.00	0.00	0.00	0.00

Force (90%)	51.3	kN
Pressure (90%)	2.57	Mpa

For experiment 2, the 90% load were too high for the samples, failing almost immediately after the experiment began. Thus we can assume the ALC reached the plastic stage at around 90% of its maximum strength, hence the plastic deformation leading to failure when cyclic load were applied at that magnitude.

4.1.3 Cyclic Loading Test (Experiment 3to5)

Experiment 3: 80% strength, 10Hz

	Sample 1	Sample 2	Sample 3	Average
Max no. of cycles before failure	336653	300980	340290	325974.3
Total duration of experiment (hours)	9.35	8.36	9.45	9.05

Force (80%)	45.6	kN
Pressure (80%)	2.28	Mpa

Experiment 4: 60% strength, 10Hz

	Sample 1	Sample 2	Sample 3	Average
Max no. of cycles before failure	561760	532901	550250	548303.7
Total duration of experiment (hours)	15.60	14.80	15.28	15.23

Force (60%)	34.2	kN
Pressure (60%)	1.71	Mpa

Experiment 5: 40% strength, 10Hz

	Sample 1	Sample 2	Sample 3	Average
Max no. of cycles abefore failure	870650	913769	955460	913293
Total duration of experiment (hours)	24.18	25.38	26.54	25.37

Force (40%)	22.8	kN
Pressure (40%)	1.14	Mpa

Experiment 6: 20% strength, 10Hz

	Sample 1	Sample 2	Sample 3	Average
Max no. of cycles before failure	1453452	1558650	1426772	1479625
Total duration of experiment (hours)	40.37	43.30	39.63	41.10

Force (20%)	11.4	kN
Pressure (20%)	0.57	Mpa

For experiment 3 to 6, the samples showed first signs of cracking around halfway through the total number of cycles that they will eventually withstand before failing.

However, the first cracking, which can be fairly describe as hairline, does not propagate until right towards the end of their maximum cycles. By then the transition from crack propagation to failure is quick and abrupt, barely lasting more than 5 minutes or 3000 cycles.

4.1.4 Cyclic Loading Test (Experiment 7)

Experiment 7: 10% strength, 10Hz

	Sample 1	Sample 2	Sample 3	Average
Max no of cycles before failure*	[redacted]	[redacted]	[redacted]	[redacted]
Total duration of experiment (hours)	111.11	111.11	111.11	111.11
Remaining strength after 4 mil cycles (kN)	52.8	56.7	57.9	55.8

Force (10%)	5.7	kN
Pressure (10%)	0.285	Mpa

For experiment 7, all samples did not fail after 4 million cycles. All samples were then loaded till failure occurs, and the compressive strength before the failure were recorded as the remaining strength of the samples. As can be seen in the table above, all samples exhibit negligible reduction in maximum compressive strength even after receiving 4 million cycles of load 0.285 MPa. In fact, sample 3, at 57.9kN, shows a slight increase (maximum was determined in experiment 1 to be 57 kN) in the maximum compressive strength after 4 million cycles. However, the 0.9 kN extra could very well be a variation in quality of individual block. No cracking was observed during the cyclic loading tests either.

4.2 Conversion of results to full scale values

$$S_l = \frac{lp}{lm} = \frac{2.0}{0.2} = 10$$

$$S_e = \frac{e_p}{e_m} = 1$$

$$L_p = L_m \times S_l = 10L_m$$

$$F_p = F_m \times S_l \times S_e = 10F_m$$

$$fp = f_m \times S_l^{-1} = 0.1f_m$$

$$Tp = T_m \times S_l = 10T_m$$

Percentage maximum strength (%)	Loading Force on scale model (kN)	Loading Force on full scale prototype (kN)	Area subjected to loading on prototype (m2)	Pressure to scale model (Mpa)	Pressure to prototype (Mpa)
100	57	570	2	2.85	0.285
90	51.3	513	2	2.565	0.2565
80	45.6	456	2	2.28	0.228
60	34.2	342	2	1.71	0.171
40	22.8	228	2	1.14	0.114
20	11.4	114	2	0.57	0.057
10	5.7	57	2	0.285	0.0285

Table 4.1

	Scale model	Full Scale Prototype
Frequency (Hz)	10	1
Wave Period Equivalent (secs)	0.1	1

Table 4.2

4.3 Discussion

4.3.1 Strength of WSS after conversion to full scale

Table 4.1 shows that when converted to full scale, the WSS can theoretically withstand a maximum of 570 kN wave force. However, as the area is also bigger in the full scale model, we only expect it to withstand a maximum of 0.285 MPa, just $1/10^{th}$ the strength of the scale model.

It means a single wave with enough height to exert 570 kN will cause the WSS to fail in one single blow. A simplistic calculation shows that it takes a 5 meter wave to destroy the WSS, which sounds promising in our country where the waves rarely exceed 3 metres.

4.3.2 Estimation of WSS lifespan is real life condition based on wave period

However, our cyclic loading tests showed that the ALC is very weak when subjected to cyclic loading.

Wave Period (secs)	Wave Frequency (Hz)	No of cycles per year
1	1	31,536,000
2	0.5	15,768,000
5	0.2	6,307,200
10	0.1	3,153,600

Table 4.3 No of cycles in a year from various wave periods

% max strength	Estimated lifespan in 1 sec wave (years)	Estimated lifespan in 10 sec wave (years)
100	0	0
90	0	0.00
80	0.01	0.10
60	0.02	0.17
40	0.03	0.29
20	0.05	0.47
10	0.13	1.27

Table 4.4 Estimated lifespan of full scale WSS in real life conditions

The two tables above show that even at only 20% strength in a 10 second long wave, the WSS is estimated to last less than half a year. Only at 10% strength does the WSS shows some promise, as it could withstand a minimum of 4 million cycles without any reduction in strength. Due to time constraint, we are unable to conduct further test to determine when the WSS will fail when cyclic load is applied at 10% strength. At the current maximum 4 million cycles, the WSS at 10% is expected to last more than 1.3 years. Judging from the integrity to of sample after the 4 million cycles, it is fair to assume the WSS will last much more 1.3 years, although at only 10% strength, its usability is limited to coastal areas with very small wave height.

4.3.3 Relationship between applied cyclic load and maximum no. of cycles

% of max strength	max cycles
90	2
80	325,974
60	548,304
40	913,293
20	1,479,625
10	> 4,000,000

Table 4.5 Relationship between % of applied strength and maximum no. of cycles the WSS can withstand before failure

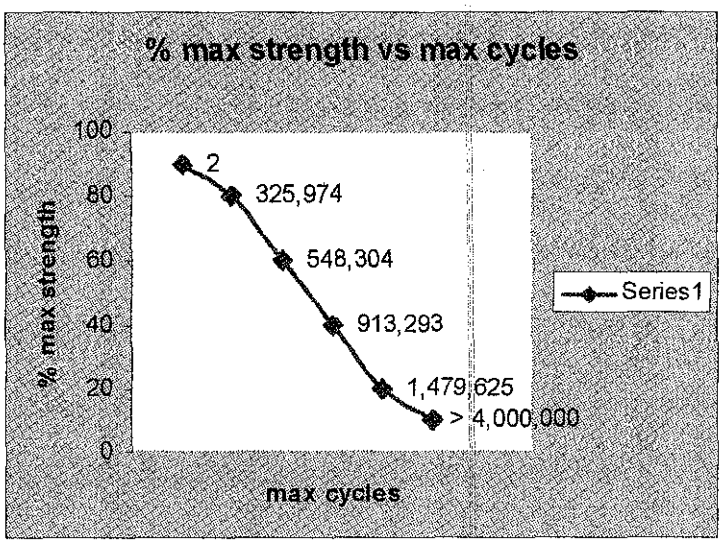


Figure 4.1 Graph of % max strength vs. max cycles

The above graph shows that from 80% to 20%, the maximum no. of cycles increase linerly with the decrease in applied cyclic load. The curve begins to flatten at 10%, indicating the possibility that fatigue is not an issue at 10% of maximum strength for the ALC material. However, further test must be done to confirm this, as the current test is only limited to 4 million cycles.

