University of Southern Queensland

Faculty of Engineering and Surveying

Control of Early Thermal Cracking of Raft Foundation by Using Slagcrete Portland Blast-Furnace Cement (PBFC)

A dissertation submitted by

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Abstract

Malaysia is a developing country located in South-East Asia. The demands for high rise buildings, are high in industry construction. A raft foundation is designed to support the load applied to it safely. The ability of building to sustain the applied loads depends on the building's foundation system.

Foundation is an important part of every building, which interfaces the superstructures to the adjacent soil or rock below it. Therefore, early thermal cracks have to be well controlled to have a durable foundation. Thermal movement occurs when the temperature of concrete changes due to environment changes or heat generated when the cement first hydrates. Thermal movements due to changes in the ambient temperature are normally not a problem in concrete structures. It can be controlled by number of movement joints or isolation membrane. However, the temperature differential between the center and the surface of the concrete is hard to be controlled by workmanship.

PBFC is recommended in order to minimize early thermal cracking of concrete for raft foundation, thick section or massive pour. It should be noted that GGBS has no cementitous properties, which is a by-product in the manufacture of iron; hence it cannot be used without blending with cement.

This research project can be separated into two main parts that are the project literature reviews and case studies. The literature reviews involve a comprehensive study on the characteristics of PBFC. The case studies of this project involve laboratory test and site monitoring test. Slump test and compressive strength test of different proportion of ground granulated blast furnace slag (GGBS) replaces ordinary Portland cement (OPC) are carried out in laboratory. Two sites are chosen for temperature monitoring tests using thermocouple.

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Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Signature

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Date

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Concrete is one of the most widely used construction materials in the world today. It is cheap, and the constituents can be easily found. Compared to other construction materials like timber and steel, concrete can be easily cast into forms. In addition, concrete structures are more durable and economical.

The compressive strength of concrete typically falls in a range of 30 Mpa to 50 Mpa. This is suitable for most construction projects. Nowadays, compressive in excess of 100 Mpa may be obtained with high strength concrete. If the quality and the mix proportions are well controlled, the expected strength can be easily achieved.

Cracks in concrete can be characterized as pre-hardening or hardened cracks. Cracks which form before concrete has fully hardened (in less than eight hours) are known as pre-hardening cracks. Volume changes in the concrete and the hydration of the cement paste cause expansion and subsequent cracking of the concrete. These are known as hardened cracks.

Shrinkage cracking is the most common form of cracking in concrete constructions. Concrete shrinks as it loses moisture. Therefore moisture loss can be controlled via insulation by polystyrene slab, plastic sheeting or a layer of sand. Also, cracks may occur due to settlement of concrete, movement of the formwork or changes in the temperature and the resulting thermal movements.

In the past, cracking at an early age has generally been attributed to restraint of shrinkage movement. Research in the UK (Incorporating Amendment no.1, 1989) has shown that it is the restraint of the early thermal movement and temperature differential for a thick section that are the dominant effects. Problems with early age cracking appear to have become more prevalent in recent years, possibly as a result of improvements in other aspects of construction technology. For instance, the development of higher early strength concretes increases the problems of early age cracking.

Early thermal movement occurs when the temperature of concrete changes as a result of environment changes or heat generated when the cement first hydrates. Thermal movements due to changes in the ambient temperature are normally not a problem in concrete structures. Cracking can be controlled by a number of movement joints or isolation membranes like polystyrene or layer of sand.

However, temperature gradients resulting from the heat generated by the hydration of the cement paste cannot be controlled by workmanship. The thermal stresses, caused by the temperature difference between the peak temperature and the lowest temperature within a cross section, result in early thermal cracking, which is particularly important in thick sections. One way of controlling this type of early cracking is through the use of ‘‘Slag Crete’’, which is Portland Blastfurnace Cement (PBFC produced by blending of Ordinary Portland Cement (OPC) and Ground Granulated Blastfurnace Slag (GGBS). This results in low hydration heat. It complies fully with the Malaysian Standard M.S. 1389:1995. Portland Blastfurnace Cement (PBFC) has been in used for more than 50 years in developed countries such as Holland, France and Germany. Currently in Holland over 60% of all concrete are produced from PBFC.

Calcium hydroxide ($Ca(OH)_2$) is liberated during the hydration process of cement. As $Ca(OH)_2$ is soluble in water, the higher the proportion of $Ca(OH)_2$, the greater the tendency to produce porous concrete. Similar to PFA (Portland Pulverised Fuel Ash Cement) in mascrete, GGBS combines with Calcium hydroxide to form additional cementitious materials, which results in low permeability. Accordingly, the Concrete Society (UK) Technical Report No 40 (page 126), recommends that “Either GGBS or PFA concrete should be specified for marine environments. In Malaysia, some leading consultants have begun to follow this recommendation from the Concrete Society. Among the major projects where GGBS have been specified are:

1. The Malaysian – Singapore Second Link
2. Johor – Port Phase IV extension

Pan Malaysia Cement Works Singapore (PMCWS) Pte. Ltd., an associate company of Associated Pan Malaysia Cement Sdn. Bhd. (APMC) has been producing and marketing PBFC in Singapore since 1981. To date, numerous prestigious projects in Singapore have successfully used PBFC. Its quality is well proven. PBFC is particularly suitable for chloride resistance, sulphate resistance, low heat applications and alkali-silica resistance.

Therefore, PBFC is recommended in order to minimize early thermal cracking of concrete for raft foundation, thick section or massive pour. It should be noted that GGBS has no cementitous properties, as it is a by-product of the manufacture of iron; therefore it cannot be used without blending with another cement such as Portland.

The use of PBFC on its own may not totally eliminate early cracking if other factors such as constituents, mixing ratios, quality of aggregates and water, delivery plan, the natural environment, the weather during construction, and the inherent hydration and curing characteristic of the concrete are not controlled. These factors, if not controlled, may lead to early cracking, which will affect both the strength of the concrete and its durability.

This project focuses on how early thermal cracking can be controlled, the benefits of using the blend of GGBS and OPC, and the optimum mix design to produce the optimum control and strength for raft foundation. After slump tests, compressive tests and temperature monitoring test, comparison and analysis will be carried out to show the optimum mix design.

1.2 PROBLEM STATEMENTS

Of all concrete mixes development in Malaysia, each has its own characteristics and we cannot produce expected final strength due to early thermal cracks.

> Schindler and McCullough 2002 stated that
>
> *... While developing from the same mix design the final strength would be different due to temperature ... the bigger the structure, the more heat that's going to be generated... There may be seasonal difficulties during construction... There may be differences in the temperatures of the concrete and the surrounding air and water... Finally, direct solar heat can increase the temperature of concrete dramatically.*
>
> Schindler and McCullough 2002 also stated that
>
> *… Changes in the temperature of concrete can cause cracking… The development of high concrete temperatures could cause a number of effects that have been shown to be detrimental to long-term concrete performance. High concrete temperatures increase the rate of hydration, thermal stresses, the tendency for drying shrinkage cracking, permeability, and decrease long-term concrete strengths, and durability as a result of cracking.*

The cracking of a reinforced concrete member is only a problem when the crack width exceeds a certain value such that the durability and serviceability of the structure, or its appearance, are impaired. Therefore, internal tensile strength consideration is essential in order to obtain the target strength of concrete. Therefore, this study is carried to answer the following research questions:

1. How can the early thermal cracking of concrete be controlled?
2. What are the benefits of using PBFC to control early thermal cracks?
3. To show that PBFC can be used for raft foundation to control early thermal cracks.
4. Based on the questionnaire to prove that GGBS and OPC can be used for raft foundation or thick section and methods to minimize early thermal cracking in construction site.

1.3 PROJECT AIMS AND STUDY OBJECTIVES

The aim of this research project is to describe ‘The Control of Early Thermal Cracking of Concrete for Raft Foundation by Using Slagcrete Portland Blastfurnace Cement (PBFC)’. The objectives are as follow:

1. Research information on the factors that would cause early thermal cracking, and the characteristic of PBFC that can overcome the problems.

2. Research other benefits by using the blend of 2 components for raft foundation and show that it is a good choice to be used as a mean of control of early thermal cracking.

3. Investigate through questionnaire, if a blend of GGBS and OPC is suitable for use in Malaysia as well as the current methods used to minimize early thermal cracking in the construction industry.

4. Experimentally prove that that early thermal cracking can be controlled and minimized by using a blend of GGBS and OPC.

1.4 LIMITATION

1. The chosen ready mix concrete firms are some of the companies that are located in Kuala Lumpur and Johor Bahru in Malaysia. Secondary data collection would be based on the progress reports, company files and manuals from the recommended firms, and journal database from respective local authorities.

2. The chosen ready mix concrete firms were recommended by the associate supervisor, Mr. Johnson, the site engineer Mr. Wong Sze San, quality control manager Mr. Neo Sek Guan and Mr. Lee Chuo Mun. Indeed, without a recommendation, it is very difficult to get access to these companies or let alone interviewing them.

3. To ensure the latest data would be obtained, the chosen company must be having projects on hand.

4. Some experiments like the compression strength test can be carried out on 150×150×150mm cube test. It should be pointed out that it is impossible to produce a thick section up to 1m^3, which is even harder to test and dispose of. Therefore, the characteristics of the thick sections will be derived based on the analysis of the small cube tests.

5. Given that the time frame of the project is relatively short, experiments such as potential of alkali-silica reactivity and chloride penetration by diffusion tests that need a time up to 200 days and years cannot be done. Therefore, this data will be cited from ready-mix concrete companies or literature.

1.5 SIGNIFICANCE OF THE STUDY

GGBS is used as a substitute for ordinary Portland cement (OPC) in the making of concrete. It is made from granulated blast furnace slag which is a by-product from the smelting of iron ore. The granulated slag resembles coarse sand and is ground into dry, fine near-white cement known as GGBS. Increased durability is particularly useful in structures, which have to withstand aggressive environments. These include raft foundation, marine developments, major bridges, tunnels, pilings and among many others. The use of GGBS can considerably enhance such structures while extending design life and reducing maintenance and replacement costs. The white nature of the cement also means it doesn't have to be painted and, if pre-pigmentation is required, color takes more easily and vibrantly.

Recent years have seen an increase in the construction of high-rise buildings, which necessitate a variety of foundations designs. Whenever possible, raft foundation is a preferred choice for high-rise buildings. However, the concrete used in raft foundations need to be well controlled in order to reduce the early thermal stress and thermal cracks, and hence the long-term durability of the structure can be achieved.

Malaysia’s hot weather, direct solar heat and surrounding temperature would be the major factors that could affect the quality of concrete mix. Therefore, the initial temperature of fresh concrete is increased due to the direct solar heat and hot air, which will lead to a higher peak temperature. This leads to thermal cracking, which is common in Malaysia. In addition, the surface temperature of concrete can be affected by environmental temperatures easily. Hence, the temperature difference between the core and the concrete surface must be well controlled below the standard temperature differential limit. One of the aims of this research is to find a way of keeping the thermal gradient across the section below the standard temperature differential limit until the concrete has gained sufficient strength.

GGBS is remarkable in that it produces great strength and durability in concrete, while emitting virtually zero CO_2 and no noxious gases to the atmosphere in the manufacturing process compared to Ordinary Portland Cement alone. Its direct availability will benefit the construction industry and assist in reducing greenhouse gas emissions. All of those who wish to exploit the potential of concrete, to work with a high quality, competitive raw material and to see the environment protected from avoidable degradation by the most economic means, will welcome to use PBFC in construction industry.

There is an urgent need to study the factors that cause the quality and strength loss in the concrete mix due to early thermal cracks and how GGBS to be used to controlled it. This research will help to improve the temperature control of the ready mix, thus increasing the efficiency and the quality of the raft foundation or thick section.

In this project, few ready mix companies and site engineers would be chosen for interviewing. This case study may be regarded as a small attempt to provide a base guideline to fill the need of temperature control of concrete mix towards an overall control system for the raft foundation or thick section. The approach used in this research is aimed to provide a control of early thermal cracking by using a blend of GGBS and OPC towards achieving this ultimate goal.

CHAPTER 2

LITERATURE REVIEW

2.1 EARLY THERMAL CRACKING

Early thermal cracking of raft foundation is mainly caused by temperature differential. The setting of concrete is a chemical reaction which liberates heat as the cement hydrates. In a thin section the peak temperature rise is soon reached and the initial expansion is then followed by thermal contraction as the concrete cools down to the ambient temperature. This will occur within only a few days in thin sections, but it may take several weeks to complete in very thick sections, especially if they are insulated.

The thicker the section, the greater will be the temperature rise. However, when the section thickness becomes greater than 1.5 to 2m the additional increase in temperature becomes so small as to be negligible. This results from concrete being a poor thermal conductor making the temperature gradient across the section more important than the peak temperature rise when the section exceeds 500mm.

In a large base pour the surface zone will cool and contract faster than the core once the temperature peak has passed. Tension cracks can then penetrate the depth of the surface zone, but due to the nature of the restraint, they cannot be continuous through the whole section. As the core cools these cracks may even close up with tensile stresses developing in the core and compressive stresses in the surface zone. In such extreme cases this can result in internal cracking. (Incoroprating Amendment no.1, 1989)

2.2 OCCURRENCE OF THERMAL CRACKING

Mass concrete has the potential to crack when temperature gradient within the concrete cause thermal stresses to exceed the tensile strength. Concrete generates heat as it sets and gains strength. The more cementitious material in the concrete, the warmer the concrete gets. In large structures such as raft foundation, temperature gradient develop because the concrete surfaces are cooled by the air or water much faster than the core (VanGeem, 2001)

2.2.1 ASSOCIATED PROBLEMS WITH THERMAL CRACKING IN RECENT YEARS

Recent years have seen an increase in problems associated with thermal cracking. Some of the reasons may be enumerated as follows:

1. First, placing larger structures faster allows less time for the concrete core to cool. The cooling rate increase exponentially with thickness.

2. A second problem is that higher cement contents are being specified to "ensure durability". Some specifiers and contractors believe that high cement contents will improve concrete durability and make up for variability in control during placement.

3. Third, in order to meet specified maximum water-to-cement ratios, the more water is added, the more cement must be added too.

All of these three factors contribute to higher temperature gradients in the concrete and a greater potential for thermal cracking. (VanGeem, 2001)

2.3 FACTORS THAT AFFECT TENSILE STRENGTH OF CONCRETE

The actual maximum allowable temperature difference can be calculated, and depends on the tensile strength of the concrete and the restraint. Tensile strength is dependent on the concrete’s age, thermal expansion, modulus of elasticity, and creep. The surface of the concrete is restrained by the warm expanding concrete core, which does not allow the surface to shrink as it cools. The bottom of the concrete experiences restraint from the base material, which does not allow the concrete to freely shrink as it cools. (VanGeem, 2001)

Traditionally, early-age thermal cracking was controlled by limiting the maximum temperature rise and the maximum temperature difference within the structure during hydration. Tests on restrained thermal specimens have shown that besides temperature change, all the factors that influence strength and stress development must be considered. The risk of early-thermal cracking may be minimized through the use of concrete mixtures with: (Browne, 2001)

- Low coefficient of thermal expansion;
- Reduce the peak temperature of the concrete;
- Crushed aggregates with rough surfaces that provide increased tensile strength;
- Certain type of fly ash and GGBS (ground granulated blast-furnace slag) that retard and reduce the heat of hydration.

If the maximum temperature difference exceeds the allowable temperature difference, VanGeem, 2001, recommends the following

- Ø Use less cement;
- Ø Allow the design strength to be met in 56 rather than 28 days;
- Ø Use GGBS as a replacement for a portion of the cement.

2.3.1 OTHER CONSIDERATIONS

Browne (2001) stated that besides temperature change, all the factors that influence strength and stress development must be considered in order to control early thermal cracking.

In raft foundation, reinforced concrete differs from conventionally placed mass concrete due to the many horizontal planes of weakness (construction joints) created during placement. Reinforced concrete is placed and compacted in layers ranging from 6 to 24 inches with each layer creating a joint with tensile strength less than that of the parent concrete. The joint strength can be improved by placing a layer of high slump bedding mortar on each lift; however, the resulting joint strength is always somewhat less than the parent concrete. The consistency of reinforced concrete can also affect tensile strength with lower strength values for harsh mixes with low paste contents.

Besides this, the flatter coarse aggregate particles in the mixes have a tendency to align themselves in the horizontal direction during the compaction process. Therefore, the material properties have to be considered.

2.4 GENERAL INFORMATION OF GGBS

2.4.1 HISTORY

The use of ground granulated blast-furnace slag (GGBS) as a cementitious material dates back to 1774 when Loriot made a mortar using GGBS in combination with slacked lime (Mather, 1975).

2.4.2 DEFINITIONS

Ground Granulated Blast-Furnace Slag (GGBS)—Granulated Blat Furnace Slag when ground to cement fineness, and in the presence of suitable activator, becomes a cementitious binder.

2.4.3 HYDRAULIC ACTIVITY

There is general agreement among researchers (Smolczyk 1978), that the principal hydration product that is formed when GGBS is mixed with Portland cement and water is essentially the same as the principal product formed when Portland cement hydrates, i.e., calcium-silicate hydrate (CSH).

GGBS hydrates are generally found to be more gel-like than the products of hydration of Portland cement, and so add denseness to the cement paste. When GGBS is mixed with water, initial hydration is much slower than Portland cement mixed with water. Therefore, Portland cement or alkali salts or lime are used to increase the reaction rate. Hydration of GGBS in the presence of Portland cement depends largely upon breakdown and dissolution of the glassy slag structure by hydroxyl ions released during the hydrations of the Portland cement.

Research by Regourd (1980), Vanden Bosch (1980), and Roy and Idorn (1982) has shown that, in general, hydration of GGBS in combination with Portland cement at normal temperature is a two-stage reaction. Initially and during the early hydration, the predominant reaction is with alkali hydroxide, but subsequent reaction is predominantly with calcium hydroxide. Calorimetric studies of the rate of heat liberation show this two-stage effect, in which the major amount of GGBS hydration lags behind that of the Portland-cement component.

2.5 PROPORTIONING CONCRETE CONTAINING GGBS

2.5.1 PROPORTIONING WITH GGBS

In most cases, GGBS has been used in proportions of 25 to 70 percent by mass of the total cementitious material. These proportions are in line with those established by ASTM C 595 for the production of Portland blast-furnace slag cement. In South Africa, its use has been predominantly at 50 percent replacement of cement due to convenience in proportioning (Wood 1981).

The proportion of GGBS should be dictated by the purposes of the concrete, the curing temperature, the grade (activity) of GGBS, and the Portland cement or other activators. Where GGBS are blended with Portland cement, the combination of cementitious material will result in physical properties that are characteristic of the predominant material. For example, as the percentage of GGBS increases, a slower rate of strength gain should be expected, particularly at early ages, unless the water content is substantially reduced or accelerators are used or accelerated curing is provided.

There appears to be an optimum blend of GGBS that produces the greatest strength at 28 days as tested by ASTM C 109. This optimum is usually found to be 50 percent of the total cementitious material, although this relationship varies depending on the grade of GGBS (Hogan and Meusel 1981, Fulton 1974).

Other considerations will depend on the requirements for temperature rise control, time of setting and finishing, sulfate resistance, and the control of expansion due to alkali-silica reaction. For example, where high sulfate resistance is required, the GGBS content would be a minimum of 50 percent of the total cementitious material, unless previous testing with a particular GGBS has indicated that a lower percentage is adequate (Chojnacki 1981; Hogan and Mensel 1981; Fulton 1982; Lea 1971; Hooton and Emery 1983)

The proportioning techniques for concretes incorporating GGBS are similar to those used in proportioning concretes made with Portland cement or blended cements. Methods for proportion are given in ACI 211.1. However, due to the high proportions of GGBS commonly used, allowances should be made for changes in solid volume due to the difference in specific gravity of slag (2.85 to 2.94) and Portland cement (3.15). Concrete with GGBS typically has greater placeability and ease of compaction, hence greater volumes of coarse aggregate may be used to reduce the stickiness of concrete mixtures (Wood 1981; Fulton 1974). This is particularly true when high cement contents are used. GGBS are usually substituted for Portland cement on a one-to-one basis by mass and are always considered in the determination of the water cementitious material ratio.

Water demand for a given slump may generally be 3 to 5 percent lower than that found with concrete without GGBS (Meusel and Rose 1983). Exceptions can be found, and should be accounted for in the trial mixture proportioning studies.

2.5.2 TERNARY SYSTEMS

Typically the use of a ternary system is for economic reasons, but it may also be used for improving engineering properties.

Combinations of GGBS, cement and silica fume were used in concrete mixtures in high-strength applications for the Scotia Plaza in Toronto (Bickley et al. 1991) and Society Tower (Engineering New Record 1991) in Cleveland, Ohio. Combinations of GGBS, fly ash, and Portland cement have all been used as ballast for tunnel sections when low heat generation in mass concrete was desired. In addition, the combination of GGBS, fly ash, and Portland cement appears to be the most appropriate binding material for the solidification and stabilization of low-level nuclear waste forms (Langton 1989, Spence et al. 1989).

2.6 EFFECTS ON PROPERTIES OF FRESH CONCRETE

2.6.1 EFFECTS ON TEMPERATURE RISE IN MASS CONCRETE

GGBS have been used commonly as an ingredient of Portland blast-furnace slag cement, and as a separate cementitious constituent to reduce the temperature rise in mass concrete (Bamforth 1980; Fulton 1974; Mather 1951; Lea 1971). There are cases where mixtures with and without GGBS were tested using the heat of solution method (ASTM C 186) and the mixtures with GGBS produced the greater cumulative heats (Bamforth 1980; Hogan and Meusel 1981; Roy and Idorn 1982).

It is important to note that, although the heat-of-solution method indicates the total heat release potential of cement, it does not indicate the rate of heat rise which is also important of GGBS reduced the early rate of heat generation; this reduction is directly proportional to the proportion of GGBS used. This will reduce in peak temperature and rate of heat gain.

2.6.2 TIME OF SETTING

Usually, an increase in time of setting can be expected when GGBS is used as a replacement for part of the Portland cement in concrete mixtures. The degree to which the time of setting is affected is dependent on the initial temperature of the concrete, the proportion of the blend used, the water-cementitious material ratio, and the characteristics of the Portland cement (Fulton 1974). Typically, the time of initial setting is extended one-half to one hour at temperatures of 23ºC (73ºF); little if any change is found at temperatures above 29ºC (85ºF) (Hogan and Meusel 1981).

Although significant retardation has been observed at low temperatures, the additions of conventional accelerators, such as calcium chloride or other accelerating admixtures, can greatly reduce or eliminate this effect. Since the amount of Portland cement in a mixture usually determines setting characteristics, changing the GGBS proportions may be considered in cold weather. At higher temperatures, the slower rate of setting is desirable in most cases, but care may need to be taken to minimize plastic shrinkage cracking.

2.6.3 COLOR

GGBS is considerably lighter in color than most Portland cement and will produce a lighter color in concrete after curing. Where color is important, correctly timed exposure to air, sunlight, or wetting and drying promotes oxidation of the concrete surface. Concrete containing GGBS has been found to yield extended blue coloration when continuously exposed to water or when sealers were applied at early ages

2.6.4 WORKABILITY

PBFC improved and retained workability for placing, ease of compaction, finishing, coping with transport and site delays. Wood (1981) reported that the workability and placeability of concrete containing GGBS yielded improved characteristics when compared with concrete not containing GGBS. He further stated that this result was due to the surface characteristics of the GGBS, which created smooth slip planes in the paste. He also theorized that, due to the smooth, dense surfaces of the GGBS particles, little if any water was absorbed by the GGBS during the initial mixing, unlike Portland cement.

Fulton (1974) investigated the phenomenon in greater detail and suggested that cementitious matrix containing GGBS exhibited greater workability due to the increased paste content and increased cohesiveness of the paste. Wu and Roy (1982) found that pastes containing GGBS exhibited different properties compared to paste of Portland cements alone. Their results indicate a better particle dispersion and higher fluidity of the pastes and mortars, both with and without water-reducing admixtures.

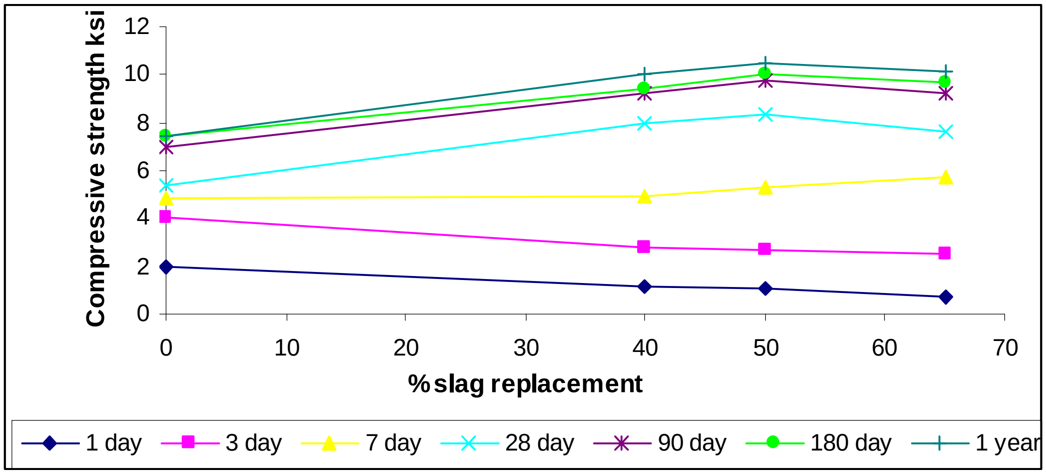
2.6.5 RATE OF SLUMP LOSS

Little information is available regarding slump loss when GGBS are used. Frigione (1983) reports a reduced rate of slump loss, whereas Meusel and Rose (1983) indicate that concrete containing GGBS at 50 percent substitution rate yield slump loss equal to that of concrete without GGBS. Experiences in United Kingdom indicate reduces slump loss, particularly when the Portland cement used in the blend exhibits rapid slump loss, such as that caused by false-set characteristics of cement (lea 1971).

2.6.6 STRENGTH AND RATE OF STRENGTH GAIN

The temperature at which the concrete is cured will have a great effect on the strength of the concrete, particularly at early ages. Concrete containing GGBS is found to respond very well under elevated temperature curing conditions in accordance to the Arrhenius Law reported by Roy and Idorn (1982). In fact, strength exceeding that of Portland cement concrete at 1 day and beyond has been reported for accelerated curing conditions (Hogan and Meusel 1981; Fulton 1974; Lea 1978). Conversely, strength reduction at early ages is expected with concrete containing GGBS, when cured at normal or low temperatures.

The proportion of the GGBS used also affects the strength and rate of strength gain as noted in Fig. 2.1. When highly active GGBS have been tested, the greatest 28-day strengths are found with blends of 40 to 50 percent (Fulton 1974; Hogan and Meusel 1981; Meusel and Rose 1983). Where early strengths are concerned, the rate of strength gain is generally inversely proportional to the amount of GGBS used in the blend.



(Source: Hogan and Meusel 1981)

Figure 2.1: Influence of GGBS replacement on mortar cube compressive strength

2.6.7 MODULUS PF ELASTICITY

Most work in this area has been with blended cement containing GGBS. Klieger and Isberner (1967) found essentially the same modulus of elasticity in concretes containing Portland blast-furnace slag cement as compared with Type I cement concrete. Stutterheim, as quoted by Fulton (1974), also confirmed this, using concrete containing equal amounts of GGBS and Portland cement and concrete with Portland cement only.

2.6.8 PERMEABILITY

The use of GGBS in hydraulic structures is well documented. The permeability of mature concrete containing GGBS is greatly reduced when compared with concrete not containing GGBS (Hooton and Emery 1990; Roy 1989; Rose 1987). As the

GGBS content is increased, permeability decreases. It is found that the pore structure of the cementitious matrix is changed through the reaction of GGBS with calcium hydroxide and alkaline released during the Portland cement hydration (Bakker 1980; Roy and Idorn 1982).

2.7 THERMAL CURING

Concrete made with slag cement hydrates more slowly than OPC concrete which can be quite beneficial. However, slag cement concrete does require greater attention to curing. Table 2.1 shows a guide to recommended wet curing times for slag cement concrete.

Average Ambient Daily Temperature	**20 – 40% Slag**	**40 – 55% Slag**	**55 – 70% Slag**
Above 20°C	5	7	7
12 - 20°C	7	9	9
5 – 12°C	9	12	12

(Australian Slag Association, ASA, 1990)

Table 2.1: Number of Wet Curing Days

Proper curing is extremely important for slag concrete to develop its potential strength and durability due to the longer curing times for massive concrete pours, especially in the raft foundation or thick section, the Contractor shall thermal cure the concrete so as to maintain a temperature differential between the internal (hottest) and external (coolest) temperature of the concrete to a 25°C maximum.

The Contractor shall sufficiently in advance of pouring any concrete, which is considered by the Employer's Representative as a massive pour, furnish the Employer's Representative with proposed methods for observing, detecting and controlling the thermal differential between the external and internal temperatures.

The contractor shall as a minimum requirement provide the following:

1. Furnish and install thermo couplers.
2. Maintain records of temperature differential.
3. Immediately apply corrective measures, in accordance with the provisions described in the Current Practice Sheets (issued by the Cement and Concrete Association, Wexham Springs, Slough SL3 6PL, England) No. 2p/15/1, No.35, when the temperature differential exceed 25°C so as to maintain it at 20°C maximum.

2.8 CONCLUSION

In conclusion, the literature review had achieved the objective of 1 and 2 as stated in the chapter 1. The quality control is most simply defined as the procedures of supervision, inspection, testing, maintenance and calibration to ensure that the specified characteristics of the concrete will be achieved (BS 5328, Part 3, 1990). A successful and well quality control can achieve a durable concrete. However, the temperature control either on fresh concrete or harden concrete is one of the most critical parts to be controlled due to this influencing factor tends to be changed in any time and places.

CHAPTER 3

METHODOLOGY

The following methodology is used to address the objectives of the study project which was stated in chapter 1. In this chapter, the research methodology adopted in the study will be presented and discussed. Method of data collection is presented with an orderly means from literature search, pre-test of the questionnaire to the implementation of questionnaires survey and case studies. The analytical methodology of the study is also presented.

This project is a general evaluation of controlling thermal cracking by using a blend of GGBS and OPC. Therefore, several companies and construction sites are chosen to be visited in order to strengthen the findings of the research. All of the visited companies are recommended by the associate supervisor Mr. U. Johnson, site engineer Mr. Wong Sze San and consultant Mr. Lee Chuo Mun.

In order to achieve the above aims and objectives, two types of data would be collected as follows:

3.1 PRIMARY DATA

For the purpose of gaining more information, primary data is required in the form of journals, newspapers, magazines, study books, progress reports (prepared by the clerk-of-work or the parties involved for the fortnightly meeting and monthly meeting). Additional details could also be collected from specific websites. The primary data will be conducted to study the background and current development of the quality control of concrete mix in Malaysia.

3.2 SECONDARY DATA

The secondary data is collected by personal interviews with the appropriate engineer. The ideal persons to be interviewed include the residential engineer/ site engineer who are employed by the contractors, clerk-of-work, consultants and managers who are in-charge in the quality control of concrete. Besides this, secondary data also include the data and information to be obtained from the various ready mix companies.

3.3 ACTIVITIES

In the second phase, a postal questionnaire was developed with regard to the decision criteria mentioned, and a survey was then conducted to assess the respondents' preference on the selection criteria. As a result, an industry-wide response was obtained. Postal questionnaire survey is adopted as the methodology for the study. In addition, two case studies were conducted as a measure to strengthen the findings of the research.

In other words, the major approach of this study was the mailed questionnaire survey. Mailed questionnaire survey was chosen as the appropriate approach because it can reach a large number of respondents in different locations of the country (Malaysia) at a relatively lower cost, shorter time and less effort as compared to other data collection methods.

The case studies were conducted to investigate (at ready mix concrete company) the advantages by using different proportional of GGBS for raft foundation and at the same time several tests will be done to prove that a blend of GGBS and OPC can be used to control the early thermal cracking of raft foundation.

Beside this, information was collected from site on how the site representative going to control and minimize the thermal cracking during the curing stage. These case studies will be presented and discussed in chapter eight and nine. The approach adopted for the data collection was as shown in Figure 3.1. This figure is a flow chart indicating the general procedures that lead up to the database of this study.

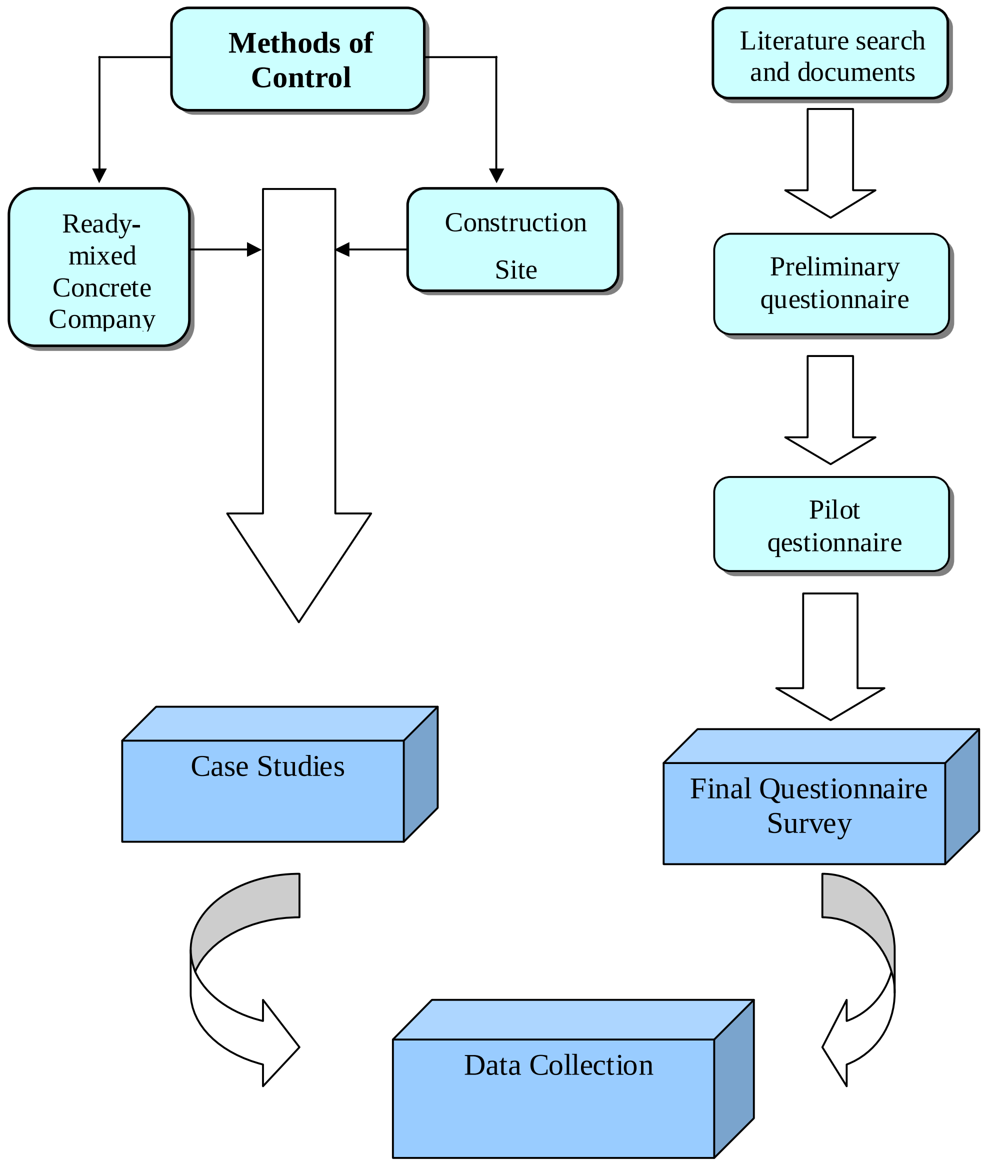


Figure 3.1: Guidelines for Data Collection

3.3.1 QUESTIONAIRE DESIGN

Questionnaire form is written and formulated based on the following objectives.

1. Determine the importance of thermal cracking.
2. Investigate type of cement and methods used to control thermal cracking.

The content of the questionnaire designed was briefly shown in figure 3.2:

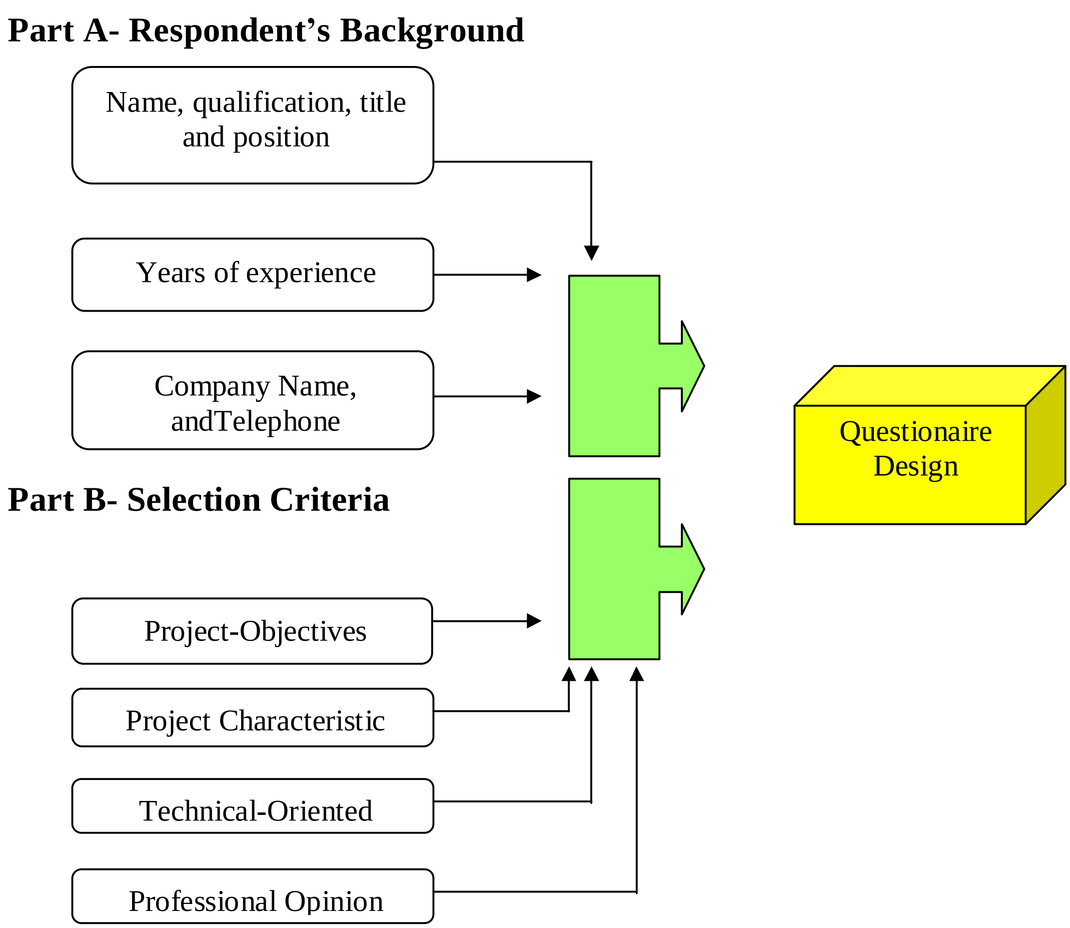


Figure 3.2: Structure of the Questionnaire

3.3.2 CASE STUDIES

Two case studies were carried out in order to strengthen that a blend of GGBS and OPC can be used to control and minimise thermal cracks. The data required for the case studies were obtained through structured instructions and interviews with the project personnel of the project selected. These case studies consist of the following information:

1. Methods used to control and minimize the thermal cracking in construction site during the curing stage;
2. Laboratory tests are carried out to show that the optimum replacement percentage of GGBS can be used to control and minimize the thermal cracking of raft foundation;
3. Two site-monitoring tests are carried out to show that PBFC can be used for raft foundation.