4.3.4 Errors and other problems encountered during experiments

The single most crippling problem that we faced was the problematically erratic behaviour of the Universal Testing Machine (UTM) that we use for both, maximum strength and cyclic loading test. The UTM was prone to hydraulic pressure lost prior and after each experiment, making conducting a series of experiments back to back a virtual impossibility. The cause of the weird pressure lost was still not identified at the time of writing.

The UTM also experience sudden hydraulic pressure surges, often in the middle of the cyclic test, which results in the immediate complete destruction of the sample on test at that particular time. As the duration of each cyclic test takes days to complete, the surges wasted a lot of time since we have to start the experiment form the beginning with new samples.

The accuracy of the UTM both in terms of load application and data reading is an unknown, as we have no control experiments to test it. Huge variations between samples are thus may be due to the inconsistent quality of the ALC block or maybe the accuracy of the UTM itself.

The ALC is also extremely soft, which requires very careful cutting via the diamond cutter.

4.3.5 Summary of weaknesses and strengths of ALC as material for WSS

Strengths

1. Higher quality control because it is precast in the factory under control environment.
2. Density of 600kg/m3 suits WSS requirements
3. Should allow faster installation.
4. Could be cheaper than conventional fixed breakwater.

Weaknesses

1. Very low strength. Could only withstand maximum of 0.285 MPa and only 10% of that reliably for extended period.
2. Only applicable in very low wave height. A big storm will likely fail it.
3. Unconfirmed anchoring methods. Highly possible that the ALC will fail at anchoring joints/points due to its very weak strength.
4. Needs steel reinforcement to make it stronger and more usable. But adding steel will increase its density beyond the required 600kg/m3 that it currently sits spot on.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From our experiments, we conclude the following:

1. The ALC has a very low maximum compressive strength of 2.8MPa, and 0.285 MPa when converted to full scale, which makes it usable only in areas of very low wave and storm free.
2. The ALC also has very low cyclic load resistance. From the results it will last less than 6 months in a 10 second wave period with wave forces never exceeding 20% of is maximum strength. Shorter wave periods or high wave forces will give a far worse result.
3. ALC showed commendable cyclic resistance when subjected to a cyclic load 10% of its maximum strength as it did not fail after the 4 million cycles limit of our experiment. The remaining strength after the 4 million cycles shows no noticeable reduction. Thus it is very possible its actual maximum cycle is far more than 4 million.
4. However, since the strength at 100% is already low, 10% strength renders it practically useless in real life condition. Thus we conclude the ALC in its present specification is not suitable for use as material for WSS.

5.2 Recommendation

1. Find other materials for WSS, possibly plastics or other more elastic and stronger materials.

2. Recommend the testing and scale conversion method to future FYP students doing any type of cyclic loading, especially involving scale models. It will give them a head start and save a lot of time looking for literature reviews just to understand the nature and purpose of cyclic loading test.
3. Although in the conclusion we deem the ALC is not suitable for WSS use, it still has potential in other areas, especially if reinforced. Further studies should be done regarding the behaviour of reinforced ALC under cyclic load. No data relating to any cyclic test from the manufacturer suggests that the behaviour of ALC under cyclic loading has yet been studied, and a thorough search in the internet reinforces this notion. Even among UTP FYP students, according to the technicians, the UTM and dynamic tester were rarely used for cyclic loading tests.
4. Cyclic loading tests are long as the cycles are done in millions, and take weeks to complete 1 experiment for 1 sample using 1 machine. If a comprehensive and conclusive set of data is to be produced, perhaps the experiments can be done by more than 1 student in a joint FYP project. UCITY can also take part in the experiments, becoming the first academic club to do academic activities instead of just organising dinners and trips and family days.