Case study 1: Ready mix concrete company

Peak temperature should be controlled from the raw materials until the concrete has gained specific strength. The data and methods will be collected from the ready mix concrete company. In this chapter, the author will use the blend of different percentage of 2 components – Ground Granulated Slag (GGBS) and Ordinary Porland Cement (OPC).

The replacement percentages of OPC with GGBS are 0%, 30%, 35%, 40%, 45% and 50%. Slump tests were carried out once the concrete were mixed. After that, 9 samples for each proportional with a total of 54 cubes are cast in 150×150×150mm's mould. Cube tests were carried out to obtain the compressive strength of concrete. The specimens of all of the concrete mixes are cast and cured in water. The cubes will be removed from curing tank at ages of 3, 7 and 28 days for compressive strength tests in accordance with BS1881: Part 116:1983 using as Avery-Denison

compression machine. For each concrete mix, three cubes cured at a certain age were tested.
(Note: 3 workers of BUILDCON SDN.BHD. assisted during casting, because the rate of casting with 1 person is too slow and the quality would be changed.)

Besides this, data relevant to other benefits of a blend of GGBS and OPC are collected and analyzed in order to find out the optimum proportional for raft foundation.

Case study 2: Construction site (Site Temperature Monitoring Test)

In this chapter, the author will collect all of the information on the methods used in the construction site to control the early thermal cracking and the temperature differential limit in the concrete section during the curing stage through questionnaire form and personal interview. Some of the methods may be suitable applied for the following test in order to minimize the effects due to lost control in construction site. It is because, thermal cracking control cannot just depend on the type of cement, a proper curing is also important for slag concrete to prevent the early thermal cracking.

The other is site temperature monitoring test. There are 3 temperature monitoring tests a blend of 50%GGBS and 50%OPC, and 70%GGBS and 30%OPC; the author will maintain records of temperature differential at different points (from the top to the bottom) of a cross section up to 200 hours. In this test, thermo couplers have to be installed before pouring concrete. The three monitoring tests of raft foundation are:

1. PANDAN III, ELEVATOR RESERVIOR 2.27ML, JOHOR.
2. 3 × 700 MW COAL FIRED POWER PLANT TANJUNG BIN, JOHOR, which started in March, 2005.

CHAPTER 4

CASE STUDY 1

Aim: To show the benefits of replacing Ordinary Portland Cement (OPC) by Ground Granular Blast-furnace Slag (GGBS), and deduce the optimum replacement percentage of GGBS for raft foundation.

Slagcrete Portland Blastfurnace Cement (PBFC) is produced by blending of Ordinary Portland Cement (OPC) and Ground Granulated Blastfurnace Slag (GGBS). It complies fully with the Malaysian Standard M.S. 1389:1995.

PBFC is particularly suitable for low heat application, alkali-silica resistance, chloride resistance and sulphate resistance. Due to time constraint, the laboratory results of the above 4 benefits are cited from technical reports and magazines. The laboratory tests of this chapter are slump test and compressive strength test, to show the strength of PBFC with different proportions of GGBS replace OPC. The following is a brief description of these special properties of PBFC, its benefits, and the characteristic of different proportions of GGBS and OPC.

4.1 REDUCED HEAT OF HYDRATION

Slag hydration is an exothermic reaction same as the Portland Cement hydration. However, it does not react quickly and thus generates heat more slowly. This enables more time for the dissipation of heat and hence peak concrete temperatures are reduced. For this reason, early thermal cracking due to thermal stresses occurs within the concrete. Thermal stresses are caused by the temperature difference between the peak temperature and the lowest temperature within a cross section. If the heat of hydration can be reduced, early thermal cracking can be minimized by producing a lower peak temperature due to the lower heat of hydration in the core. This is an advantage of using PBFC when thermal cracking would be a problem.

For normal Blast-Furnace Cement concretes, the peak temperatures may be reduced by 8-10°C for 40% slag blends and proportionally more for the higher slag blends (Fig 8.1). In addition, with lower heat of hydration, PBFC is suitable for all mass concrete works, particularly in hot climatic conditions such as Malaysia.

Based on the responses from the questionnaire, Mascrete High Slag Blastfurnace Cement has been successfully used in numerous mega projects in Malaysia such as:

i. Kuala Lumpur City Centre (K.L.C.C)
ii. K.L Telekom Tower raft foundation
iii. Kuala Lumpur International Airport (K.L.I.A) – Sepang
iv. Pergau Dam and
v. Bukit Jalil Stadium etc.

Similarly PBFC, with lower heat of hydration is suitable for all mass concreting works in Malaysia’s hot climatic conditions. BS 8110 Part 1 Clause6.2 (b) recommended “the use of material with a lower release of heat of hydration to be considered for mass concreting works”.

In addition, BS 6349: 1989 on Code of Practice for Maritime Structure Clause 58.4.1, recommends that, “In order to minimize cracking at an early stage, when member thicknesses exceed 300mm and cement contents exceed 350kg/m^3, consideration should be given to methods of avoiding excessive temperature differentials due to heat of hydration”. The benefit of using PBFC in terms of lower heat of hydration is shown in Figure 4.1.

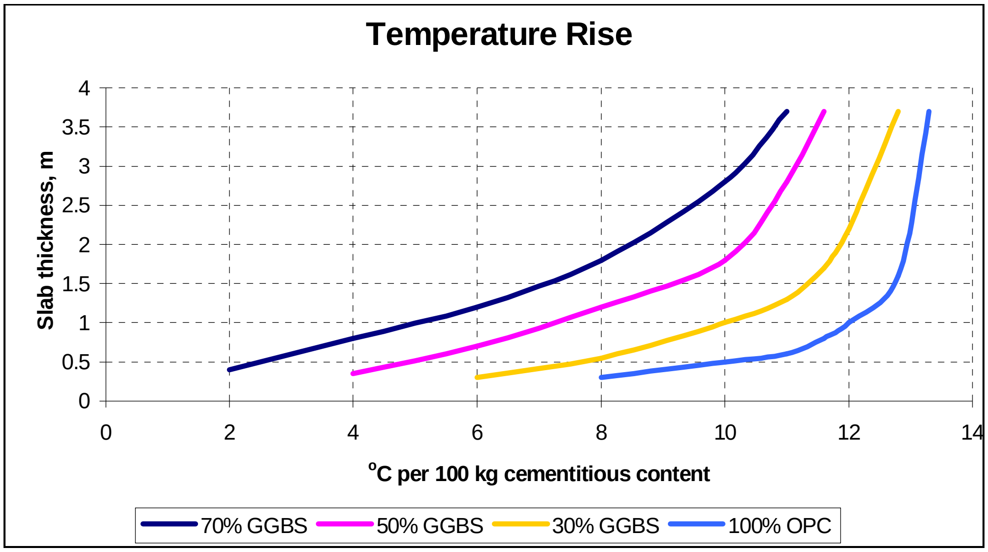
For GGBS and OPC combinations, the reduction in the heat of hydration is partially attributed to the utilization of the heat generated by the Portland cement hydration reaction in the GGBS hydration reactions. Examples in kJ/kg obtained using the heat of solution method (BS 4550) is shown in Table 4.1. Based on table 4.1, the reduction in the heat of hydration is directly proportional to the replacement percentage of GGBS. However, OPC cannot be replaced by 100 percent of GGBS because it has no cementious properties. It is a by-product in the manufacture of iron; therefore it cannot be used without blending with cement.

%GGBS	**0**	**30**	**40**	**50**	**70**	**90**
7 days	360	325	305	225	200	125
28 days	400	395	360	325	260	185

(Source: UK Concrete Technical Report No.40, 1991)

Table 4.1: Heat generated by hydration, kJ/kg

Peak temperature in raft foundations normally occurs within 7 days (Mr. Hew Choong Wei—Area Manager of Buildcon Concrete Sdn. Bhd). Therefore, 50% replacement should be a good choice since the heat of hydration due to 50% replacement of GGBS is approximately 36% lower than 40 replacement percent and only 11% higher than 70 replacement percent of GGBS. (Table 4.1).



(Sources: P.B BAMFORTH – Concrete Society Digest No 2, "Mass Concrete", 1984)

Figure 4.1: The Relationship Between Lift Height, Temperature Rise And Proportion Of GGBS

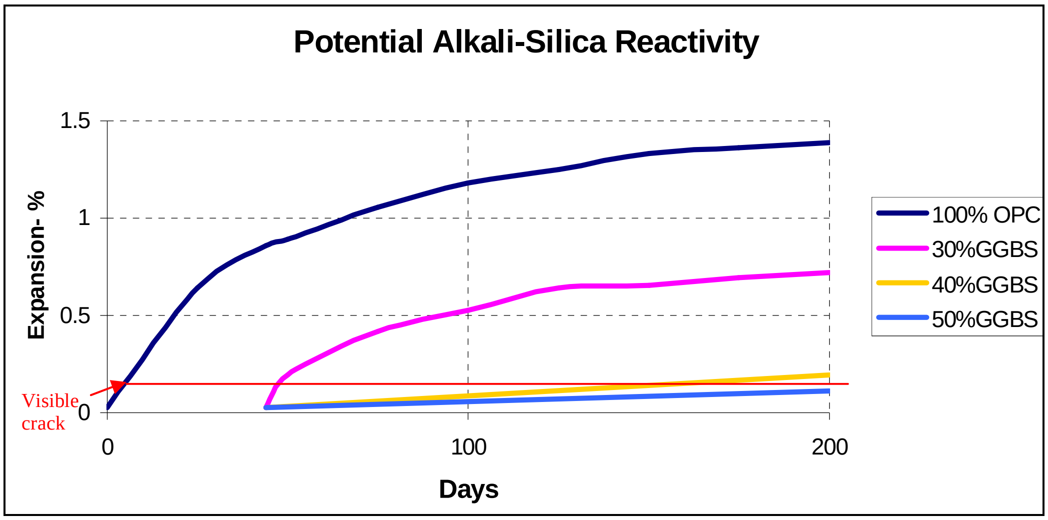
4.2 OTHER BENEFITS BY USING A BLEND OF GGBS AND OPC

Tests on restrained thermal specimens have shown that besides temperature change, all the factors that influence strength and stress development must be considered. (Browne, 2001). Therefore, PBFC is used to minimize attacks from chloride, sulphate and minimize alkali-silica reaction in order to improve the strength.

4.2.1 RESISTANCE TO ALKALI-SILICA REACTION (ASR)

Alkali – Silica Reaction, which causes concrete to crack and disintegrate, is caused by deleterious aggregates which react with the Sodium Equivalent (Na_2O_3 Eq.) in cement.

Figure 4.2 shows that the percentage of expansion decreases with the increasing percentage of replacement of OPC by GGBS. In addition, the replacement of OPC by 40% and 50% of GGBS produces the concrete totally below the visible cracking up to 200 days. Therefore, it can be deduced that the alkali-silica reaction would be less with increasing the replacement percentage of GGBS. A blend of GGBS and OPC is effective in reducing the risk of ASR is shown in Figure 4.2.



(Adapted from the Magazine of Concrete Research, Vol 34 No119, 1982)

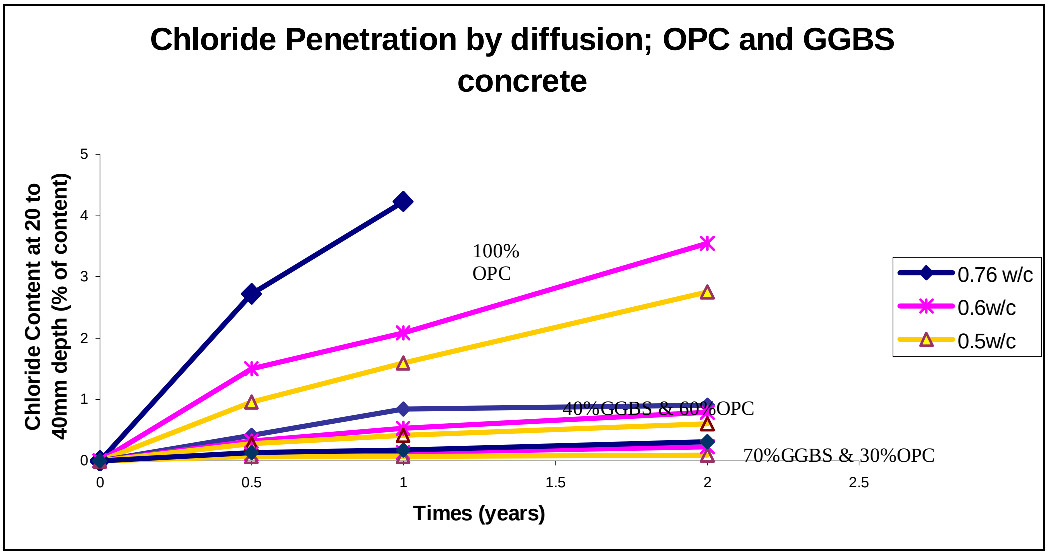
Figure 4.2: Potential Alkali-Silica Reactivity

4.2.2 RESISTANCE TO CHLORIDE ATTACK

Due to the tropical climate in Malaysia, chloride attack is a severe problem for concrete construction in the marine environment. Therefore, strength and durability can be affected if chloride attack is uncontrolled. Chloride attack, can be measured by chloride diffusion into concrete, is greatly reduced by using PBFC (Figure 4.3).

GGBS concrete is substantially more resistible to chloride penetration by diffusion than OPC concrete, whether compared on the basis of equivalent cement content or grade (Figure 4.3). In marine exposure, GGBS concrete exhibits enhanced durability.

The slag cement (40%-70% GGBS) showed a better behavior than standard Portland cements



(Source: Concrete Society (UK), Technical Report No.40, Page 126)

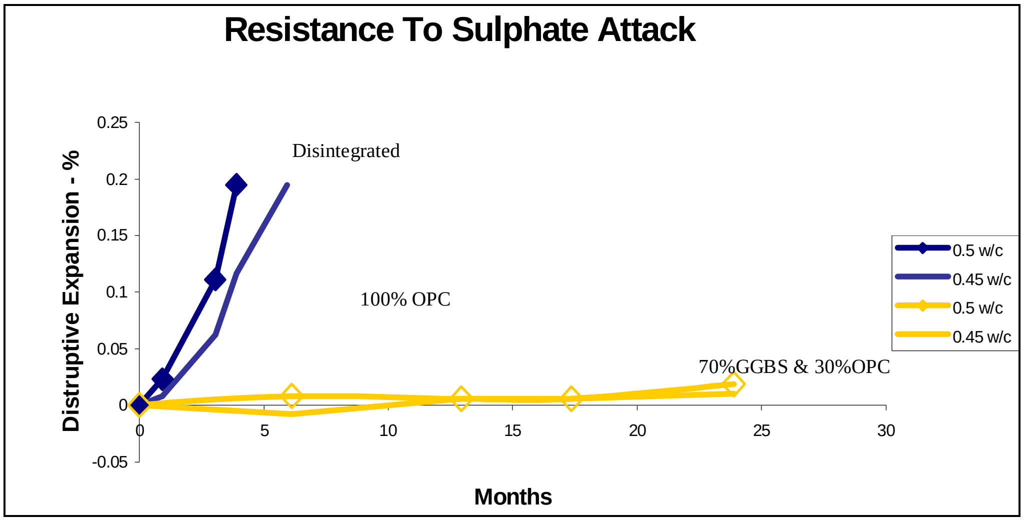
Figure 4.3: Chloride Penetration by diffusion; OPC and GGBS concrete

4.2.3 RESISTANCE TO SULPHATE ATTACK

Apart from the points above, concrete especially raft foundation is exposed to sulphate attack by various sources including ground water, industrial effluent and its by-products, decay of organic matter, sewage and etc.

Slag cement improves concrete resistance to sulphate attack by reducing the permeability of the cement paste and reacting with the calcium hydroxide in the hardened cement paste. By reducing the availability of one of the compounds, it is highly susceptible to sulphate attack, thus, the strength and durability can be improved.

Worked by CSIRO, using a test method that developed by the Cement and Concrete Association of Australia, has shown that slag cement contains 40% to 80% slag has higher resistance than OPC and some sulphate resisting cements. A British study which compare the performance of concrete containing GGBS (70%) blended cement and OPC is summarized in Figure 4.4.



(Source: Report X 133 – Messrs. Sandberg - London)

Figure 4.4: The Effectiveness Of PBFC (70%GGBS & 30% OPC For Sulphate Resistance.

4.3 APPLICATION OF PBFC

Based on the interview with the quality control managers of different companies, PBFC is superior as compared to OPC for the following applications:

- Marine structures and buildings located near to the coastline.
- Mass concreting works.
- Sulphate and acid sulphate soil conditions.
- Water retaining structures and basements where improvement impermeability is essential.
- Risk of alkali-silica reactive aggregates.

Since PBFC not only can control early thermal cracking but also can protect the raft foundation attacking from harmful material hence, PBFC is fully suitable for raft foundation.

4.4 LABORATORY TEST

Aim: To determine slump height and compressive strength for different percentage of replacement of GGBS.

Method: **1. Slump Tests**

Slump tests were carried out on each sample once the concrete mixes were ready. The mould for this test was a frustum of a cone with 300mm high (Figure 4.5). The concrete was placed in the mould and compacted in a standard manner (figure4.6). Then, the mould was raised to leave the concrete (figure 4.7). The subsidence of the concrete was then measured as slump (figure 4.8).

Figure 4.5: Tools preparation

Figure 4.6: Fill in 3 layers and compact in standard manner.

Figure 4.7: Lift the mould carefully

Figure 4.8: Measure the slump

2. Compressive Strength Tests

Cube tests were carried out to obtain the compressive strength of concrete using different percentage of GGBS (with 0%, 30%, 35%, 40%, 45% and 50% of GGBS). 9 samples for each proportional with a total of 54 cubes are cast in 150×150×150mm's mould (figure 4.9).

The standard compressive strength test in Malaysia is cube test, which is different from Australia using cylinder. The specimens of all the concrete mixes were cast with standard procedures (figure 4.10) and cured in water tank after 24 hours (figure 4.11). The cubes were removed from curing tank at the age of 3, 7 and 28 days (figure 4.12) for compressive strength tests in accordance with BS1881: Part 116:1983 using as Avery-Denison compression machine (figure 4.14). For each concrete mix, three cubes cured at a certain age were tested.

Expected: Target

1. As the water cement ratio and the raw materials are same in every batch, therefore similar slump should be expected.
2. As the percentage of GGBS increase, a slower rate of strength gain should be expected, particularly at early ages, unless the water content is substantially reduced or accelerators are used or accelerated curing is provided.

Figure 4.9: 54 standard moulds.

Figure 4.10: Fill in 3 layers and compact in standard manner (Compressive Strength test)

Figure 4.11: Cured in curing tank.

Figure 4.12: Prepared cubes for compressive strength test.

Figure 4.13: Measure the weight to make sure the densities are same.

Figure 4.14: Take readings

Result:

Date Cast	1/7/2005	1/7/2005	1/7/2005	1/7/2005	1/7/2005	1/7/2005
No.	1	2	3	4	5	6
% OPC	100	70	65	60	55	50
%GGBS	0	30	35	40	45	50
OPC (kg/m^3)	336	235	218	202	185	168
GGBS (kg/m^3)	0	101	118	134	151	168
Total (kg/m^3)	336	336	336	336	336	336
Type Of Cement	Perak	Perak	Perak	Perak	Perak	Perak
20mm (kg/m^3)	1000	1000	1000	1000	1000	1000
Sand (kg/m^3)	840	840	840	840	840	840
P332N (ml/100kg)	400	400	400	400	400	400
R1100H (ml/100kg)	0	0	0	0	0	0
H_20 (l/m^3)	185	185	185	185	185	185
Slump (mm)	100	95	95	100	100	100

3 days (Mpa)

1st cube	26.0	24.3	23.0	22.0	22.5	20.8
2nd cube	26.0	24.7	23.5	23.5	22.5	21.5
3rd cube	27.5	23.0	24.0	23.5	22.7	23.7

7 days (Mpa)

1st cube	31.5	29.2	27.5	26.2	25.2	24.9
2nd cube	31.5	28.3	27.6	25.9	25.2	24.5
3rd cube	31.5	28.0	27.5	25.3	24.8	24.1

28 days (Mpa)

1st cube	40.0	41.0	41.9	41.0	42.7	42.0
2nd cube	40.0	40.7	41.1	41.0	42.6	41.0
3rd cube	39.0	40.0	40.5	40.8	42.3	41.0

Mean Compressive Strength (Mpa)

3 days	26.5	24.0	23.5	23.0	22.6	22.0
7 days	31.5	28.5	27.5	25.8	25.1	24.5
28 days	39.7	40.6	41.2	40.9	42.5	41.3

(Witnessed by : BUILDCON Sdn. Bhd.)

Table 4.2: Lab trial for grade 30 by using different proportion of GGBS replaces OPC

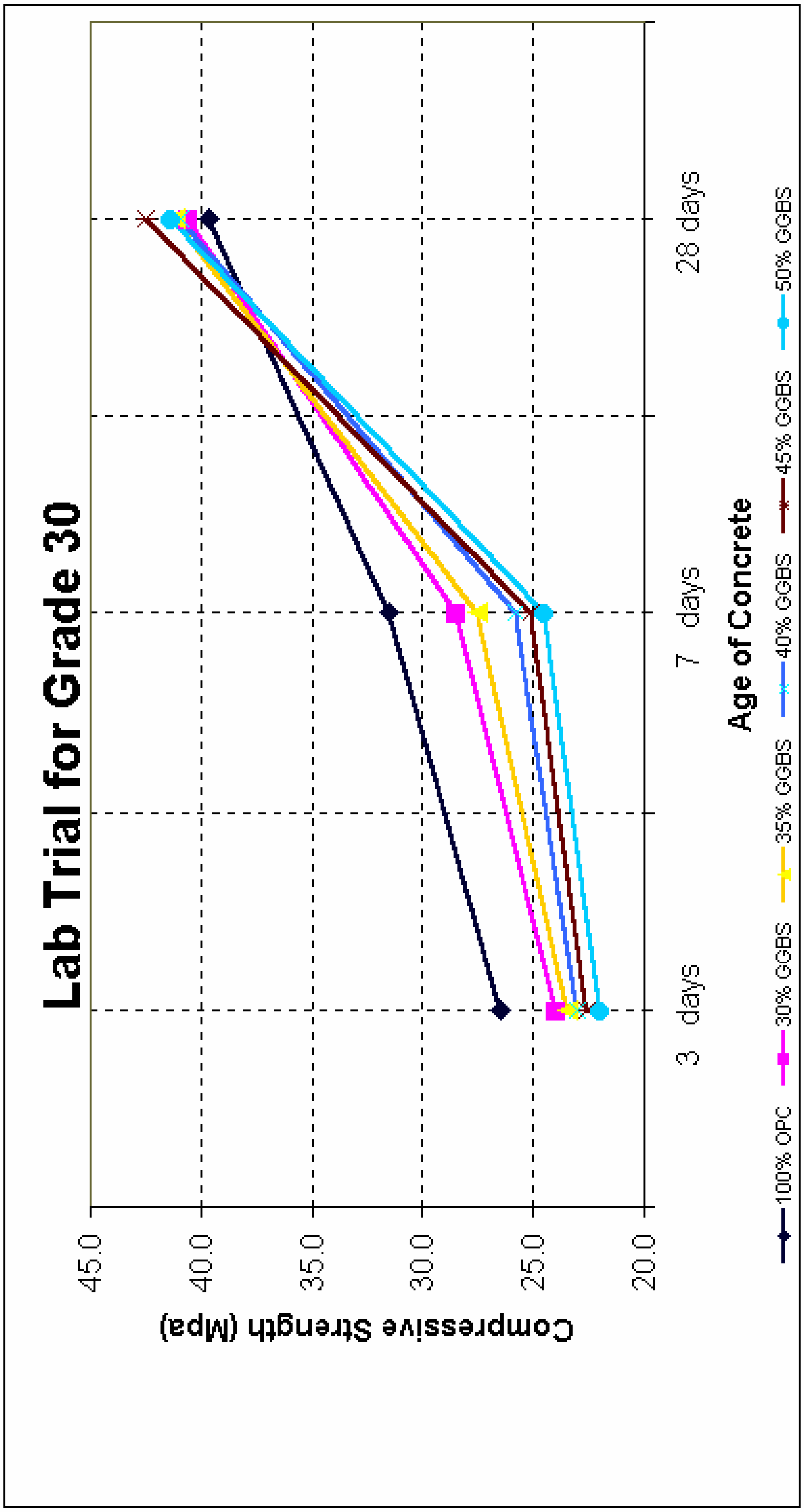


Figure 4.15: Laboratory test results

4.5 ANALYSIS

As expected, the slump heights of every batch are similar. In the laboratory test, the obtained results may not be the same as the value in construction site, because the site condition cannot be controlled as well as laboratory. Based on the inherent characteristic of heat of hydration for PBFC, figure 4.15 shows that the blend with 50% of GGBS replaces OPC has the lowest strength up to 7 days mean that it has the lowest heat of hydration and hence the early thermal cracking can be minimized the most (compared the proportion of GGBS from 0% to 50%). In addition, Figure 4.15 also shows that the compressive strength of the blend with 45% of GGBS replaces OPC increases simultaneously after 7 days and has a highest strength at 28 days (compared the proportion of GGBS from 0% to 50%).

The optimum blend of GGBS is found to have 50% of the total cementitious material, although this ratio may varies according to the grade of GGBS (Hogan and Meusel 1981, Fulton 1974). But the laboratory tests (figure 4.15) show that the optimum proportion is a blend of 45% of GGBS replaces OPC, the 4 % difference may be caused by human error or the fineness of GGBS (for example: it may be improperly compacted and etc).

Lower heat of hydration, chloride resistance, sulphate resistance and alkali-silica resistance can be improved by increasing the percentage of GGBS in PBFC. It is because the higher GGBS content, the lower temperature rises and lower permeability of the concrete can be expected. Therefore, early thermal cracking can be minimized due to the temperature difference and peak temperature can be reduced. Besides this, PBFC can improve durability of foundation (prevent from chloride, sulphate attack and alkali-silica reaction).

Furthermore, the price of GGBS is relatively low compared special purpose cements and admixtures, because it has no cementitious property which is a by-product in the manufacture of iron, and it cannot be used without blending with cement.

Benefits	Optimum Replacement Percentage of GGBS
Reduce heat of hydration	50%
Chloride resistance	Resist with increasing % of GGBS
Sulphate resistance	Minimum 50% for high sulphate resistance -- stated by Hogan and Meusel 1981.
Alkali-silica reaction resistance	Minimum 40% -- figure 8.2
Compressive strength improvement	45% -- lab test 40-50% -- stated by Hogan and Meusel 1981, Fulton 1974.

Table 4.3: Suggested Optimum replacement percentage of GGBS

The raft foundation may be exposed to attack from sulphate from various sources including ground water, industrial effluent and its by-products, decay of organic matter, sewage and etc. The blend with 50% of GGBS replaces OPC is good enough to minimize the alkali-silica reaction for the normal condition, and Wood (1981) stated that, in South Africa, its use has been predominantly at 50% of replacement of cement due to convenience in proportioning. Therefore it is chosen for the minimum case for sulphate resistance,

For raft foundation, higher proportion of GGBS in PBFC is expected in order to reduce the heat of hydration and peak temperature and protect from aggressive environment, but it will lead to longer wet curing day (Table 2.1). Proper curing is extremely important due to longer curing time, early thermal cracking will happen if the contractor lost control within this time. Due to the explanation stated above, 50% of replacement of GGBS will be the best to reduce the peak temperature, heat of hydration and produce a moderate wet curing time.

CHAPTER 5

CASE STUDY 2

Aim:

1. To find out methods used to control and minimize the thermal cracking in construction site during the curing stage.

2. To prove that early thermal cracking can be controlled through site monitoring tests by a blend of GGBS and OPC by the following sites:

(i) PBFC with a blend of 50% of GGBS replaces OPC

-- The first site is located at Pandan III, Elevator Reservior, in Johor Bahru. This monitoring is requested by Messrs. Hayasan Sdn. Bhd., the contractor, and Ranhill Civil Sdn. Bhd. as the client. The concrete temperature monitoring using thermocouples for a reservoir footing was carried out by Messrs. Geolab (M) Sdn. Bhd. The data were recorded through the prepared monitoring forms (appendix B) twice a day when the technician was analysing data.

The concrete volume of this footing is 2270 m^3. The concrete grade is C30 which is widely used for raft foundation. Chilled water was used to control the initial placing temperature at 30 ^oC.

(ii) PBFC with a blend of 70% of GGBS replaces OPC

-- The second site is located at 3 × 700 MW Coal Fired Power Plant Tanjung Bin, in Johor Bahru. This monitoring was requested by Messrs Shimizu Corporation. The concrete temperature monitoring using thermocouples and datalogger for raft foundation of chimney was carried out by Messrs. Geolab (M) Sdn. Bhd. from 5th August 2005 9.30am until 12th August 2005 10:29am. This is an on-going project so the data were daily recorded when the technician doing analysis.

The concrete volume of this raft foundation is 12000 m^3 and the grade is C35. PBFC with a blend of 70% of GGBS replaces OPC is used for this raft foundation because the foundation is located near to the sea and its thickness is 3.5 meters. Hence, temperature difference and peak temperature can be reduced and the durability of the structure can be improved.

Method: 1. Through questionnaire forms and personal interviews. Collect the data on the methods used at the construction site to control early thermal cracking and the temperature differential limit in the concrete section during the curing stage.

2. Through site temperature monitoring test. The author will maintain a record of the temperature differential at different points (from the top to the bottom) of a cross section of the raft foundation up to 200 hours for every monitoring test.

5.1 CURING METHODS

The following curing methods are collected through interviewing and questionnaire answered by quality control managers of different ready mix companies. Proper curing is extremely important for slag concrete to develop its potential strength and durability due to its inherent characteristic of lower heat of hydration and the longer curing times. For massive concrete pours, especially in the raft foundation or thick section, the contractor shall thermal cure the concrete to maintain a temperature differential between the internal (hottest) and external (coolest) temperature in order to reduce the temperature difference between the core and the surface of the concrete. Hence the early thermal cracking can be controlled.

5.1.1 PRECAUTION OF HOT WEATHER BEFORE CONCRETING IN CONSTRUCTION SITE

Due to the tropical climate in Malaysia, several precautions are important to limit the damaging effects of hot weather on concrete. However, damage to concrete caused by hot weather can never be fully alleviated. In concrete, the easiest ingredient to cool is water. The mixing water should be kept cool, or ice should be used. Warm water should be cooled or avoided.

However, do not add water at the job site to compensate for a loss in slump. Adding water increases the water-to-cement ratio to yield a lower overall strength at all ages and adversely affects other desirable properties of the hardened concrete, including durability and water tightness.

Prior to placement, cool all handling equipment such as mixers, chutes, pump lines and belts, by wetting them with cool water. Keep equipment shaded from direct sunlight, paint surfaces white, or covered with wet burlap to reduce the effect of the sun’s heat. Mist forms, reinforcing steel and sub-grade with cool water immediately prior to placement.

For the raft foundation, moisten the ground the evening before placement; taking special care to avoid leaving puddles on the sub-grade when concrete is placed. The hours for placement should be limited to the cooler hours of the day such as early morning, evening, or night. Placement during the evening or night hours allows the concrete to attain its primary set before the heat of the next day.

Avoid delays during placement. Traffic plan is very important for the major project because the traffic flow in Malaysia is always congested. The concrete should be delivered in the evening when after the peak hours or during weekends will be the best choice. Besides this, everything and everyone should be ready once the concrete arrives so placement can begin immediately. If delays do occur, avoid prolonged mixing even at agitation speed. It is best to stop mixing, and then agitate intermittently. Floating and finishing should begin promptly after placement. However, site mix plant can be proposed for mega project.

5.1.2 METHODS TO CONTROL AFTER CONCRETING

Suggest covering the concrete with insulating blankets to control the surface temperature of the concrete. These keep the surface warmer and prevent cracking. Temporary coverings such as polyethylene sheeting (Figure 5.1), layer of sand or wet burlap may be used to protect the concrete during the curing stage. Polyethylene sheeting is the most common method in Malaysia (comments from the site engineers), because it is the cheapest material, easy to cut in required shape and easy to handle.

Forms should be loosened or removed as soon as possible without causing physical damage to the concrete. Water should be applied sparingly to the surfaces, as excess water added to the surface during finishing will decrease the durability of the concrete. Avoid using water much warmer or colder than the concrete as temperature differentials can lead to early thermal cracking.

Adequate curing is critical for mass concrete. Continuous moist curing should begin as soon as surfaces are finished and should continue for at least 24 hours. The application of curing paper, plastic sheets (Figure 5.2), or membrane-forming curing compounds can be applied after the initial 24-hour moist curing period. These precautions pay off with increased concrete strength and durability and prevent the early thermal cracking.

As a concluded that, the materials used and the preparation before and after concreting are important, hence thermal cracking of raft foundation can be well controlled.

Figure 5.1: Concrete temporary covered by polyethylene sheeting on the plastic sheets to protect from the Sun.

Figure 5.2: Concrete is protected by a layer of plastic sheets to prevent lost of water during curing stage.

5.2 SITE TEMPERATURE MONOTORING TESTS

5.2.1 REVIEW OF TEMPERATURE CRITERIA TO AVOID CRACKING IN CONCRETE

1. Specified Criteria.

Fresh Concrete Temperature	≤ 32 °C
Maximum Internal Curing Temperature	≤ 90 °C
Limiting Temperature Differential	≤ 27 °C

2. Discussion On Limiting Temperature Differential

Fresh concrete must be kept below 32 °C to prevent the fresh concrete from excess water loss and early hydration. Besides this, OMEGA Thermocouple Wire Type K with a maximum temperature of 90 degree Celsius as a sensor is used (http://www.efunda.com), therefore maximum internal curing temperature must keep below 90 °C to avoid wrong measurement. The main factor which will cause the early thermal cracking is the temperature differential across a section.

Referring to BS 8110: Part 2: 1985 (Clause 3.8.4), early thermal cracking may occur through two different mechanisms.

(a) Internal Temperature Gradient In Mass Concrete
(b) External Restraint During Cracking of Mass Concrete

Based on the above understanding, a construction technique which can properly insulate the mass concrete in order to control heat loss and temperature differential will be most efficient and economical to avoid early thermal cracking. BS 8110: Part 2: 1985 (Clause 3.8.4) recorded that limiting temperature differential to 20°C has been successful to avoid early thermal cracking, but this apply to Gravel typed aggregate at the corresponding restraint factor, R, = 0.36 (Table 5.1).

When referring to Table 5.1, the Granite typed aggregate typically used in the local Malaysian construction industry can have an increased limiting temperature differential of 27.7 °C at the same corresponding restraint value, R = 0.36. This can be a conservative value as studies have found that massive pour cast into blinding concrete has typical restraint factor of R = 0.1 to 0.2 (Table 5.2). Therefore, thermal cracking can be controlled if the temperature differences do not exceed 27°C.

Aggregate Type	**Limiting temperature drop for varying restraint factor (*R*)**				**Limiting temperature differential when R=0.36**
	1.00	0.75	0.50	0.25	
	°C	°C	°C	°C	°C
Gravel	7.3	9.7	14.6	29.2	20.0
Granite	10.0	13.3	20.0	40.0	27.7
Limestone	16.0	18.8	32.0	64.0	39.0
Sintered p.f.a.	19.6	26.2	39.2	78.4	54.6

(Source: Table 3.2 of clause 3.8.4 of BS8110: Part2: 1985)

Table 5.1: Estimated limiting temperature changes to avoid cracking

Pour configuration	**Restraint factor (*R*)**
Thin wall cast on to massive concrete base	0.6 to 0.8 at base 0.1 to 0.2 at top
Massive pour cast into blinding	0.1 to 0.2
Massive pour cast onto existing mass concrete	0.3 to 0.4 at base 0.1 to 0.2 at top
Suspended slabs	0.2 to 0.4
Infill bays, i.e. rigid restraint	0.8 to 1.0

(Source: Table 3.3 of clause 3.8.4 of BS8110: Part2: 1985)

Table 5.2: Values of external restraint recorded in various structures

3. Concrete Temperature Control

The heat of hydration for the structural elements needs to be controlled to eliminate the thermal crack in concrete. The followings measures are employed;

- Ø Ground granulated blast-furnace slag as a cement substitute to reduce heat of hydration and to increase durability and water tightness of concrete.
- Ø Superplasticiser admixture is incorporated in mix proportion to increase workability, improve durability and reduce total cement content and thus heat of hydration.
- Ø Usage of flaked ice and chilled water for the control of the fresh concrete temperature.
- Ø Controlled insulation and suitable timing for striking of formwork of the concrete during curing period to limit excessive heat loss to the environment.

The temperature of fresh concrete at the place of concreting shall not exceed 32 °C. The rise in temperature within a period of 30 minutes shall not exceed the rate of heating. The temperature difference between any two points within any concrete section shall not exceed 27 °C at any time. The maximum core temperature shall not exceed 90 °C due to the thermocouple wire Type K with a maximum temperature of 90 degree Celsius as a sensor.

5.2.2 EQUIPMENT

The equipments used to monitor the concrete temperature were:

1. Thermocouple wire

A thermocouple is a sensor for measuring temperature. It consists of two dissimilar metals, jointed together at one end, which produce a small unique voltage at a given temperature. This voltage is measured and interrupted by a thermocouple thermometer.

Thermocouples are available in different combinations of metals or calibrations. The four most common calibrations are J, K, T and E. Each calibration has different temperature range and environment, although the maximum temperature varies with the diameter of the wire used in the thermocouple. Type K thermocouple are the most common used in industrial applications due to their large temperature range (http://www.efunda.com).

The thermocouple, which used in these two monitoring tests, is OMEGA Thermocouple Wire Type K with a maximum temperature of 90 degree Celsius as a sensor (Figure 5.3).