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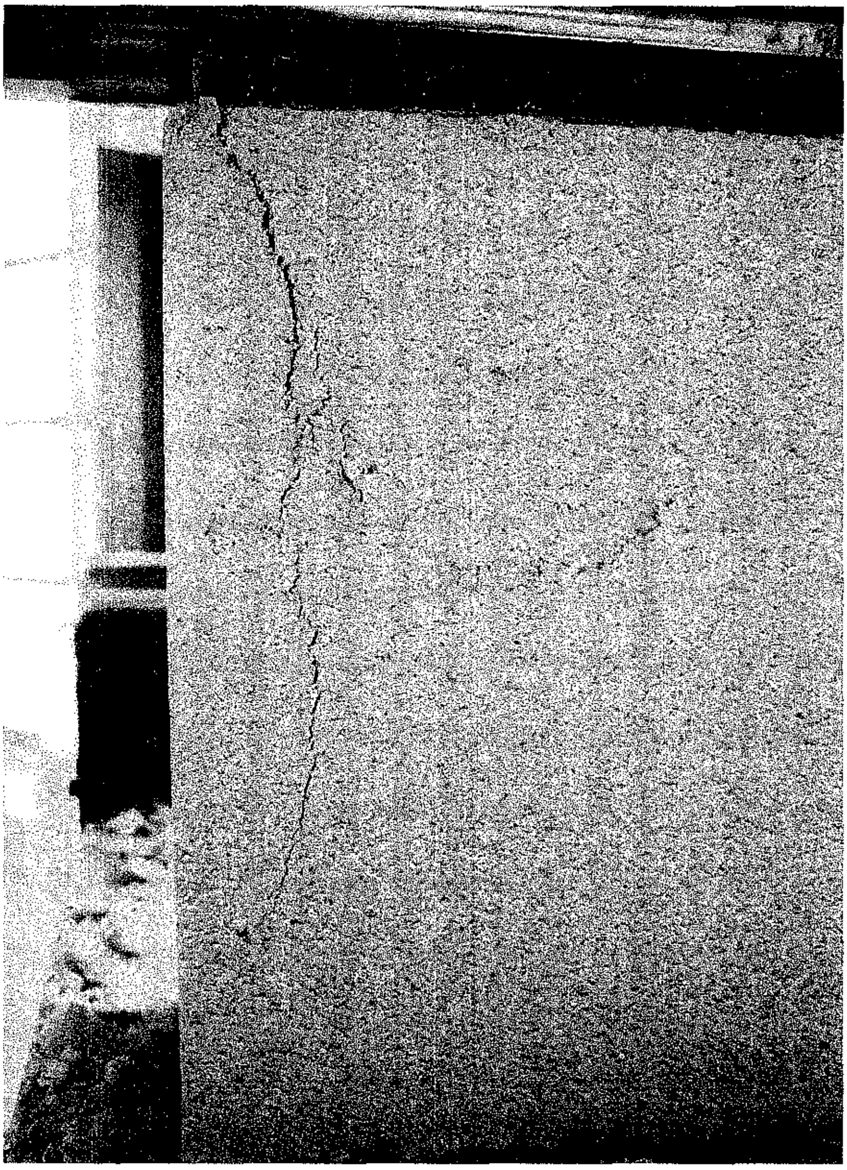
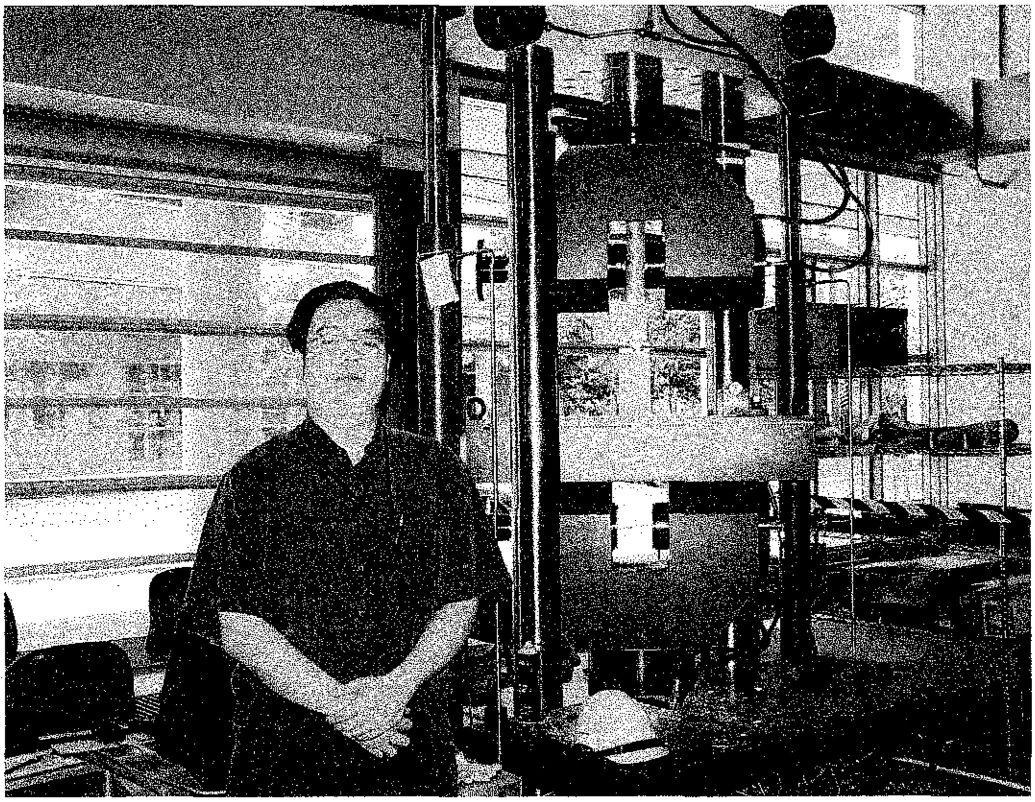
APPENDICES





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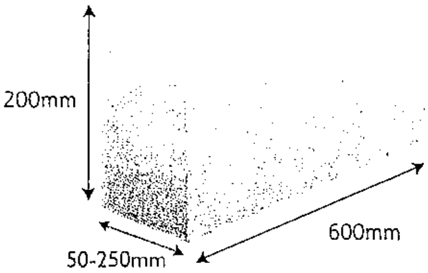


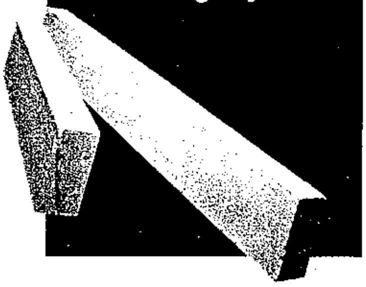
CSR Building Materials (M) Sdn Bhd is a subsidiary of CSR Limited, Australia's leading manufacturer and supplier of building products with operations throughout Australia, New Zealand and Asia.

CSR Building Materials (M) Sdn Bhd's ALC Division produces ALC (Autoclaved Lightweight Concrete) products such as blocks, reinforced panels, lintels, mortars, tools and accessories for use in housing, commercial and industrial construction.

ALC has been available in Malaysia since the early 90's and has been used in Europe for over 60 years. Today, the product is extensively used throughout the world.

ALC has won wide acceptance as an innovative building material due to its speed of construction, excellent thermal properties and ability to provide for versatility in design.

Components Of The CSR ALC Building System



CSR ALC Blocks

CSR ALC blocks can used for external and internal load-bearing and non load-bearing walls.

The blocks are produced with a nominal face dimension of 600mm x 200mm and in a thickness range of 50-250mm *(25mm increments)*. There are 8.33 blocks per square meter of wall area.

Due to their dimensional accuracy, the blocks are easily laid in CSR ALC Thin Bed Adhesive with 2-3mm joints. The first course is laid in regular mortar to take out irregularities in the slab. A DPC is required between the slab and CSR ALC blocks on the ground floor and in wet areas. It is essential that the first course is laid accurately so that speed is achieved in subsequent courses. Subsequent courses are then glued together using thin bed adhesive. This method makes for rapid and easily constructed walls. Wastage is minimized as blocks can be cut to size using a tungsten tip handsaw.

Block Properties

Property	Value	Units
Length	*600*	*mm*
Height	*200 or 400*	*mm*
Thickness	*50 - 250*	*mm*
Nominal Dry Density	*490*	*kg/m³*
Working Density Range	*495 - 650*	*kg/m³*
Compressive Strength, f'_c	*2.8*	*MPa*
Minimum Compressive Strength, f'_m	*2.5*	*MPa*
Modulus of Elasticity, E	*1500*	*MPa*
Modulus of Rupture, f'_{ut}	*0.44*	*MPa*
Ultimate Tensile Strenght, f'_{mt}	*0.44*	*MPa*

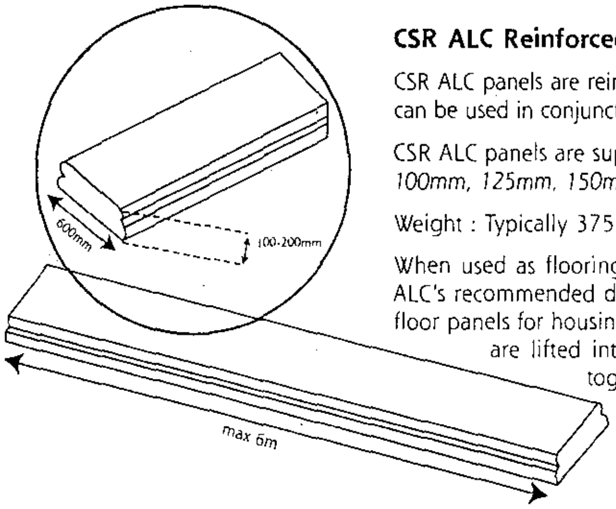
Notes:

1. *All dimensions and densities are nominal, for actual dimensional tolerances, please refer to the CSR ALC product specification.*
2. *The product characteristics listed in the above table are based on testing carried out by CSIRO (in Australia and recognised in Malaysia) and SIRIM.*
3. *400mm high blocks available in 100mm blocks only on special order.*
4. *Block thicknesses available in 25mm increment from 50mm to 250mm.*
5. *Modulus of rupture refers to the tensile strength in flexure of a single masonry unit, whereas ultimate tensile strength refers to the tensile strength of several masonry units bonded together.*

CSR ALC carries a stock of standard block sizes as shown in the following table. It is recommended that these standard sizes be used whenever possible to facilitate quick deliveries. If non-standard sizes are required, allow additional time for production and delivery.