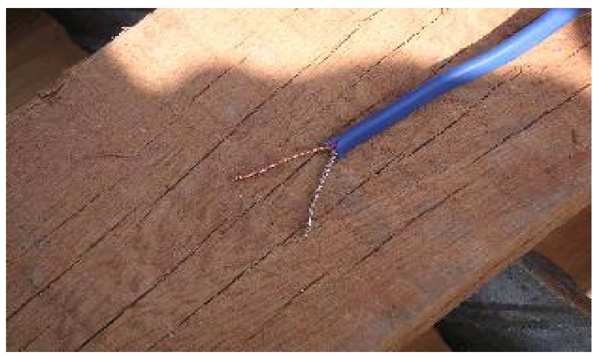


Figure 5.3: Thermocouple wire

2. Measurement And Control System – Datalogger

Figure 5.4: A rugged instrument with Research-Grade performance

Campbell Scientific dataloggers are at the center of our rugged, reliable data acquisition systems. The dataloggers share similar measurement and programming capabilities; selection of the appropriate datalogger depends mainly on the type, number, precision, and speed of measurements required. Multiplexers and/or SDM devices may be added to augment measurement and control capabilities that include (http://www.campbellsci.com.au):

- Ø Measuring most sensors.
- Ø Providing non-volatile data storage and on-board battery-backed clock (excludes CR7).
- Ø On-board data processing.
- Ø Initiating measurement and control functions based on time or event.
- Ø Controlling external devices such as pumps, motors, alarms, freezers, valves, etc.
- Ø Using our PC support software or keyboard/display to program.
- Ø Operating independently of ac power, computers, and human interaction.
- Ø Consuming minimal power from a 12 Vdc source.
- Ø Interfacing with on-site and telecommunication devices such as telephone modems (including cellular and voice-synthesized), short haul modems, radio transceivers, satellite transmitters, and Ethernet interfaces.
- Ø Operating temperature range of -25° to +50°C; optional extended ranges are available.

Multiplexers

Multiplexers increase the number of sensors that can be measured by a CR1000 by sequentially connecting each sensor to the datalogger (Figure 5.5). Several multiplexers can be controlled by a single CR1000. The CR1000 is compatible with the AM16/32 and AM25T. (http://www. Campbellsci.com.au/loggers.htm)

Figure 5.5: Campbell Scientific Datalogger (AM 16/32 Relay Multiplexer)

5.2.3 PROCEDURES TO INSTALL THERMOCOUPLE

1) Prior to installation, the thermocouple wires were tied to additional steel bars, which are then secured onto the reinforcement at the required position. This was to ensure the thermocouples would not dislocate during concreting (figure 5.6).

2) The thermocouple wire will be tied to the vertical reinforcing bars running to the top of the structure and the horizontal to the sides where there will be terminated at one point for monitoring (figure 5.7). Besides this, make sure the ends of the wires are not destroyed (figure 5.9).

3) All the thermocouple wires were numbered and tagged so as to avoid confusion at the time of installation (figure 5.10).

4) Connect the thermocouple wires to the datalogger (figure5.11), and the last step will be technician setting the timer for each monitoring point at site (figure5.12).

Figure 5.6: Prior to installation, the thermocouple wires were tied to additional steel bars.

Figure 5.7: The additional steel bar was tied to the structure.

Figure 5.8: The wires were pulled to the Datalogger.

Figure 5.9: Make sure end of the thermocouple wires are in good condition

Figure 5.10: The thermocouple wires are numbered with yellow color tag.

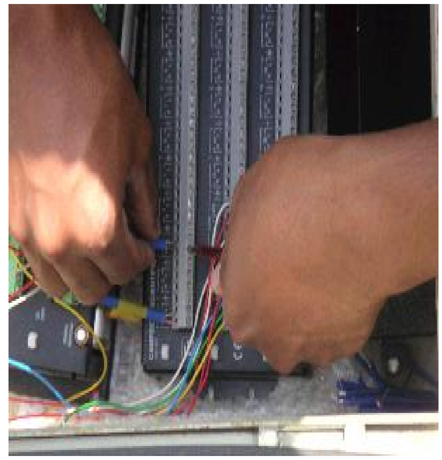


Figure 5.11: Connect the wires to Datalogger.

Figure 5.12: Technician sets timer for the data

5.3 LOCATION OF THERMOCOUPLES AT TWO SITES

A total of 15 thermocouples were installed at each site as shown in Figure 5.13 and 5.14.

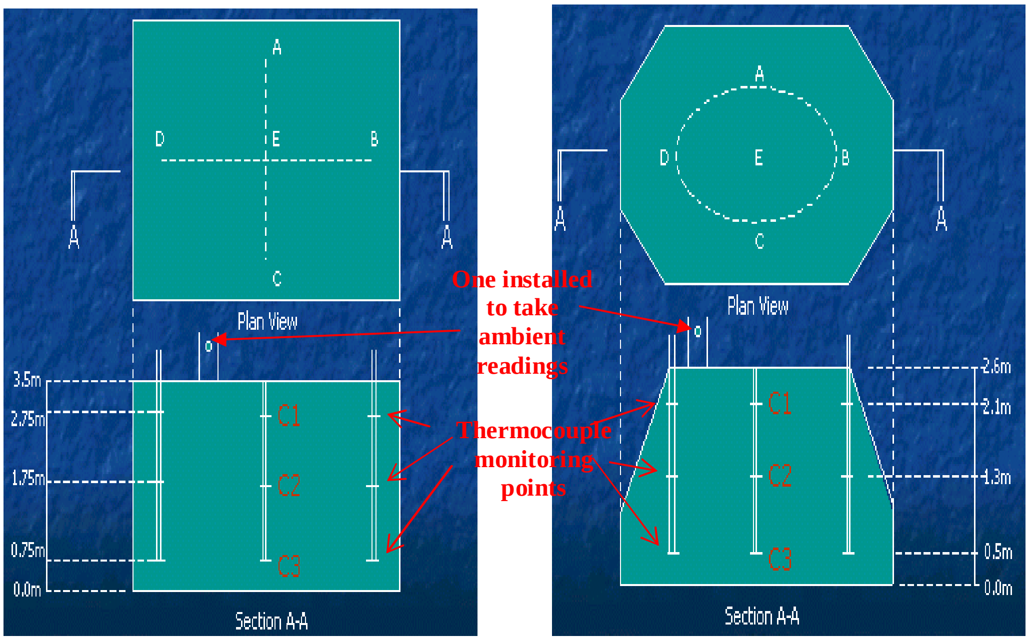


Figure 5.13: Location of thermocouples at raft foundation of chimney in Tanjung Bin.

Figure 5.14: Location of thermocouples at elevator reservoir in Pandan III

5.4 MONOTORING RESULTS

Tabulated data of all thermocouples at 2 monitoring sites are presented in Appendix. Figure 5.15 to 5.23 are the graphic plots analysis of point A, B and E in elevator reservoir. Besides this, figure 5.24 to 5.32 are the graphic plots analysis of point A, B and E in raft foundation of Chimney.

Point A

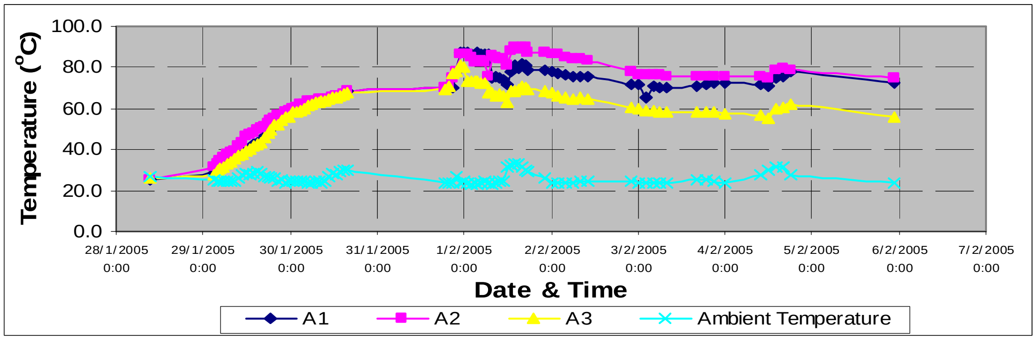


Figure 5.15: Thermocouple readings at point A of Elevator reservoir in Pandan III.

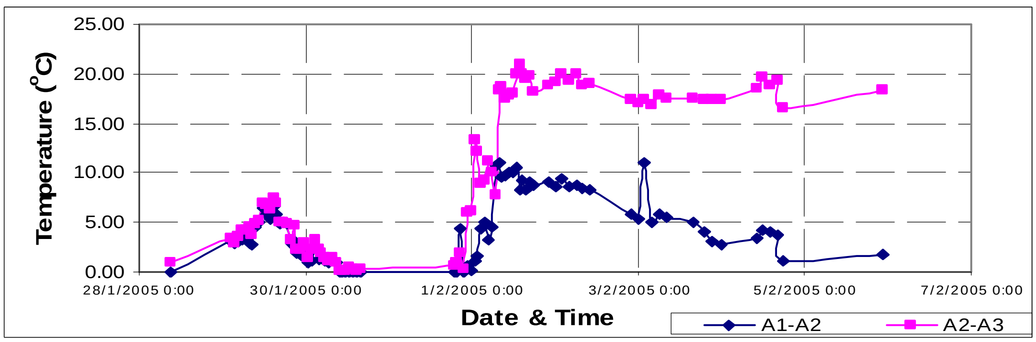


Figure 5.16: Differential readings at A1-A2 & A2-A3 at Elevator Reservoir in Pandan III.

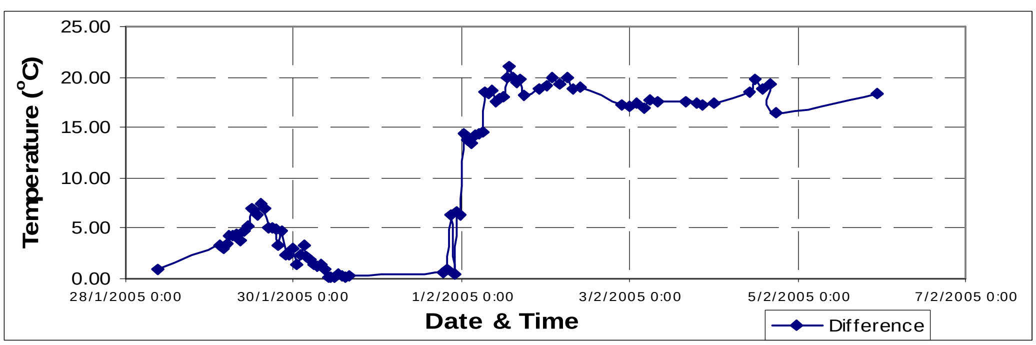


Figure 5.17: The difference of maximum and minimum readings at point A of Elevator Reservoir in Pandan III.

Point B

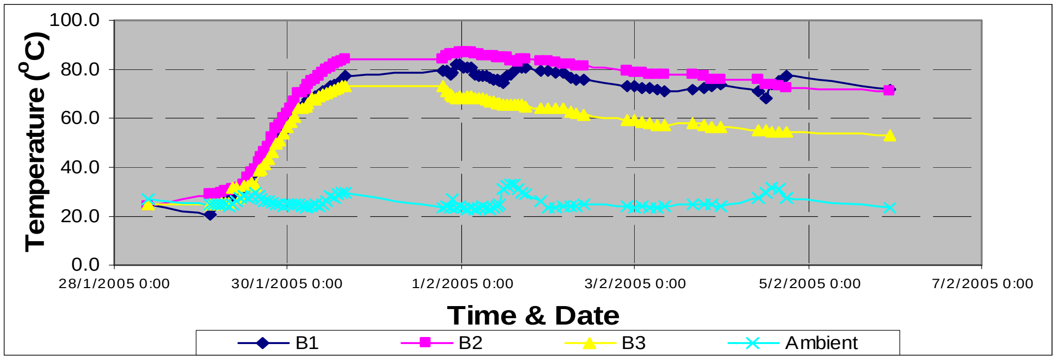


Figure 5.18: Thermocouple readings at point B of Elevator reservoir in Pandan III.

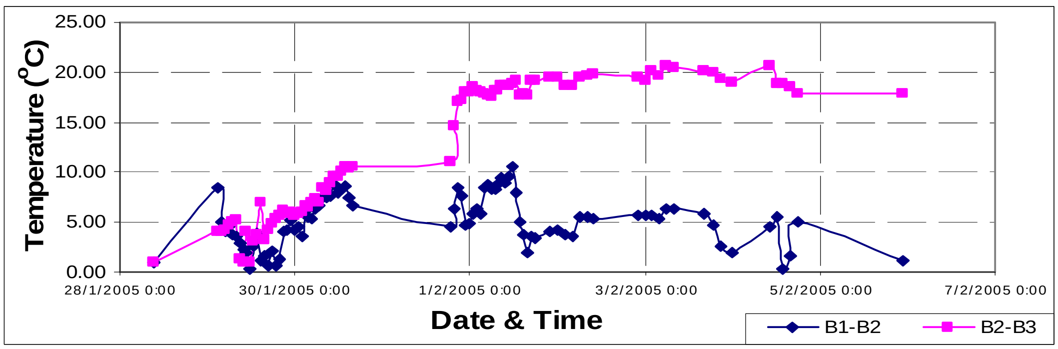


Figure 5.19: Differential thermocouple readings at B1-B2 and B2-B3 of Elevator Reservoir in Pandan III.

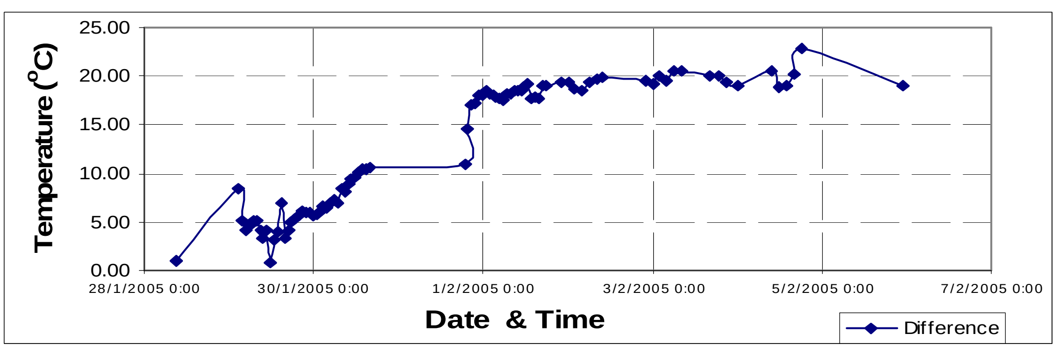


Figure 5.20: The difference of maximum and minimum thermocouple readings at point B of Elevator Reservoir in Pandan III.

Point E

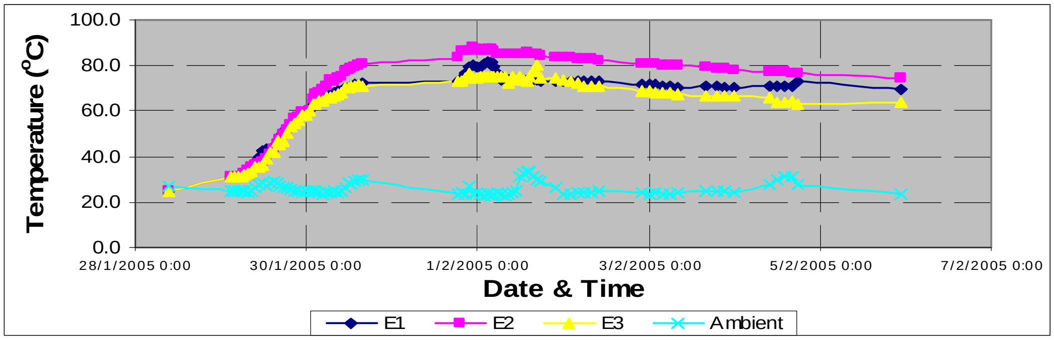


Figure 5.21: Thermocouple readings at point E of Elevator reservoir in Pandan III.

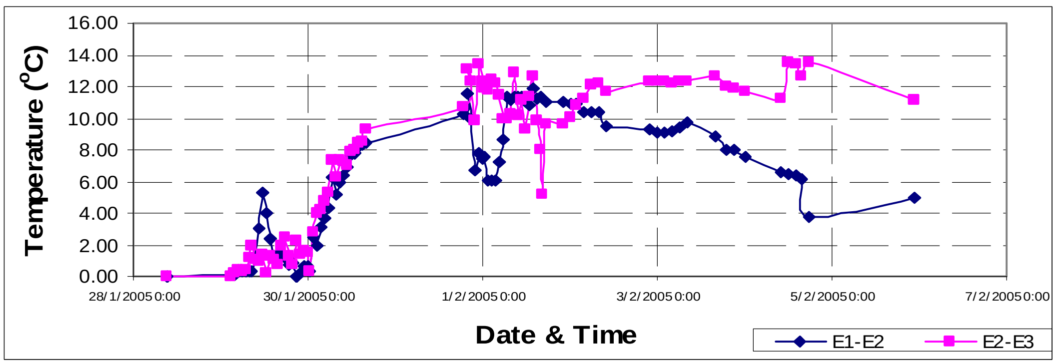


Figure 5.22: Differential thermocouple readings at E1-E2 and E2-E3 of Elevator Reservoir in Pandan III.

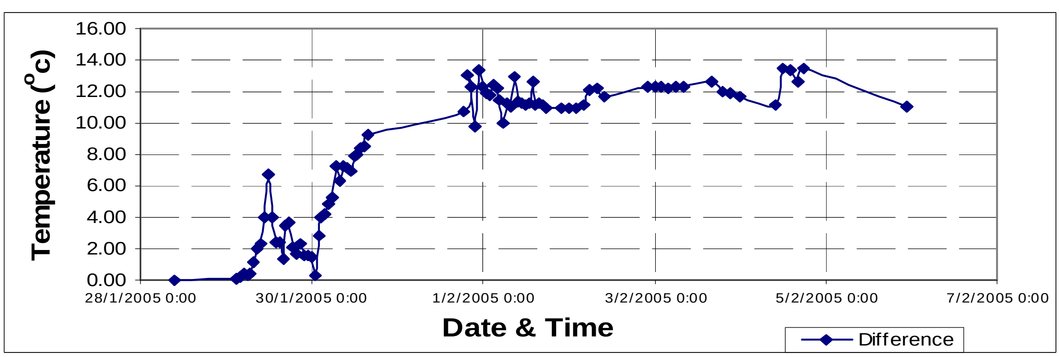


Figure 5.23: The difference of maximum and minimum thermocouple readings at point E of Elevator Reservoir in Pandan III.

Point A

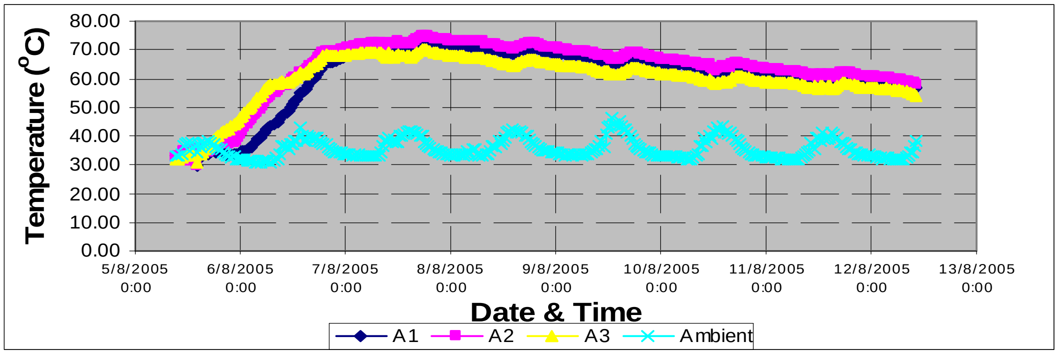


Figure 5.24: The thermocouple readings at point A of raft foundation in Tanjung Bin.