CSR ALC Standard Block Size Range

Product Code	Standard Nominal Length *(mm)*	Standard Nominal Height *(mm)*	Nominal Block Thickness *(mm)*	m² per pallet	No. of pieces per pallet
62100	600	200	100	21.60	180
62125	600	200	125	17.28	144
62150	600	200	150	14.40	120
62200	600	200	200	10.08	84



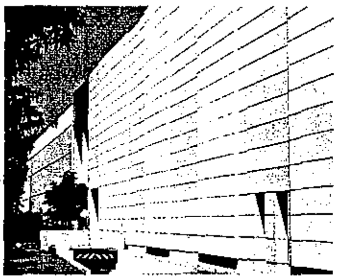
CSR ALC Reinforced Panels

CSR ALC panels are reinforced load bearing panels used for floors, walls or roofs. Panels can be used in conjunction with ALC blocks to provide a total load bearing system.

CSR ALC panels are supplied in the following thicknesses:
100mm, 125mm, 150mm, 175mm & 200mm.

Weight : Typically 375kg per 6m long panel, 150mm thick.

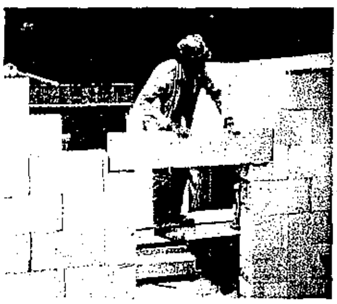
When used as flooring, the thickness of the slab should be in accordance with CSR ALC's recommended designs taking into account the required span and load. Typical floor panels for housing are 150mm in thickness with maximum span of 3.7m. Panels are lifted into position one by one using a crane. The panels are butted together, joint reinforcement on spacers are installed and mortar is then poured to form the ring anchor system. Ensure that the reinforcement has adequate cover around it.



Panel Properties

Property	Value		Units
	Floor	Wall	
Length	0.6 - 6.0	0.6 - 6.0	m
Width or Height	300 - 600	300 - 600	mm
Thickness	100 - 200	75 - 200	mm
Nominal Dry Density	550	550	kg/m³
Working Density Range	780 - 820	780 - 820	kg/m³
Compressive Strength, f'_c	3.5	3.5	MPa
Modulus of Elasticity, E	2190	2190	MPa

Notes:
1. *All dimensions and densities are nominal, for actual dimensional tolerances please refer to the CSR ALC product specification.*
2. *The product characteristics listed in the above table are based on testing carried out by CSIRO (in Australia and recognised in Malaysia) and SIRIM.*
3. *Panel thicknesses available in 25mm increment from 75mm to 200mm.*
4. *Panel length and width can be varied increments of 10mm.*



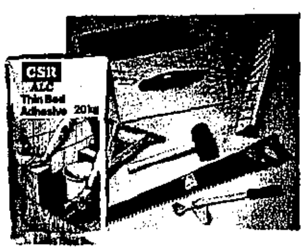
CSR ALC Lintels

CSR ALC lintels are available in a range of sizes to bridge common sized openings for doors and windows. Since they are constructed out of the same material as CSR ALC blocks and panels, the wall remains a homogenous unit and surfaces are easily finished.
CSR ALC lintels are designed for a minimum of 200mm support at both ends with a maximum span between supports of 3000mm. CSR ALC Technical Department will advise on the appropriate lintel for the required application.

Lintel Properties

Property	Value	Units
Nominal Dry Density	600	kg/m³
Working Density Range	780 - 820	kg/m³
Compressive Strength, f'_c	5.0	MPa
Modulus of Elasticity, E	2190	MPa

Notes:
1. *All dimensions and densities are nominal, for actual dimensional tolerances please refer to the CSR ALC product specification.*
2. *The product characteristics listed in the above table are based on testing carried out by CSIRO (in Australia and recognised in Malaysia) and SIRIM.*

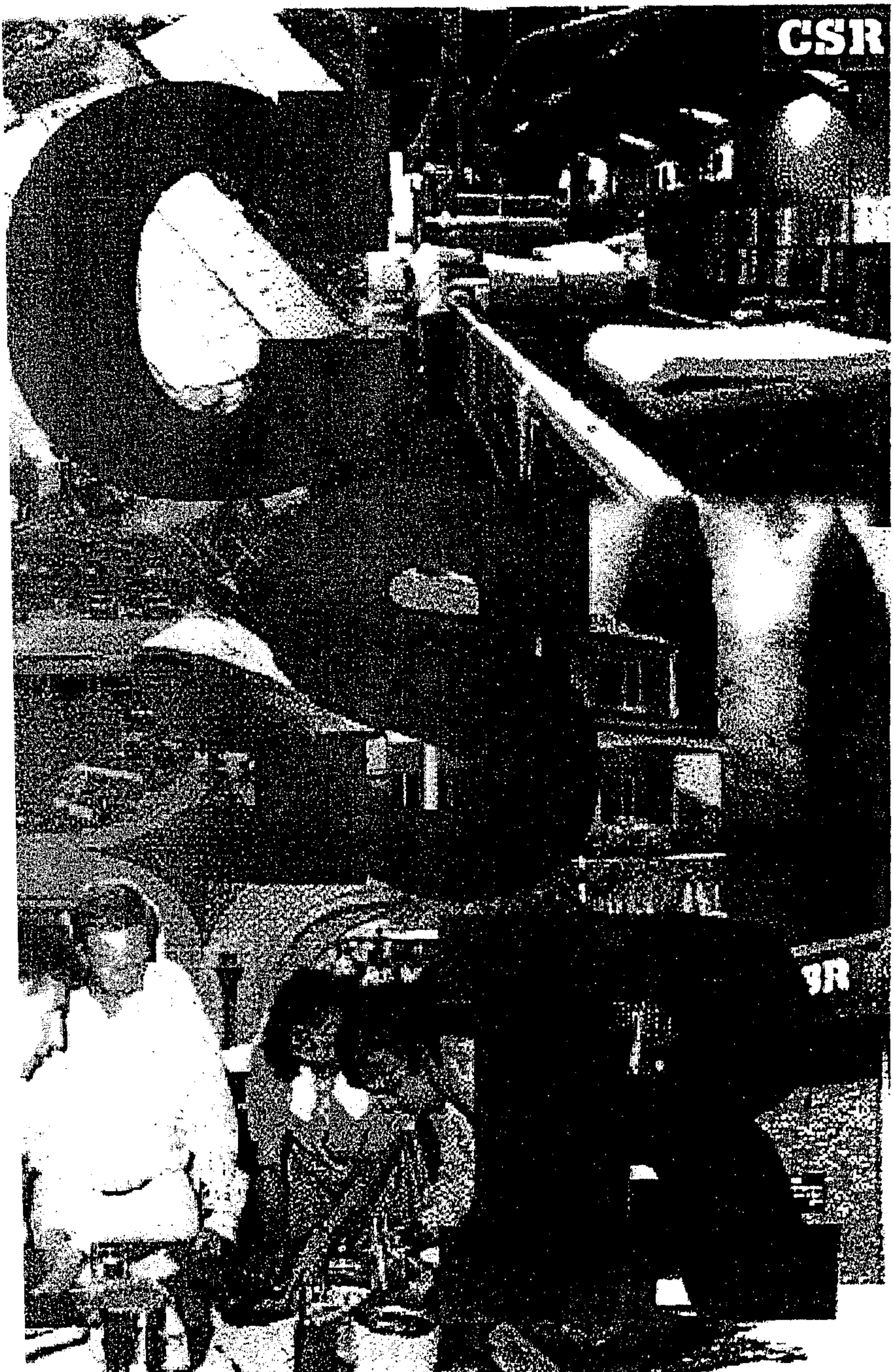


Mortars, Tools and Ties

CSR ALC provides a range of tools, mortars and ties which have been designed for use with its products.

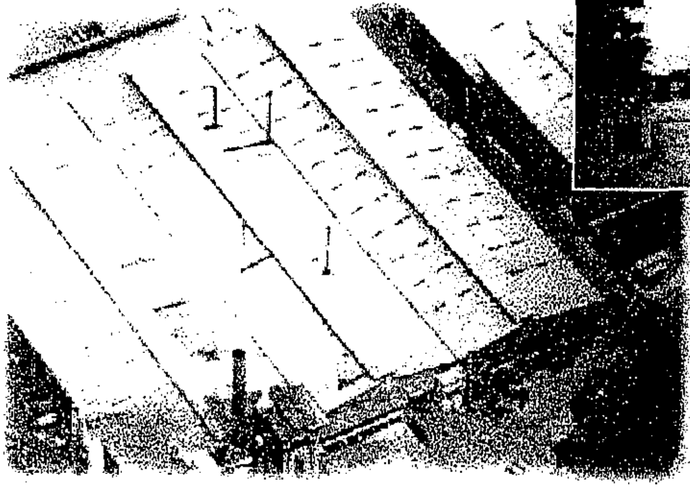
CSR™
Building Materials

Company Profile


CSR

The CSR Foundation

The history of CSR began in 1885 when it was founded in Australia. We started manufacturing construction and building materials in 1936. We are the market leader in Australia and North America, and one of the largest manufacturers of construction and building materials in the world. Today, CSR is a Fortune 500 company that is well diversified and has substantial investment in profitable industries like sugar, timber and aluminium in Australia.



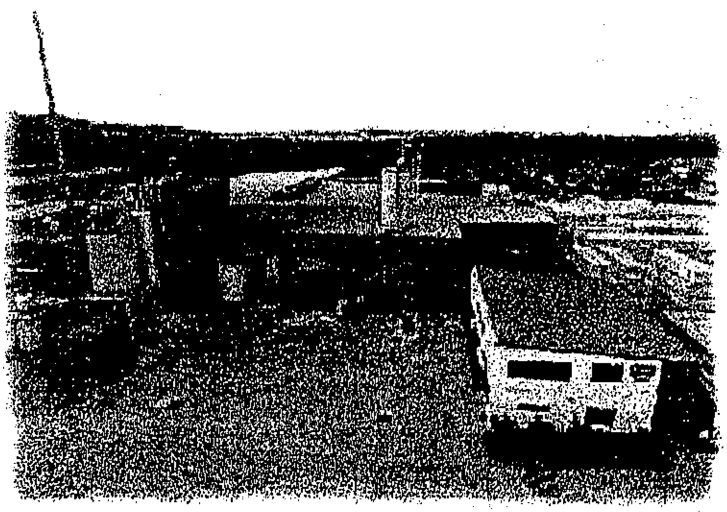
BM's Rockwool & Glasswool plants in Bukit Raja, Klang, Selangor

We employ over 23,000 employees in 13 countries with annual sales averaging at A$6 billion per annum. In terms of profitability, we have been paying dividend to our shareholders every year since our incorporation as a public company.

The new business paradigm of globalization has brought us to a few selected high growth markets in Asia. We now have businesses in Malaysia, Taiwan, Singapore, Thailand, China and Indonesia.

In Malaysia, CSR Building Materials (M) Sdn Bhd ("CBM") is a joint venture company between PFM Capital Holdings, a subsidiary of Permodalan Nasional Berhad and CSR Ltd., Australia. CBM was originally established in 1981 to manufacture rockwool insulation materials for the Asian market.

The product line has since proliferated to include glasswool and autoclaved lightweight concrete ("ALC") products. The latest addition to CBM is CSR Climate Control, which handles the contracting and home insulation part of the business.



ALC factory in Senawang, Negeri Sembilan

CSR

Mission Statement

"By Redefining what is possible,

we build our Pride and Energy

to become World Class".

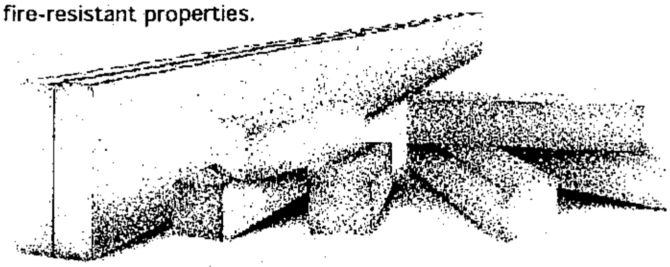
BENEFITS

Our 3 Pillars Of Strength

Autoclaved Lightweight Concrete ("ALC")

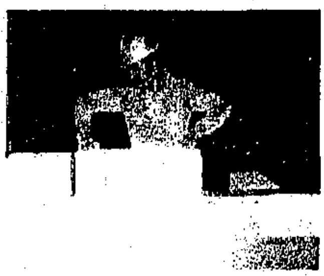
Our CSR ALC Division offers a total system approach to building and construction with its Autoclaved Lightweight Concrete ("ALC") products, accessories and services. ALC is extremely popular in Australia, Europe, Asia and the Middle East and is fast gaining acceptance in the Malaysian construction and building industry because of its speed of construction and versatility in design. The finished product is only one fifth the weight of regular concrete and has good insulation, acoustic and fire-resistant properties.

CSR ALC is designed for walls, floors and roofs applications and is available in various sizes for different requirements.



CSR ALC is a mix of sand, lime and cement together with a gas-forming agent. This combination of raw materials are then poured into moulds, cut and cured under pressure in an autoclave. Reinforced panels and lintels utilise corrosion protected steel reinforcing mesh to increase product durability.

Weld Tower



Block Laying

All these processes are undertaken in CSR's ALC state-of-the-art manufacturing facility in Senawang, Negeri Sembilan, which was commissioned in August 1995. This ALC factory sits on a 30,000 square meter site and has a capacity to produce approximately 130,000 cubic meters of CSR ALC Blocks, Panels and Lintels annually.

CSR ALC products consist of:

* CSR ALC Blocks are produced in a face dimension of 600mm x 200mm and a thickness range of 50mm 250mm for use in internal and external, load bearing and non- load bearing walls. CSR ALC Blocks can be used for single skin external or internal walls, as an internal lining with external face brick or as a veneer construction on timber or steel studs.