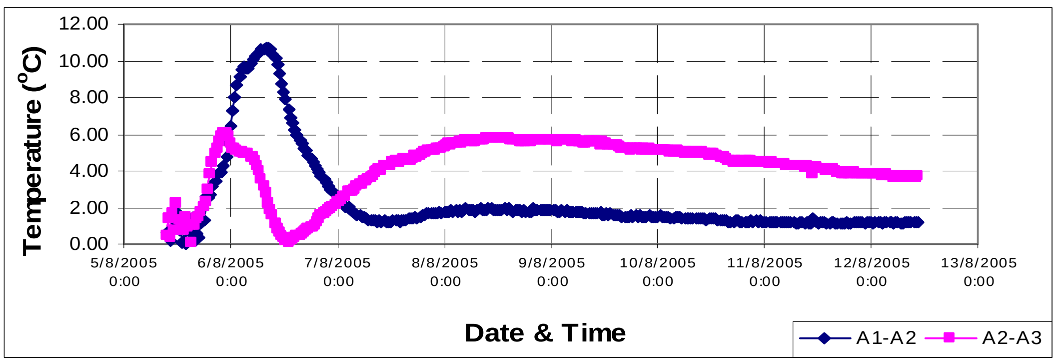


Figure 5.25: Differential thermocouple readings at A1-A2 and A2-A3 of raft foundation in Tanjung Bin.

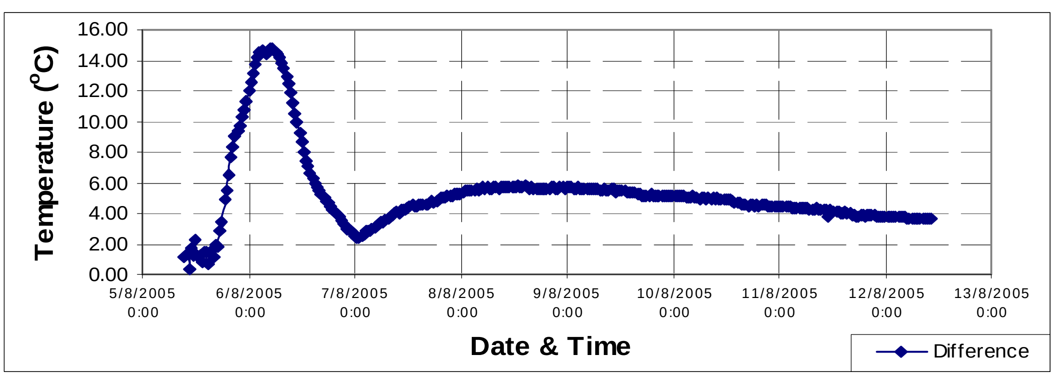


Figure 5.26: The difference of maximum and minimum thermocouple readings at point A of raft foundation in Tanjung Bin

Point B

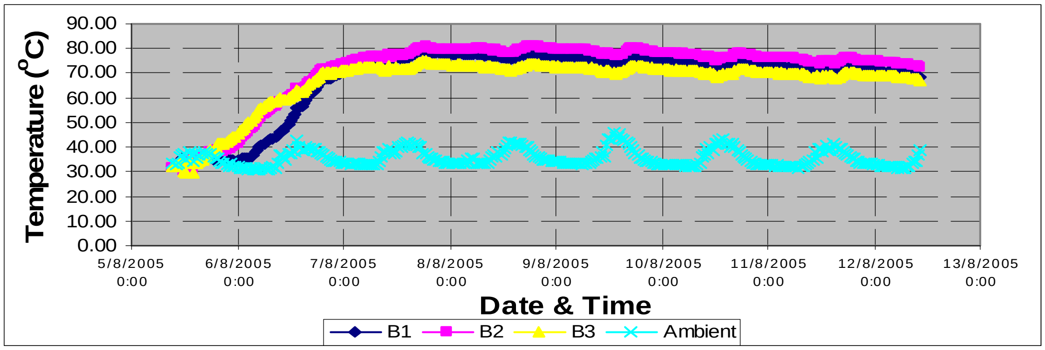


Figure 5.27: The thermocouple readings at point B of raft foundation in Tanjung Bin.

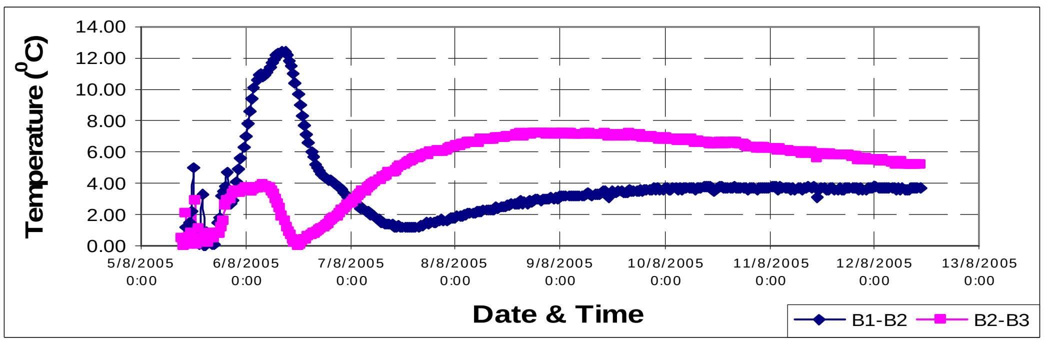


Figure 5.28: Differential thermocouple readings at B1-B2 and B2-B3 of raft foundation in Tanjung Bin.

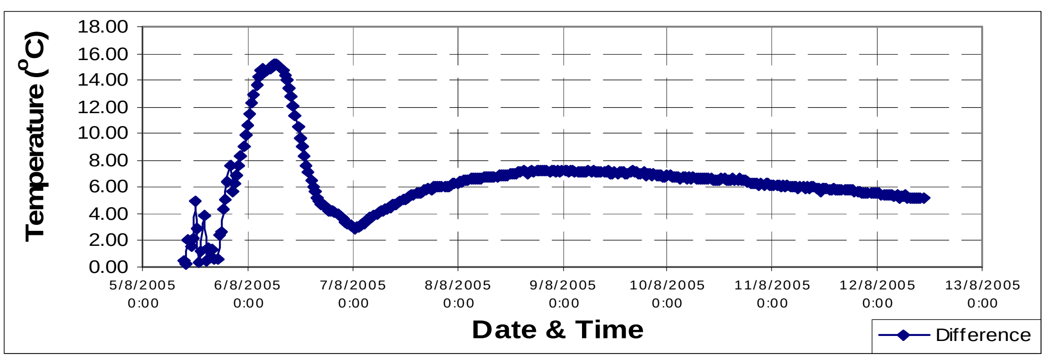


Figure 5.29: The difference of maximum and minimum thermocouple readings at point B of raft foundation in Tanjung Bin.

Point E

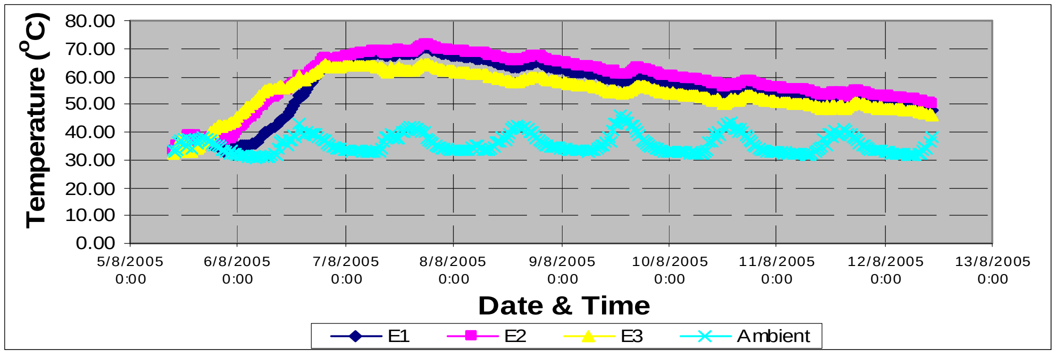


Figure 5.30: Thermocouple readings at point E of raft foundation in Tanjung Bin.

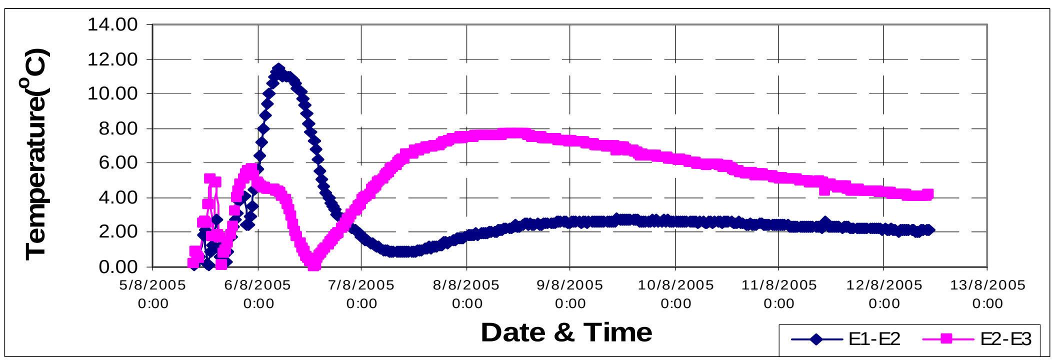


Figure 5.31: Differential thermocouple readings at E1-E2 and E2-E3 of raft foundation in Tanjung Bin.

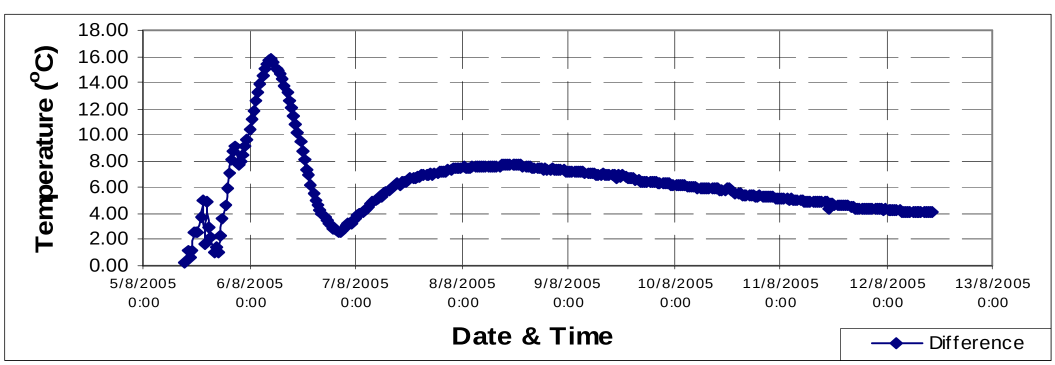


Figure 5.32: The difference of maximum and minimum thermocouple readings at point E of raft foundation in Tanjung Bin.

5.5 COMMENTS AND OBSERVATIONS

During the course of the monitoring at elevator reservoir in Pandan III, temperature readings were recorded and indicated by sensor at point A, B, C, D and E from 28th January 2005 9.15am until 5th February 2005 10:45am. The readings analysis at A1, A2, A3, B1, B2, B3, E1, E2, E3 and ambient temperature are shown at figure 5.15, 5.18 and 5.21, besides this the monitoring data of the symmetrical point C and D are shown in Appendix D.

There are three specified criteria which stated in section 5.2. From figure5.15, 5.18 and 5.21, the monitoring temperature at the beginning is 25˚C which mean the temperatures of fresh concrete are kept below 32˚C. Besides this, the maximum temperature is lower than 90˚C because Thermocouple Wire Type K with a maximum temperature of 90 degree Celsius as a sensor, therefore two specified criteria are satisfied.

From figure 5.16, 5.17, 5.19, 5.20, 5.22 and 5.23, the temperature difference across the reservoir at point A, B and E can be kept below the specified limit of 27 degree Celsius, hence the induced thermal stresses will not caused any cracking within the block of concrete by using 50 percent of OPC replaced by GGBS.

The second temperature monitoring site is a raft foundation of chimney in 3×700 MW Coal Fired Power Plant Tanjung Bin, Johor Bahru. The PBFC used in this foundation is 70 percent of OPC replaced by GGBS. The full tabulated temperature readings at point A, B, C, D and E are shown in Appendix E. The data of temperature were recorded and indicated by sensor from 5th August 2005 9.30am until 12th August 2005 10:29am.

Based on figure 5.24 to 5.32, the concrete temperatures fulfill the following three specified criteria. Therefore, early thermal cracking can be controlled in this raft foundation.

i. Fresh Concrete Temperature ≤ 32 °C

ii. Maximum Internal Curing Temperature ≤ 90 °C

iii. Limiting Temperature Differential ≤ 27 °C

The PBFC used in raft foundation of chimney is 70 percent of OPC replaced by GGBS because the foundation is near to sea. Therefore, higher percentage of OPC replaced by GGBS can result in higher resistance to sulphate and chloride attack. Besides this, the temperature difference across the raft foundation is lower although the thickness is higher than the reservoir (compared figure 5.17 and 5.26, 5.20 and 5.29, 5.23 and 5.32). It can prove that the concrete will have lower heat of hydration by increasing the percentage of GGBS in PBFC.

CHAPTER 6

ENVIRONMENTAL BENEFITS OF GGBS

One of the remediation options to reduce the reliance on landfill is by the re-use of resources in a sustainable way which represents a more acceptable environmental solution. Ground granulated blast furnace slag, GGBS is a by-product of the steel industry. When iron is manufactured in a blast furnace, the purified slag will floats on the top. This is drawn off and cooled in a carefully controlled process. When finely ground, the resulting material is identical to Portland cement but with different chemical ratio. It has been widely and effectively used since 1861 in the European construction industry.

GGBS is technically superior and environmentally friendly cement used widely throughout the world. GGBS is remarkable in that it produces great strength and durability in concrete, while emitting virtually zero carbon dioxide (CO_2) and no noxious gases to the atmosphere in the manufacturing process. Its direct availability for the first time will benefit the construction industry and assist in reducing greenhouse gas emissions.

6.1 PROCESS OF MANUFACTURING GGBS

As a co-product of the iron making industry, GGBS is a blast furnace slag which has been rapidly cooled, dried and ground to a fine powder. Iron ore, limestone and coke are carefully dry blended in ore blending beds. This material is initially burnt on a sinter strand to produce an open textured material that represents 70-80 percent of the furnace burden. The balance of the burden is made up with coke and direct charge materials. Complex reactions take place in the furnace resulting in temperature of around 2000 ^{o}C and reducing the iron ore to metallic iron and slag. These liquids are tapped from the furnace and separated for further processing.

An efficient furnace is needed to ensure that high quality blast furnace slag can be produced. Molten blast furnace slag is cooled instantaneously by quenching in large volumes of cold water, known as granulation, to produce Granulated Blast Furnace Slag. This process produces a glassy, homogeneous, non-crystalline material.

To produce GGBS, the granulated blast furnace slag needs to be dried and ground. The dry granulate is fed at a prescribed rate into high pressure roller crusher reducing the granulate size, and a higher concrete strength can be obtained by increasing the fineness. This powder is GGBS that has cementitious properties, but it is not a viable product on its own, because GGBS harden in very slow rate without blending of cement (Annual Report, Washington, 1991).

6.2 ENVIRONMENTAL BENEFITS

OPC is oproduced by a highly energy intensive process, utilising GGBS to replace OPC will bring environmental benefit. Manufacturing of Portland cement is a major contributor of greenhouse gases. The manufacture of one tonne of traditional Portland cement involves approximately 1.6tonnes of quarry materials and the output up to one tonne of CO_2 to the atmosphere, in addition to noxious gases including sulphur dioxide, oxides if nitrogen and carbon monoxide. In the other word, the manufacture of Portland cement is responsible for about 5% of all global carbon dioxide emissions. In comparison, manufacture of GGBS requires less than one fifth of the energy and produces virtually zero CO_2 and no noxious gases to the atmosphere. Therefore, the use of GGBS will assist in reducing greenhouse gas emissions.

GGBS also has no impact on the natural landscape, as there is no need for quarrying of raw materials. As a result, GGBS has an important role to play in environment protection and reduction of greenhouse and other gas emission.

Each year, the UK uses nearly 2 million tonnes of GGBS as cement, which:

- reduces carbon dioxide emissions by almost 2 million tonnes;
- reduces primary energy use by 2,000 million kWh;
- saves 2.5 million tonnes of quarrying;
- saves a potential landfill of nearly 2 million tonnes.

There are also strong and economically significant public health reasons to use GGBS in place of Portland cement for the elimination of each tonne of CO_2 emissions caused by fossil fuel use. Health and environmental benefits arise mainly through reduced emissions of noxious gases and dust particles, combinations of which cause respiratory problems, acid rain, and damage to agricultural productivity. About 43% of CO_2 emissions from the production of Portland cement currently arise from the use of fossil fuels. It is estimated that each tonne of ordinary Portland cement made, costs the country approximately €15 in health costs which equating to a figure of approximately €50millions per annum.

As concluded, the replaced of OPC by GGBS produces better, more durable concrete at lower economic and environmental cost.

CHAPTER 7

CONCLUSION

The above chapters achieve the study objectives mentioned in chapter 1, and proved that early thermal cracking of raft foundation can be controlled by different percentage of Ordinary Portland Cement (OPC) replaced by Ground Granulated Blast-furnace Slag (GGBS). Besides this, Portland Blast Furnace Cement (PBFC) has a long history of successful use throughout the World, being first produced over 100 years ago.

As a consequence there is a technical data, experience and examples to support the choice of PBFC for every application. The established advantages may be summarized as:

Improved workability	Ø For placing, ease of compaction and finishing.
Retained workability	Ø For coping with transport and site delays.
Reduced heat of hydration	Ø For developing lower peak and less overall heat of hydration, thus reducing risk of thermal cracking and for retained-strength capability.

Long term strength gain	Ø For long-term structural integrity.
Increased durability	Ø For aggressive environment providing -Higher resistance to sulphate attack -Higher resistance to chloride penetration -Resistance to acids -Protection against Alkaline-Silica reaction
Light colour	Ø For architectural appeal.

For general use, the proportion of GGBS which replaces the OPC is between 40 percent and 55 percent. This level is usually governed by the performance of the OPC and the type and quality of the aggregates. By reducing the addition rate to 30 percent of GGBS, sufficient early age strength may be achieved for operations such as early handling of precast units.

However, depending on the specific application to raft foundation, higher addition rates enhance the benefits of using GGBS. By using up to 70 percent GGBS, a greater degree of durability is imparted and temperature rise is further reduced. Nevertheless, concrete cannot be made using only GGBS with no cement because the hydration (setting and hardening) of GGBS on its own is too slow to be of practical use. When cement and GGBS are used together the release of alkalis causes the hydration process to accelerate resulting in a much improved rate of gain of strength in the concrete.

Apart from the intrinsic advantages of PBFC, there are additional environmental benefits to be derived through their choice with the production of GGBS and make more economical end product. GGBS is a by-product of iron and hence PBFC has the following criteria compared with Portland cement alone:

- Reduce the demand on naturally occurring raw materials.
- Reduce energy consumption.
- Reduce emission of carbon dioxide and other noxious gas.
- Save quarrying and landfill.

For the Company that has agreement with the Government which requires continuous improvement in the energy saving, PBFC will be the best choice for industry construction because it reduces the use of fossil fuels and decreasing carbon dioxide emissions.

Concrete containing GGBS will cost no more than the equivalent concrete produced with OPC alone, and will almost certainly be less than concrete with sulfate resisting Portland cement and other special purpose cements. For raft foundation, a large amount of concrete will be needed, therefore, the usage of GGBS not only improved the quality and environmental enhancement but also reduced the total cost.

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APPENDIX

A

University of Southern Queensland

Faculty of Engineering and Surveying

ENG 4111/2 Research Project
PROJECT SPECIFICATION

FOR:	Kong Mun Kai
TOPIC:	The Control of Early Thermal Cracking of Raft Foundation by Using Slagcrete Portland Blast-Furnace Cement (PBFC).
SUPERVISOR:	Dr. Amar, Khennane
ASSOCIATE SUPERVISOR:	Mr. Johnson
PROJECT AIM:	Describe 'The Control of Early Thermal Cracking of Concrete for Raft Foundation by Using Slagcrete Portland Blast-Furnace Cement (PBFC)' and analyze the other benefits for raft foundation by using PBFC.
SPONSORSHIP:	none
PROGRAMME:	**Issue A, 21 March 2005**

1. Research information on the factors that would cause early thermal cracking and the characteristic of PBFC that can overcome the problems.
2. Research other benefits by using the blend of 2 components for raft foundation and show that it is a good choice to be used as controlling early thermal cracking.
3. Investigate through questionnaire, if a blend of GGBS and OPC is suitable used in Malaysia and the methods used to minimize early thermal cracking in construction site.
4. Proved by experiments that early thermal cracking can be controlled and minimized by using a blend of GGBS and OPC.