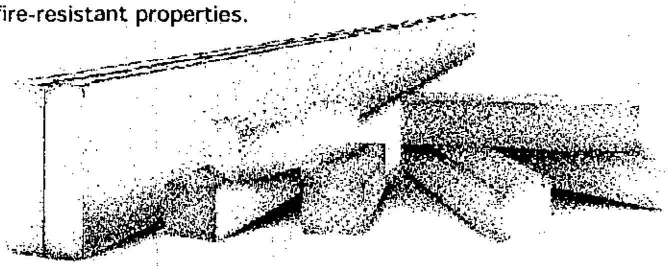
BENEFITS

Our 3 Pillars Of Strength

Autoclaved Lightweight Concrete ("ALC")

Our CSR ALC Division offers a total system approach to building and construction with its Autoclaved Lightweight Concrete ("ALC") products, accessories and services. ALC is extremely popular in Australia, Europe, Asia and the Middle East and is fast gaining acceptance in the Malaysian construction and building industry because of its speed of construction and versatility in design. The finished product is only one fifth the weight of regular concrete and has good insulation, acoustic and fire-resistant properties.

CSR ALC is designed for walls, floors and roofs applications and is available in various sizes for different requirements.



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Insulation Materials

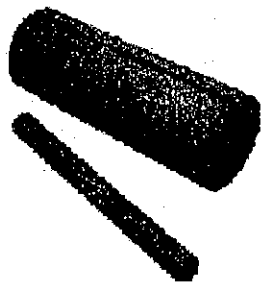
Rockwool

CSR Rockwool insulation as the name suggests, resembles wool but is made from rock. The most suitable raw materials are limestone and basalt. However, other forms of material such as blast furnace slag can also be used.

The rocks are melted in a furnace using coke as fuel at approximately 1300 degree Celsius and then molten lava is fiberized by the use of four water cooled spinning wheels. The fibers are then coated with a thermosetting binder which, when heat cured, bonds the fibers into a mat. The mat is then cut into suitable sizes for packaging.

Rockwool production plant

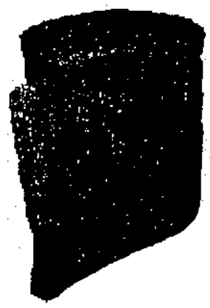
CSR Rockwool products are produced to cover the temperature range from -240 to +820 degree Celsius. In addition to its excellent thermal properties, the open fibrous nature of CSR Rockwool enables it to be widely used for acoustic control.



Fibertex Sectional Pipe Insulation

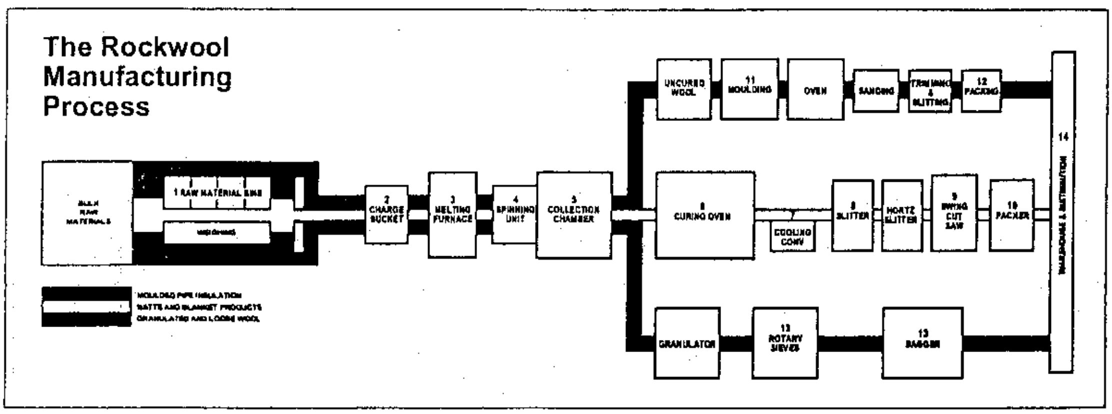
CSR range of Rockwool products can be divided into 4 broad product groups:-

- ☆ Fibertex Batts and Blankets
- ☆ Fibermesh Wirefaced Flexible Blankets
- ☆ Fibertex Sectinal Pipe Insulation & V-Lock
- ☆ Fibertex Loose (Loose & Loose CR)



Fibermesh Wirefaced Flexible Blankets

The range of products produced by CSR Rockwool covers all applications in the power generation, industrial, building, air handling, acoustic and fire protection markets.



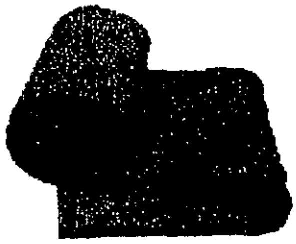
CSR

QUALITY SYSTEM

SIRIM

Rockwool was accredited in 1992.

Glasswool was accredited in 1993.

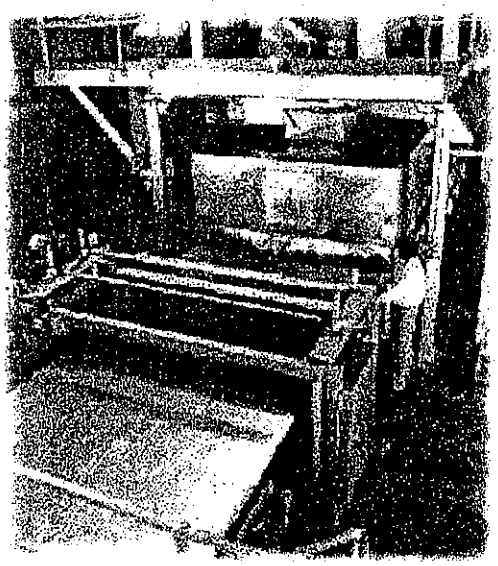


Fibertex Blanket

Thermocon

CSR Thermocon Computer Programme provide solutions to simplify the complex and time consuming equations in calculation of E.T.I. (Economic Thickness of Insulation), CSR has developed the "Thermocon" computer programme. This programme provides a clear output showing minimum annual cost or maximum nett present value for a range of E.T.I. as well as estimates of total installed cost, of insulation, and calculated energy savings.

Glasswool



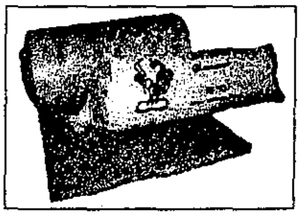
Glasswool production plant

CSR Glasswool is used in providing thermal and acoustic insulation. In air- handling systems,it can be used for air conditioning ducting, hot water tanks, storage tanks and process vessels.

CSR produces 2 types of Glasswool insulation material:

- ✯ Tuffskin Glass Rigid
- ✯ Tuffskin Glasswool Blanket

Tuffskin Glasswool Ridig



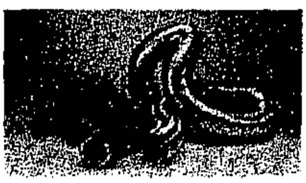
Tuffskin Glasswool Blanket

Other Accessories

In addition, CSR distributes a range of insulation accessories such as Thermofoil Aluminium Foil (CSR Australia), Flexible Air Handling Ducts (CSR Singapore), roof mesh, aluminium, etc.

Thermofoil 731

Thermofoil 730 Perforated



Flexible Ducts

CSR

CSR Home Insulation- CSR "Climate Control (M) Sdn Bhd"

Keep your house cool with rockwool, on your ceiling under your roof

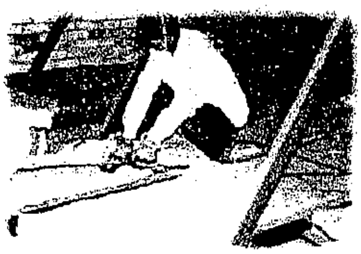
Control your own Climate - come home to a cool Home

Home Insulation has been used in temperate countries like England and Australia for over a century to save energy on heating and cooling and maintaining a comfortable home temperature.

After extensive testing and close collaboration with the University of Malaya, CSR Climate Control is proud to be the first MNC to offer a domestic Professional Home Insulation service. No fuss, no mess. We can give a normal double storey link house the same quality heat protection treatment that we provide to factories, power stations and office buildings - under the roof of your very own house and at an affordable price. Its cheaper than installing an extra air-cond.

We have insulated hundreds of houses all over Klang Valley, Melaka, Ipoh, Johor and Penang with excellent results. House owners have experienced as much as 50% savings off their air-cond bills. Some non air-cond homes have enjoyed such a cooler bedroom temperature that the owners have decided against installing an air-cond.

Suspended Ceiling



Normal Flat Ceiling

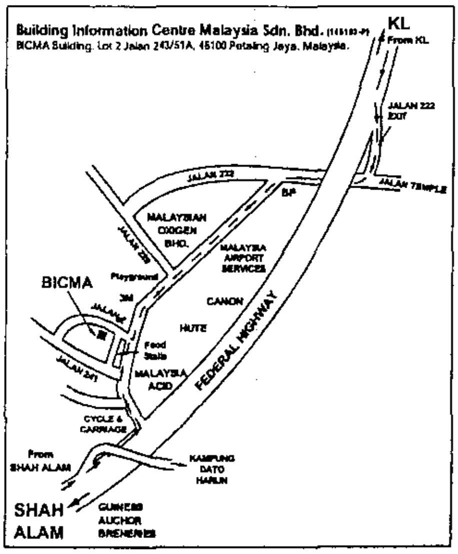
You have to feel it to believe it. Call us to find out what a difference Rockwool Ceiling Insulation makes to your home. Look after your family. Give them a cool home with Rockwool Insulation - on the ceiling under your roof.

We also supply Thermofoil Aluminium Foil, Roof Turbine Ventilators and Solar Reflective Film for windows.

For more information and customer service, please contact our Home Insulation Toll Free line:-

1800 - 880204

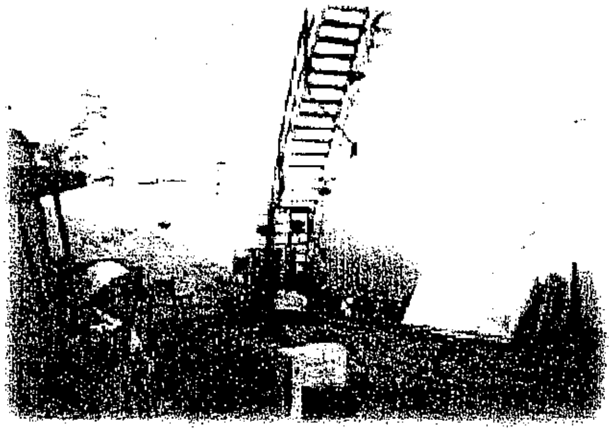
You are also invited to visit our permanent exhibit at the BICMA showroom at Jalan 223 to experience the difference Rockwool Insulation can do to your home.



CSR

CSR Industrial Insulation - CSR "Climate Control (M) Sdn Bhd"

Sales and engineering division



Thermaclad

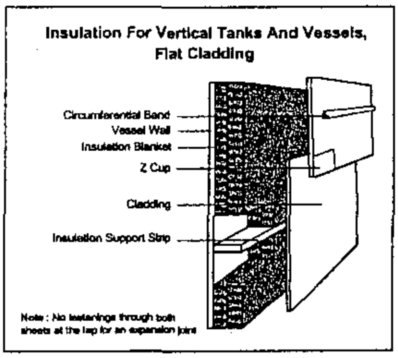
Experts in Industrial and Commercial Lagging Work

No job too small or too big for us to tackle. With over 15 years of experience in Malaysia, Thailand, Indonesia and Sri Lanka; we have the skills and confidence to provide you with the best quality workmanship and finish.

Elbows, valve boxes, pipes, tanks and ducting - there is no shape that our skilled fabricators cannot cut and fabricate a cladding that will give your equipment weather proof protection.

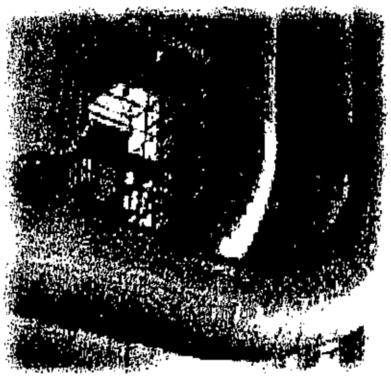
Our expertise goes beyond just labour and material supply. We can advise and consult on operating temperatures and heat loss calculations, personal safety from burns and scalds, fire proofing and acoustic performance where noise is an occupational hazard.

Some of our reference projects include Port Klang Kapar Power Stations, storage tanks for Shell and Petronas, Oilfin Paper Mills, power plants, insulation of dry cavity wall systems, and even sound treatment for church halls.



We are able to work on a wide range of insulation products like Rockwool, Glasswool, calcium silicate ceramic fibre, foam glass, and a whole range of cladding materials. Sectional Piping Insulation is another one of our specialty.

Thermaclad is a patented system of interlocking panels that are customized for round storage tank skins. This is our own in-house design and fabricated cladding system to give you a world class cladding over your insulation barrier. We have used this system on storage tanks in Singapore and Port Dickson for Shell.



Piping

For more information and customer service please contact:-

Contracts Manager

Tel: 603-341 3444, Fax: 603-342 3142

Project References

ALC

Some of our past achievements can be seen in the numerous projects that we vere involved in.Below are some of the major projects hat we have secured:

UKM Hospital, Kuala Lumpur

MALAYSIA

- Kuala Lumpur International Airport, Sepang
- Syquest Technology Factory, Penang
- Taman Bukit Nibong, Malacca
  (29 units of load bearing bungalows)
- Taman Air Biru, Johor
  (75 units of load bearing link houses)
- Hospital UKM, Kuala Lumpur
- Weld Tower, Kuala Lumpur
- Marriot Hotel, Kuala Lumpur

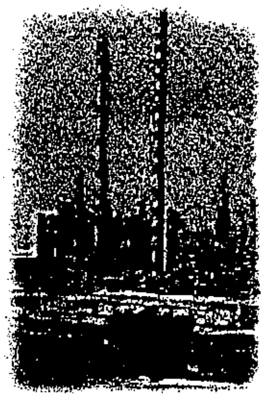
29 units of 1 1/2 storey bungalows in Malacca