AGREED: ……………………………. (student) …………………. (Supervisor)

……………………………. (dated) …………………. (dated)

APPENDIX

B

QUESTIONNAIRE FORM

Date :

Name :

Name of company :

Designation :

Years of experience :

Telephone :

Objectives

- Ø **Determine the importance of thermal crack**
- Ø **Investigate type of cement and the methods used to control thermal crack.**

  (All of the information provided will be treated as confidential)

1. **For raft foundation, is the thermal crack an important issue?**

   □ Not important □ Moderate Important □ Important □ Very Important

2. **Is thermal crack mainly caused by thermal movement and temperature different of a cross section of concrete? (**For ready mix concrete company**)**

   □ Yes □ No

   If yes, what type of cement is normally used to control it?

   ____

   If no, what is the major factor that would produce thermal crack?

   ____

3. **Can the High Slag Blastfurnace Cement (blend of OPC & GGBS) be used to control the thermal crack?** (For ready mix concrete company)

   □ Yes, what is the normal proportional?________________________________

   □ No____

4. **Is temperature of concrete important during the curing stage? Why? (**In construction site**)**

   □ Yes ____

   □ No ____

5. **Is 'spray water' the only common method that used to control the moisture of the concrete during curing stage? Why? (**In construction site**)**

   □ Yes ____

   □ No ____

6. **What are the methods that can be used to control the surface temperature in order to reduce the temperature different between the concrete surface and its core? (**In construction site**)**

   ____

   ____

7. **What is the blended cement normally be used for raft foundation? And what is the blended proportion?**

   ____

   ____

8. **Give an example that PBFC has successfully been used in Malaysia's project.**

   ____

   ____

APPENDIX

C

THERMOCOUPLE TEMPERATURE MONITORING FORM

Temperature in °C																	
		Location A			Location B			Location C			Location D			Location E			
DATE	TIME	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	AMBIENT

Prepared by Kong

APPENDIX

D

PANDAN III, ELEVATOR RESERVOIR

THERMOCOUPLE TEMPERATURE MONITORING RECORD

Date & Time	Temperature in °C															
	Location A			Location B			Location C			Location D			Location E			AMBIENT
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	
28/1/2005 9:15	25.0	25.0	26.0	25.0	24.0	25.0	25.0	25.0	25.0	27.0	25.0	25.0	25.0	25.0	25.0	27.0
29/1/2005 2:45	28.1	31.2	27.8	20.5	28.9	24.8	31.2	31.8	31.2	31.7	31.8	31.5	31.1	31.0	31.0	25.0
29/1/2005 3:45	29.7	32.7	29.8	24.0	29.1	25.0	31.3	32.0	31.2	31.9	32.0	31.8	31.2	31.3	31.1	24.8
29/1/2005 4:45	31.2	34.3	30.8	25.3	29.3	25.1	31.4	32.1	31.4	32.0	32.1	31.9	31.0	31.4	31.0	24.8
29/1/2005 5:45	32.8	36.0	31.7	25.4	30.0	25.3	31.5	32.3	31.5	33.1	33.2	33.0	31.2	31.5	31.2	24.8
29/1/2005 6:45	33.5	37.5	33.3	26.8	30.5	25.4	31.7	33.1	31.6	34.5	34.7	34.2	32.0	32.3	31.9	24.7
29/1/2005 7:45	35.7	38.7	34.2	27.1	30.6	25.4	32.1	33.7	31.5	36.5	36.7	36.0	33.8	34.1	32.9	24.3
29/1/2005 8:45	36.3	39.1	35.3	27.8	30.7	32.0	33.2	34.1	32.0	37.4	38.2	37.2	34.9	35.2	33.2	24.7
29/1/2005 9:45	37.2	41.7	36.9	28.7	31.0	32.0	34.1	36.2	32.6	39.9	40.2	39.8	37.5	36.3	35.2	26.3
29/1/2005 10:45	38.1	43.2	38.0	29.8	31.7	27.6	36.2	38.7	34.0	42.0	42.1	42.0	39.8	36.8	35.8	27.8
29/1/2005 11:45	39.7	46.2	39.2	32.7	33.0	32.1	37.2	39.8	36.4	43.2	43.2	43.1	42.8	37.5	36.1	28.1
29/1/2005 12:45	41.1	47.0	40.2	33.1	35.7	32.6	39.4	40.1	37.4	45.2	45.7	45.2	43.0	39.0	39.2	27.3
29/1/2005 13:45	42.8	48.1	41.7	34.0	37.9	34.1	40.9	41.2	38.5	48.0	48.3	47.2	43.2	40.8	42.1	28.1
29/1/2005 14:45	43.1	49.7	42.3	38.1	39.2	32.2	42.1	44.3	40.0	49.2	50.1	47.9	44.4	43.1	42.0	29.4
29/1/2005 15:45	44.4	50.2	43.2	40.1	41.8	38.5	44.6	46.2	42.5	51.7	52.1	48.1	47.1	45.7	46.5	28.2
29/1/2005 16:45	46.3	51.1	46.0	43.2	43.8	39.6	46.5	47.6	44.1	53.1	54.8	50.0	48.7	47.2	45.2	27.0
29/1/2005 17:45	48.1	53.1	48.0	44.3	46.4	41.5	47.8	49.8	46.2	54.1	55.8	52.1	50.8	49.6	47.1	26.5
29/1/2005 18:45	49.9	54.7	49.8	47.8	48.5	43.2	49.8	50.2	47.6	55.4	56.1	53.2	52.3	51.5	50.2	26.1
29/1/2005 19:45	52.1	55.1	51.8	50.8	52.1	46.4	50.9	51.2	50.3	55.2	57.2	54.7	54.9	54.0	53.2	25.6
29/1/2005 20:45	53.7	56.8	52.1	51.7	55.8	49.6	54.0	55.0	52.7	57.1	58.7	56.3	56.8	56.8	54.5	24.6
29/1/2005 21:45	55.0	57.0	54.7	52.8	57.0	51.1	54.2	56.3	53.8	58.3	59.8	57.8	57.8	57.6	56.2	24.9
29/1/2005 22:45	56.3	58.3	56.0	54.8	60.0	54.0	56.7	58.1	56.2	60.2	62.1	59.8	59.2	59.8	58.2	24.0
29/1/2005 23:45	57.6	59.1	56.1	57.8	62.1	56.4	58.3	59.7	57.7	61.9	62.1	59.8	59.2	59.8	58.3	24.6
30/1/2005 0:45	58.8	59.8	58.3	59.7	64.3	58.5	60.2	61.2	59.2	62.1	63.2	60.2	60.2	60.5	60.2	24.8
30/1/2005 1:45	59.1	60.3	58.0	63.5	67.0	61.0	61.7	62.2	31.2	63.2	65.8	62.0	63.1	65.6	62.8	24.5
30/1/2005 2:45	59.8	62.4	59.1	64.2	70.4	63.8	64.0	64.7	63.4	63.8	71.3	62.8	65.4	67.3	63.3	24.7
30/1/2005 3:45	61.0	62.3	60.1	65.1	70.6	64.1	63.8	64.1	63.8	64.2	73.0	63.2	65.3	68.4	64.2	24.1
30/1/2005 4:45	62.1	63.7	61.8	66.1	71.4	64.5	65.2	65.7	64.5	66.3	75.1	64.2	65.5	69.2	64.4	23.7
30/1/2005 5:45	62.6	63.8	62.4	67.3	73.7	66.4	65.9	66.2	65.8	68.1	77.2	65.8	66.7	71.0	65.7	23.9
30/1/2005 6:45	63.0	64.0	62.8	68.5	75.2	68.2	67.9	67.3	66.7	69.7	78.0	67.5	67.3	73.6	66.3	24.3

Sheet 1 of 3

PANDAN III, ELEVATOR RESERVOIR

THERMOCOUPLE TEMPERATURE MONITORING RECORD

Date & Time	Temperature in °C															AMBIENT
	Location A			Location B			Location C			Location D			Location E			
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	
30/1/2005 7:45	63.5	64.8	63.3	68.8	76.2	67.7	68.0	68.2	67.6	70.2	79.1	68.7	67.9	73.1	66.8	24.5
30/1/2005 8:45	64.0	64.9	64.0	69.8	77.2	69.1	68.9	69.1	68.6	71.5	80.2	69.8	68.6	74.6	67.3	24.0
30/1/2005 9:45	64.1	64.1	64.0	70.9	78.6	69.7	69.7	69.9	69.4	72.8	82.1	70.1	69.1	75.5	68.3	24.6
30/1/2005 10:45	64.7	64.7	64.5	71.3	80.1	70.6	70.3	70.5	70.2	73.0	84.7	70.9	70.1	77.0	70.0	26.4
30/1/2005 11:45	65.3	65.3	65.1	72.9	80.9	71.3	70.7	70.9	70.9	74.2	85.2	72.1	70.4	78.1	70.2	28.1
30/1/2005 12:45	65.8	65.8	65.3	73.8	82.0	71.9	71.0	71.2	71.7	75.1	86.1	73.0	71.2	79.0	71.0	27.8
30/1/2005 13:45	66.2	66.2	66.5	74.1	82.7	72.2	71.9	72.8	72.1	76.3	87.3	74.2	71.3	79.5	71.1	29.1
30/1/2005 14:45	67.1	67.1	67.3	75.8	83.3	72.9	72.1	73.1	72.7	77.2	88.2	75.2	71.8	80.1	71.6	29.6
30/1/2005 15:45	68.3	68.3	68.0	77.2	83.9	73.3	72.8	73.2	73.2	78.2	89.2	76.2	72.1	80.5	71.2	29.6
31/1/2005 18:45	69.8	69.8	69.2	79.6	84.2	73.2	73.2	74.6	72.8	79.4	90.6	77.5	73.2	83.5	72.8	23.7
31/1/2005 19:45	70.1	70.1	71.0	79.2	85.6	71.0	75.6	74.9	72.6	78.6	90.8	77.6	74.7	86.3	73.2	23.8
31/1/2005 20:45	70.4	74.8	76.8	78.0	86.5	69.5	76.4	75.2	70.8	78.2	91.0	78.1	76.5	86.5	74.2	23.7
31/1/2005 21:45	77.7	77.7	78.1	78.8	86.4	69.2	78.9	78.4	72.6	77.5	91.2	79.4	79.5	86.2	76.4	26.8
31/1/2005 22:45	87.4	86.8	80.8	81.8	86.5	68.4	82.3	90.9	74.9	77.7	91.9	79.6	79.9	87.7	74.3	23.7
31/1/2005 23:45	87.1	86.9	80.7	81.9	86.8	68.8	82.4	91.0	74.3	77.4	91.8	78.6	79.6	87.1	74.8	24.1
1/2/2005 0:45	87.4	86.3	73.0	81.0	86.9	68.4	82.2	90.6	74.3	77.9	92.4	81.2	79.2	86.8	74.9	23.4
1/2/2005 1:45	86.9	85.2	73.1	80.7	87.0	68.8	79.6	90.6	74.1	78.1	89.3	81.3	80.7	86.8	75.0	23.0
1/2/2005 2:45	86.8	82.4	73.4	80.8	86.7	68.7	79.6	90.7	74.0	77.4	89.1	80.1	81.4	87.5	75.1	23.6
1/2/2005 3:45	87.4	82.4	73.1	77.9	86.4	68.5	79.5	90.7	71.3	77.7	89.1	80.2	81.3	87.4	75.2	22.9
1/2/2005 4:45	86.8	83.6	72.4	77.4	86.1	68.4	77.8	88.2	71.2	77.4	89.1	77.9	79.6	86.8	75.3	23.7
1/2/2005 5:45	86.9	82.4	72.4	77.4	85.7	68.1	77.3	87.9	70.7	76.3	86.3	76.3	76.8	85.4	75.4	24.1
1/2/2005 6:45	86.4	75.7	67.9	77.4	85.7	67.5	77.4	87.9	70.2	75.0	85.8	70.2	74.1	85.4	75.4	23.7
1/2/2005 7:45	74.9	86.0	67.7	76.7	85.4	67.2	75.7	85.4	70.2	75.2	86.8	71.3	74.3	85.4	75.1	23.0
1/2/2005 8:45	75.3	84.9	66.3	75.9	85.3	66.7	71.7	85.4	69.7	75.4	84.7	70.3	73.7	85.1	72.2	23.7
1/2/2005 9:45	74.5	84.3	66.8	75.9	84.9	66.3	74.1	87.3	69.3	74.1	85.7	69.9	73.7	85.1	74.9	24.2
1/2/2005 10:45	74.1	84.2	66.3	75.1	84.7	66.1	74.1	86.8	68.9	74.0	86.0	69.1	73.7	85.0	73.9	24.7
1/2/2005 11:45	71.4	81.4	63.3	74.2	84.7	65.8	74.1	84.7	68.9	73.9	85.5	70.2	73.6	84.8	75.5	31.3
1/2/2005 12:45	77.9	88.4	68.4	76.9	84.8	65.6	72.8	83.3	68.9	74.9	86.3	73.7	74.1	84.9	73.6	32.4
1/2/2005 13:45	81.3	89.6	68.6	78.2	83.3	65.6	73.8	85.1	68.9	75.2	86.8	72.7	74.1	86.0	73.4	33.2
1/2/2005 14:45	79.8	89.1	69.1	79.5	83.3	65.4	75.8	85.2	68.7	75.8	86.8	71.5	74.0	85.2	75.4	33.1

Sheet 2 of 3

PANDAN III, ELEVATOR RESERVOIR

THERMOCOUPLE TEMPERATURE MONITORING RECORD

Date & Time	Temperature in °C															
	Location A			Location B			Location C			Location D			Location E			AMBIENT
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	
1/2/2005 15:45	81.6	89.9	70.5	81.0	82.9	65.2	75.7	86.2	68.8	76.1	87.2	71.3	73.8	85.1	77.1	31.3
1/2/2005 16:45	80.8	89.9	70.1	80.8	84.3	65.2	75.4	86.5	68.7	75.7	87.1	70.8	73.8	85.0	79.8	29.9
1/2/2005 17:45	78.9	87.6	69.4	80.6	84.0	64.9	77.8	87.0	68.1	76.1	87.2	70.7	73.4	84.4	74.8	29.2
1/2/2005 22:00	78.5	87.6	68.7	79.3	83.4	64.0	75.8	86.1	67.1	75.9	86.6	70.3	73.0	84.0	74.4	25.9
2/2/2005 0:00	78.0	86.6	67.4	79.0	83.2	63.8	75.6	85.8	66.3	75.7	86.1	70.1	73.0	83.9	73.8	23.5
2/2/2005 2:00	76.9	86.3	66.3	78.8	82.5	63.8	75.4	85.8	65.2	75.3	85.9	69.6	72.9	83.8	73.0	23.4
2/2/2005 4:00	76.1	84.7	65.4	78.8	82.4	63.8	74.7	85.4	61.8	75.2	85.2	68.5	72.9	83.3	72.1	23.8
2/2/2005 6:00	75.8	84.6	64.7	76.6	82.1	62.7	73.6	85.3	63.5	74.9	85.2	68.3	72.9	83.3	71.2	24.0
2/2/2005 8:00	75.6	84.1	65.2	76.1	81.7	62.0	72.9	85.0	62.7	74.8	84.7	67.8	72.8	83.2	71.0	24.3
2/2/2005 10:00	75.6	83.8	64.8	76.1	81.4	61.6	72.1	84.4	61.8	74.6	83.7	66.8	72.8	82.3	70.6	24.6
2/2/2005 22:00	71.8	77.6	60.3	73.4	79.1	59.6	71.3	81.3	62.9	70.9	81.9	65.1	71.9	81.2	68.9	24.3
3/2/2005 0:00	71.4	76.7	59.6	73.1	78.8	59.6	71.0	81.2	62.6	70.3	81.7	62.2	71.8	80.9	68.6	23.7
3/2/2005 2:00	65.7	76.7	59.3	72.7	78.4	58.3	70.8	80.9	62.3	70.0	81.4	61.6	71.5	80.6	68.3	23.8
3/2/2005 4:00	71.0	76.0	59.1	72.4	77.8	58.2	70.6	80.6	62.1	69.8	81.2	61.6	71.2	80.4	68.2	23.5
3/2/2005 6:00	70.2	76.1	58.3	71.7	78.0	57.4	70.4	80.3	61.8	69.6	81.0	61.3	70.8	80.2	67.9	23.6
3/2/2005 8:00	70.0	75.6	58.1	71.3	77.7	57.2	69.9	80.0	61.5	69.1	80.7	61.1	70.3	80.0	67.7	23.8
3/2/2005 16:00	70.7	75.8	58.3	71.9	77.8	57.7	70.3	79.6	60.7	70.1	79.5	60.9	70.6	79.5	66.9	25.1
3/2/2005 19:00	71.6	75.6	58.2	72.4	77.1	57.1	71.2	79.1	60.4	70.9	79.0	60.6	70.7	78.7	66.7	24.9
3/2/2005 21:00	72.3	75.4	58.1	73.4	76.0	56.7	72.1	78.6	60.0	68.3	78.4	60.3	70.4	78.4	66.5	24.8
4/2/2005 0:00	72.5	75.2	57.8	73.6	75.6	56.6	72.4	78.3	59.6	68.3	78.3	60.1	70.5	78.1	66.4	24.0
4/2/2005 10:00	71.8	75.2	56.7	71.2	75.7	55.1	69.9	76.7	58.5	71.7	78.1	60.1	70.8	77.4	66.2	27.7
4/2/2005 12:00	70.7	75.0	55.3	68.3	73.8	54.9	69.4	75.1	58.2	74.3	76.8	62.9	70.7	77.2	63.7	30.0
4/2/2005 14:00	74.8	78.9	60.1	73.9	73.6	54.8	71.0	75.8	58.1	75.0	75.8	58.3	70.6	77.0	63.6	31.4
4/2/2005 16:00	75.8	79.6	60.3	74.9	73.2	54.7	72.9	78.0	58.1	73.1	78.1	60.6	70.6	76.8	64.2	31.2
4/2/2005 18:00	77.8	78.9	62.4	77.2	72.2	54.4	76.2	80.8	75.6	75.8	80.2	63.3	72.8	76.6	63.1	27.9
5/2/2005 22:45	72.7	74.5	56.1	71.9	70.7	52.8	71.4	75.1	56.3	71.1	72.3	59.2	69.7	74.7	63.6	23.6