Project References

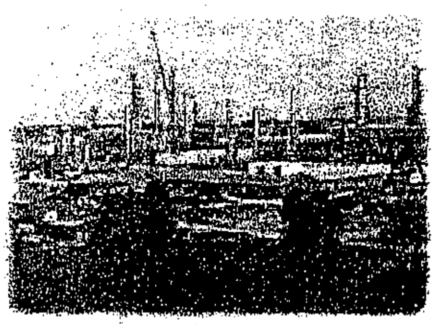
NSULATION MATERIALS

ae Moh Project, Thailand

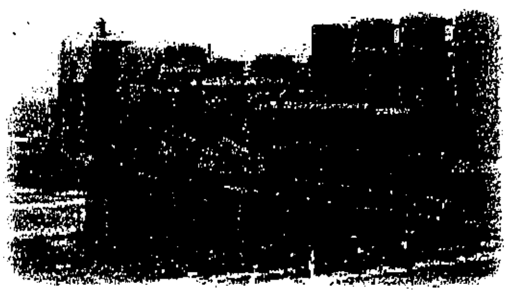
KL City Centre (KLCC), Malaysia



NPC Project, Thailand

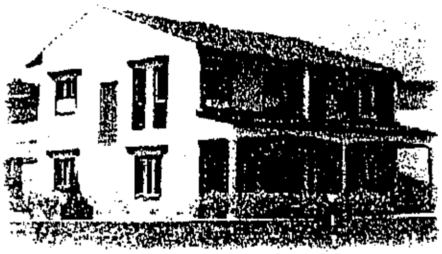


PSR2 Malacca, Malaysia



Indah Kiat Pulp Project, Indonesia

CSR



Double storey link houses in Senawang, Seremban

Double storey bungalows in Damansara Heights

and Insulation Materials divisions are involved in
truction work and supplying of building materials to
ultra-modern Kuala Lumpur International Airport,
ng. CSR ALC Blocks, Panels & lintels were used in
onstruction of all internal & external masonry walls
e Main Terminal Building, Satellite 'A' Building and
act Pier. It was also extensively used in the MAS
o, MAS Advanced Cargo Centre, Short Term Carparks
KLAS (Kuala Lumpur Airport Services) Centre.

Rockwool also contributed to the
truction of KLIA in terms of supplying insulation
rials to be incorporated into the roof and ceiling of
ral main buildings of KLIA.

MALAYSIA

- ★ Kuala Lumpur International Airport, Se pang
- ★ Kuala Lumpur City Centre, Kuala Lumpur
- ★ Petronas Second Refinery (PSR2), Malacca
- ★ Malaysian Liquidified Natural Gas, Bintulu
- ★ Port Klang Power Station (Phase 1 & 2), Selangor

SINGAPORE

- ★ Tuas Incinerator
- ★ IHI/Pulau Seraya Power Station
- ★ Senoko Incinerator
- ★ SHELL Tanks
- ★ Singapore Aromatic Plant

INDONESIA

- ★ Formosa Plastic Project
- ★ Indorama Project
- ★ Indah Kiat Pulp Project
- ★ Cement Nusantara
- ★ KMI-METHANOL Project

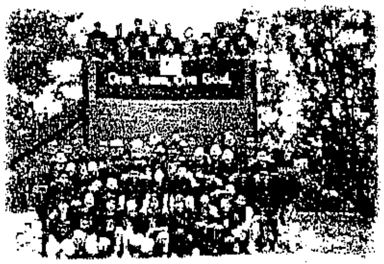
Thailand

- ★ NPC Project
- ★ Mae Moh Project
- ★ Thai Lube Base Oil Project

People Power - The CSR Way

Training and Development is a key element to help people find success and have pride in their work. We can greatly assist in energising our people by supporting them with effective tools and skills. CSR has undertaken many training and development projects for skill enhancement of its employees. Some of them are as follow:

BIQ Training (Building In Quality) - This is the basic training that all employees are required to undergo, the objective is to instill in them the Quality culture. The BIQ training besides other things, trains employees on how to use Measurement tools in their daily work, teaches the importance of Customer - Supplier relationship, Problem Solving methods and others.



One Team One Goal (OTOG) - The word OTOG just like BIQ, has become a household name at CSR. The OTOG training is a team building experiential training conducted for all employees right from the factory floor, office staff and up to top management level. The objectives of this training are to:

- ☆ understand CSR values and how these values guide our everyday decisions and behaviours.
- ☆ understand the value of working in teams, including how to create more effective teams.
- ☆ learn the CSR Leadership Behaviours plus the application of these behaviours.

Managing For Results - This is one of the latest training programs being introduced; the objective being to give our front-line Supervisors/Managers the necessary knowledge, understanding and skills to carry out his/her job. It is intended, over time, to result in behavioural changes in the way our Supervisors/Managers manage their responsibilities.

Competencies Identification - Competencies are descriptions of skill levels and behaviours displayed when undertaking work tasks. In today's competitive and dynamic environment, an organisation's ability to compete depends to a large extent on its core competencies. Assessments of employees' competencies levels were carried out in order to gauge at what level they currently stand and from there on to identify what the gaps are and subsequently coming up with a development plan to address these areas of improvement. The developmental plan can include both developmental assignments and formal training program. These Competencies Identification process carried out at CSR forms a part of Managerial Training Needs Analysis. We believe that CSR's commitment to Training and Development will bring it a step closer to becoming a 'World Class' company.

Across The Causeway - CSR S.E.A

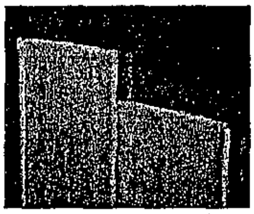
Welcome to CSR South East Asia Pte Ltd

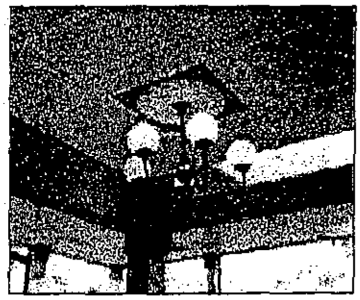
Our presence in Singapore is represented by CSR South East Asia Pte Ltd which was established in 1988. It enables efficient and cost effective distribution of a wide range of our building materials throughout the Asian countries.

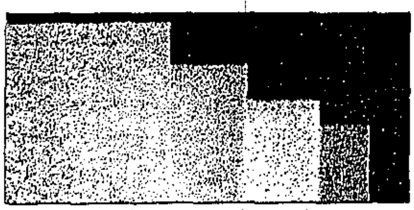
Today, our operation in Singapore is driven by a 80,000 square feet factory cum warehouse. A decade of presence and continual growth has made CSR South East Asia Pte Ltd a trusted name in building material supplies. The efficient logistic and excellent customer service support are well in place to meet the exacting demands and needs of the building industries in this region.

The range of CSR products manufactured by CSR South East Asia Pte Ltd are:

- Rockwool Insulation
- Glasswool Insulation
- Thermofoil Aluminium Foil Insulation
- PGH Pavers
- Wunderlich Roof Tiles
- Thermaclad Tank Insulation Panel
- Acousticlad Wall Acoustic Panel
- Rondo Steel Building System
- ALC Lightweight Concrete Blocks/Lintels/Panels
- Aluminium Tapes
- Plasterboard and Accessories

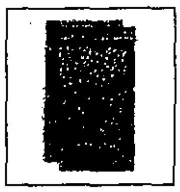

Acousticlad Wall Acoustic Panel


Rondo Steel Building System


Plasterboard


Plasterboard Accessories


PGH Pavers


Wunderlich Roof Tiles

Any inquiries about/pertaining to CSR South East Asia Pte Ltd can be directed to:

CSR SOUTH EAST ASIA PTE LTD

No.8, Tuas Avenue 2, Jurong Town

639448 Singapore

TEL: 65-861 4722, FAX: 65-862 3533

CSR

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Facsimile (603) 344 1758 (ALC) (603) 341 5779 (Ins)
Telephone (603) 341 3444

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639448 Singapore
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