Sheet 3 of 3

APPENDIX

E

TANJUNG BIN, RAFT FOUNDATION OF CHIMNEY

THERMOCOUPLE TEMPERATURE MONITORING RECORD

Date & Time	Temperature in °C															
	Location A			Location B			Location C			Location D			Location E			AMBIENT
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	
5/8/2005 9:30	32.93	32.27	31.82	32.20	31.67	32.20	31.82	32.30	33.12	32.52	32.11	31.99	32.54	32.59	32.35	33.24
5/8/2005 10:00	32.55	33.15	31.78	32.70	32.50	32.48	32.19	33.08	33.54	34.33	33.51	32.41	33.92	33.63	32.74	32.96
5/8/2005 10:30	32.49	32.66	32.27	32.87	31.62	33.67	31.84	31.98	33.19	33.98	34.49	33.60	34.75	35.35	34.75	33.72
5/8/2005 11:00	33.41	35.02	33.32	34.35	32.83	32.95	32.52	32.45	34.09	33.82	35.24	34.90	35.65	35.05	34.52	36.44
5/8/2005 11:30	33.92	32.62	33.32	35.22	33.06	33.90	34.14	35.39	31.78	34.31	38.08	34.77	36.83	35.01	37.58	37.07
5/8/2005 12:00	32.84	31.10	33.34	34.98	29.97	30.38	32.50	35.96	30.69	32.35	35.53	35.82	34.40	36.52	33.90	37.57
5/8/2005 12:30	33.12	32.40	33.70	31.75	32.69	29.74	31.63	33.63	31.82	33.02	32.86	32.86	35.24	35.45	32.88	34.78
5/8/2005 13:00	35.49	35.44	34.28	35.22	34.93	34.86	34.76	35.25	30.77	36.54	38.87	35.92	38.99	38.87	35.25	37.82
5/8/2005 13:30	33.81	34.03	33.28	34.77	34.87	33.72	34.08	34.25	32.95	36.51	37.59	34.34	37.87	38.74	33.72	36.77
5/8/2005 14:00	29.43	29.45	30.93	33.55	30.20	29.70	30.15	30.95	29.79	31.17	32.35	31.60	33.05	34.30	32.59	34.18
5/8/2005 14:30	33.11	34.58	33.62	33.33	33.33	33.76	33.35	33.47	33.86	35.40	35.83	34.05	36.26	39.00	34.15	37.22
5/8/2005 15:00	32.66	33.24	33.36	34.81	33.96	33.31	33.39	34.97	33.14	36.15	35.38	33.36	36.68	35.65	33.77	35.67
5/8/2005 15:30	33.64	35.10	34.12	34.55	33.83	34.04	35.44	34.50	33.85	36.26	33.32	34.07	36.69	36.11	34.48	36.91
5/8/2005 16:00	34.01	34.16	35.17	36.39	35.91	35.10	36.32	34.88	34.86	35.00	35.07	35.19	36.61	35.53	35.63	37.74
5/8/2005 16:30	33.85	34.43	35.85	35.32	35.20	35.75	35.22	35.37	35.44	36.14	35.75	35.85	36.93	35.51	36.28	38.25
5/8/2005 17:00	34.68	35.04	36.53	35.83	35.88	36.43	35.50	36.00	36.07	36.12	36.22	36.55	36.31	36.05	37.06	37.42
5/8/2005 17:30	35.10	36.18	37.91	35.51	37.02	37.87	35.56	37.27	37.34	35.80	37.34	38.06	36.30	37.19	38.59	36.69
5/8/2005 18:00	35.66	36.98	39.05	36.26	38.06	38.88	35.85	38.23	38.40	36.17	38.06	39.41	36.31	38.09	39.91	37.18
5/8/2005 18:30	34.29	36.87	39.17	34.68	37.87	39.03	34.82	37.78	38.09	34.99	37.73	39.31	35.18	37.54	39.86	35.88
5/8/2005 19:00	34.56	37.04	40.06	34.78	38.26	39.89	34.59	38.10	38.48	34.37	38.07	40.28	35.00	37.76	40.92	35.29
5/8/2005 19:30	34.74	37.47	41.31	34.86	38.70	41.29	34.78	38.43	39.13	34.83	38.46	41.55	35.05	38.15	42.12	35.24
5/8/2005 20:00	34.39	37.51	42.02	34.00	38.73	41.66	33.04	38.21	39.28	34.17	38.35	42.11	34.19	37.97	42.35	34.46
5/8/2005 20:30	33.55	36.97	41.93	35.72	38.41	41.45	32.59	37.57	39.01	33.09	37.73	42.14	33.24	37.30	42.02	33.41
5/8/2005 21:00	33.14	36.94	42.19	35.36	38.29	41.62	32.52	37.35	39.20	35.60	37.64	42.57	33.00	37.13	42.19	33.21
5/8/2005 21:30	33.15	37.02	42.56	35.01	38.44	41.94	32.36	37.22	39.33	35.41	37.55	43.18	34.67	37.07	42.39	32.77
5/8/2005 22:00	33.49	37.41	43.26	34.99	39.12	42.56	32.39	37.44	39.83	35.25	37.89	44.09	35.03	37.46	42.97	32.48
5/8/2005 22:30	33.58	37.88	43.89	34.76	39.63	43.10	32.71	37.69	40.28	34.83	38.29	44.73	34.93	37.81	43.39	33.22
5/8/2005 23:00	33.66	38.42	44.43	34.60	40.24	43.69	32.99	37.96	40.81	34.45	38.68	45.62	34.74	38.27	43.88	32.07
5/8/2005 23:30	33.80	39.30	45.14	34.47	40.76	44.33	33.22	38.51	41.55	34.11	39.49	46.36	34.67	39.11	44.37	31.97
6/8/2005 0:00	34.16	40.59	46.11	34.61	41.60	45.28	33.65	39.66	42.50	34.20	40.88	47.50	34.78	40.40	45.25	31.94

Sheet 1 of 12

TANJUNG BIN, RAFT FOUNDATION OF CHIMNEY

THERMOCOUPLE TEMPERATURE MONITORING RECORD

	Temperature in °C															
Date & Time	Location A			Location B			Location C			Location D			Location E			AMBIENT
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	
6/8/2005 0:30	34.70	41.99	47.22	34.94	42.76	46.46	34.17	40.89	43.71	34.60	42.02	48.73	35.11	41.51	46.27	31.79
6/8/2005 1:00	35.05	43.03	48.22	35.17	43.80	47.45	34.54	41.93	44.73	34.83	42.94	49.72	35.29	42.48	47.17	31.65
6/8/2005 1:30	35.31	43.94	49.02	35.26	44.70	48.24	34.73	42.79	45.61	34.88	43.70	50.50	35.31	43.27	47.85	31.41
6/8/2005 2:00	35.85	44.96	49.99	35.57	45.63	49.21	35.18	43.64	46.63	35.11	44.70	51.44	35.45	44.17	48.70	31.43
6/8/2005 2:30	36.10	45.61	50.59	35.66	46.23	49.92	35.35	44.20	47.35	35.02	45.32	52.09	35.28	44.75	49.18	31.09
6/8/2005 3:00	36.96	46.68	51.59	36.22	47.16	50.90	35.98	45.15	48.40	35.38	46.25	53.09	35.55	45.61	50.09	31.29
6/8/2005 3:30	37.93	47.50	52.41	36.93	47.98	51.77	36.59	45.93	49.39	35.65	47.03	53.91	35.70	46.29	50.77	30.98
6/8/2005 4:00	38.60	48.14	53.05	37.79	48.60	52.46	36.97	46.52	50.17	35.91	47.57	54.55	35.79	46.81	51.27	30.67
6/8/2005 4:30	39.45	49.32	54.10	38.87	49.79	53.60	37.79	47.58	51.46	36.86	48.58	55.60	36.50	47.82	52.22	30.96
6/8/2005 5:00	40.63	50.64	55.35	40.01	51.07	54.87	38.81	48.83	52.90	38.28	49.78	56.89	37.56	48.99	53.37	31.19
6/8/2005 5:30	41.43	51.62	56.14	40.71	52.14	55.85	39.44	49.76	54.00	39.10	50.59	57.73	38.55	49.83	54.09	31.34
6/8/2005 6:00	42.41	52.69	56.97	41.52	53.24	56.75	40.18	50.74	55.12	39.89	51.60	58.56	39.73	50.76	54.81	31.43
6/8/2005 6:30	42.92	53.34	57.33	41.98	53.91	57.23	40.57	51.36	55.76	40.31	52.15	58.92	40.23	51.22	55.14	31.15
6/8/2005 7:00	43.49	54.13	57.69	42.56	54.74	57.71	41.08	52.03	56.48	40.91	52.80	59.28	40.79	51.82	55.39	30.84
6/8/2005 7:30	44.17	54.82	58.02	43.21	55.48	58.19	41.65	52.70	57.10	41.46	53.44	59.59	41.39	52.39	55.65	31.37
6/8/2005 8:00	44.55	55.25	58.00	43.57	55.91	58.26	41.90	53.04	57.38	41.80	53.73	59.54	41.78	52.68	55.58	32.39
6/8/2005 8:30	44.88	55.58	57.81	43.83	56.24	58.19	41.99	53.29	57.48	41.96	53.87	59.28	42.11	52.89	55.32	31.85
6/8/2005 9:00	45.98	56.55	58.43	44.93	57.29	58.90	43.07	54.37	58.28	42.95	54.87	59.80	43.23	53.82	55.89	33.78
6/8/2005 9:30	47.21	57.56	59.12	46.23	58.39	59.62	44.17	55.49	59.10	44.01	55.94	60.54	44.44	54.78	56.53	36.60
6/8/2005 10:00	47.44	57.55	58.69	46.46	58.29	59.22	44.22	55.39	58.79	43.96	55.80	59.90	44.51	54.63	55.96	36.77
6/8/2005 10:30	47.91	57.64	58.47	46.90	58.37	59.04	44.47	55.48	58.66	44.16	55.83	59.61	44.95	54.69	55.76	36.27
6/8/2005 11:00	48.83	58.13	58.74	47.97	58.93	59.34	45.37	56.08	58.98	44.91	56.42	59.86	45.89	55.21	56.04	35.09
6/8/2005 11:30	49.88	58.65	59.11	49.17	59.53	59.70	46.45	56.80	59.44	45.83	57.09	60.27	47.07	55.95	56.54	37.21
6/8/2005 12:00	51.22	59.53	59.87	50.72	60.44	60.44	47.83	57.80	60.20	47.12	58.06	60.98	48.55	56.85	57.30	37.26
6/8/2005 12:30	52.33	60.20	60.34	52.09	61.12	60.98	49.07	58.61	60.67	48.14	58.82	61.45	49.71	57.51	57.78	38.53
6/8/2005 13:00	53.04	60.43	60.48	53.09	61.42	61.14	49.99	59.05	60.85	48.85	59.15	61.59	50.52	57.84	57.82	37.99
6/8/2005 13:30	55.22	62.10	62.27	55.74	63.40	63.00	52.77	61.36	62.88	51.32	61.39	63.83	53.31	60.08	60.20	42.89
6/8/2005 14:00	54.99	61.64	61.33	55.52	62.64	62.21	52.43	60.34	61.71	50.95	60.38	62.23	52.62	58.82	58.32	39.82
6/8/2005 14:30	55.48	61.75	61.34	56.29	62.84	62.24	53.22	60.58	61.75	51.56	60.56	62.17	53.34	58.92	58.26	38.53
6/8/2005 15:00	56.41	62.41	61.96	57.60	63.60	62.89	54.55	61.39	62.32	52.68	61.30	62.77	54.53	59.57	58.76	38.51

Sheet 2 of 12

TANJUNG BIN, RAFT FOUNDATION OF CHIMNEY

THERMOCOUPLE TEMPERATURE MONITORING RECORD

	Temperature in °C															
Date & Time	Location A			Location B			Location C			Location D			Location E			AMBIENT
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	
6/8/2005 15:30	57.54	63.24	62.74	58.94	64.61	63.80	56.09	62.43	63.14	54.03	62.24	63.52	55.79	60.44	59.47	39.99
6/8/2005 16:00	58.81	64.26	63.72	60.47	65.71	64.88	57.79	63.72	64.07	55.48	63.43	64.55	57.17	61.47	60.38	39.59
6/8/2005 16:30	59.65	64.89	64.25	61.45	66.43	65.51	58.92	64.39	64.61	56.47	64.16	64.96	58.04	62.00	60.74	39.27
6/8/2005 17:00	60.41	65.48	64.77	62.37	67.13	66.09	60.00	65.14	65.12	57.44	64.84	65.43	58.86	62.59	61.16	39.70
6/8/2005 17:30	61.16	66.01	65.21	63.22	67.81	66.68	61.04	65.82	65.61	58.33	65.45	65.90	59.64	63.10	61.54	39.33
6/8/2005 18:00	62.32	66.99	66.04	64.43	68.88	67.65	62.30	66.90	66.52	59.60	66.49	66.75	60.76	64.03	62.32	38.23
6/8/2005 18:30	63.41	67.88	66.91	65.68	69.96	68.61	63.64	67.98	67.41	60.89	67.57	67.67	61.91	64.97	63.17	37.89
6/8/2005 19:00	64.61	68.87	67.81	66.86	71.10	69.68	65.01	69.08	68.45	62.24	68.73	68.63	63.17	66.06	64.11	37.21
6/8/2005 19:30	65.44	69.51	68.26	67.69	71.90	70.30	65.92	69.80	69.02	63.24	69.40	69.06	63.95	66.75	64.54	36.83
6/8/2005 20:00	65.42	69.32	67.97	67.71	71.80	70.10	65.94	69.58	68.70	63.26	69.20	68.66	63.76	66.39	64.07	35.89
6/8/2005 20:30	65.59	69.33	67.79	67.84	71.80	70.00	66.14	69.66	68.53	63.51	69.16	68.38	63.74	66.32	63.79	35.35
6/8/2005 21:00	65.72	69.24	67.61	67.97	71.80	69.91	66.29	69.58	68.32	63.66	69.06	68.11	63.73	66.17	63.49	34.83
6/8/2005 21:30	66.03	69.36	67.61	68.39	72.10	70.00	66.69	69.79	68.37	64.04	69.25	68.09	63.94	66.26	63.42	34.47
6/8/2005 22:00	66.32	69.51	67.64	68.76	72.40	70.10	67.05	70.00	68.40	64.45	69.42	68.07	64.14	66.39	63.36	34.24
6/8/2005 22:30	66.74	69.75	67.83	69.27	72.70	70.40	67.55	70.30	68.57	64.94	69.72	68.19	64.52	66.63	63.45	34.04
6/8/2005 23:00	67.12	70.00	67.95	69.68	73.00	70.60	67.98	70.60	68.69	65.42	69.92	68.24	64.81	66.82	63.55	34.10
6/8/2005 23:30	67.51	70.20	68.05	70.20	73.30	70.70	68.46	70.90	68.86	65.92	70.20	68.29	65.17	67.11	63.60	33.67
7/8/2005 0:00	67.84	70.40	68.10	70.60	73.60	70.90	68.90	71.10	68.88	66.37	70.40	68.33	65.45	67.24	63.60	33.67
7/8/2005 0:30	68.20	70.60	68.27	71.00	73.90	71.10	69.38	71.40	69.05	66.82	70.60	68.36	65.76	67.49	63.63	33.34
7/8/2005 1:00	68.48	70.70	68.31	71.40	74.20	71.20	69.75	71.60	69.07	67.20	70.80	68.41	66.04	67.60	63.62	33.43
7/8/2005 1:30	68.73	70.90	68.33	71.70	74.40	71.40	70.10	71.90	69.14	67.53	70.90	68.40	66.23	67.74	63.62	33.09
7/8/2005 2:00	69.13	71.20	68.56	72.20	74.80	71.60	70.60	72.20	69.32	68.01	71.20	68.54	66.57	67.94	63.73	33.41
7/8/2005 2:30	69.27	71.30	68.46	72.50	74.90	71.60	70.90	72.30	69.29	68.30	71.30	68.46	66.71	68.04	63.61	33.29
7/8/2005 3:00	69.60	71.50	68.65	72.90	75.30	71.80	71.30	72.70	69.48	68.72	71.60	68.58	67.02	68.25	63.71	33.37
7/8/2005 3:30	69.87	71.60	68.72	73.30	75.50	72.00	71.70	72.90	69.57	69.09	71.80	68.64	67.30	68.45	63.74	33.33
7/8/2005 4:00	70.10	71.80	68.78	73.60	75.80	72.10	72.10	73.20	69.65	69.44	72.00	68.70	67.47	68.63	63.76	33.03
7/8/2005 4:30	70.30	71.90	68.77	73.90	75.90	72.10	72.40	73.30	69.64	69.64	72.10	68.65	67.59	68.67	63.68	32.93
7/8/2005 5:00	70.40	72.00	68.77	74.10	76.10	72.20	72.60	73.50	69.67	69.89	72.20	68.61	67.71	68.73	63.64	32.91
7/8/2005 5:30	70.60	72.10	68.80	74.40	76.30	72.30	72.90	73.70	69.70	70.10	72.30	68.66	67.87	68.87	63.59	32.89
7/8/2005 6:00	70.80	72.30	68.88	74.70	76.50	72.40	73.30	73.90	69.85	70.50	72.50	68.73	68.07	69.00	63.67	32.99

Sheet 3 of 12

TANJUNG BIN, RAFT FOUNDATION OF CHIMNEY

THERMOCOUPLE TEMPERATURE MONITORING RECORD

Date & Time	Temperature in °C															
	Location A			Location B			Location C			Location D			Location E			AMBIENT
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	
7/8/2005 6:30	71.00	72.40	68.96	75.00	76.70	72.50	73.60	74.10	69.93	70.70	72.70	68.75	68.23	69.15	63.66	33.00
7/8/2005 7:00	71.00	72.30	68.75	75.10	76.60	72.40	73.70	74.10	69.76	70.80	72.60	68.58	68.13	69.05	63.44	33.15
7/8/2005 7:30	71.20	72.50	68.84	75.40	76.90	72.50	74.00	74.40	69.88	71.00	72.80	68.65	68.30	69.20	63.47	32.96
7/8/2005 8:00	71.20	72.50	68.78	75.50	76.90	72.50	74.10	74.40	69.84	71.10	72.90	68.59	68.33	69.23	63.36	34.17
7/8/2005 8:30	70.80	72.10	68.22	75.10	76.50	72.00	73.80	74.00	69.29	70.80	72.40	67.94	67.89	68.76	62.75	36.39
7/8/2005 9:00	70.40	71.60	67.62	74.70	76.10	71.40	73.30	73.50	68.76	70.40	71.90	67.24	67.43	68.31	62.17	38.18
7/8/2005 9:30	70.00	71.30	67.22	74.40	75.80	71.10	73.10	73.20	68.38	70.20	71.60	66.86	67.17	68.05	61.79	38.13
7/8/2005 10:00	71.50	72.70	68.71	76.10	77.30	72.60	74.90	75.00	69.77	71.70	73.10	68.37	68.52	69.42	63.21	39.62
7/8/2005 10:30	70.70	72.00	67.73	75.30	76.50	71.70	74.00	74.10	68.89	70.90	72.20	67.35	67.73	68.63	62.16	37.54
7/8/2005 11:00	70.60	71.80	67.53	75.10	76.40	71.40	73.90	73.90	68.73	70.80	72.10	67.05	67.57	68.45	61.96	38.95
7/8/2005 11:29	70.80	72.00	67.76	75.60	76.80	71.70	74.40	74.40	69.06	71.10	72.40	67.48	68.02	68.87	62.39	37.63
7/8/2005 11:59	71.60	72.80	68.48	76.40	77.60	72.50	75.20	75.30	69.83	72.00	73.30	68.26	68.76	69.64	63.13	37.87
7/8/2005 12:29	71.10	72.40	67.94	75.90	77.10	71.90	74.80	74.80	69.22	71.40	72.70	67.54	68.16	69.06	62.40	40.11
7/8/2005 12:59	70.80	72.10	67.58	75.70	76.90	71.60	74.60	74.60	68.92	71.20	72.50	67.24	67.88	68.85	62.11	39.88
7/8/2005 13:29	70.80	72.10	67.59	75.80	77.00	71.60	74.60	74.70	68.94	71.20	72.50	67.26	67.88	68.87	62.15	40.60
7/8/2005 13:59	71.10	72.30	67.82	76.10	77.30	71.90	75.00	75.10	69.24	71.50	72.80	67.47	68.11	69.12	62.30	41.18
7/8/2005 14:29	70.90	72.20	67.64	76.00	77.20	71.70	75.00	75.10	69.11	71.40	72.70	67.31	67.90	68.95	62.10	41.79
7/8/2005 14:59	70.80	72.10	67.49	76.00	77.20	71.60	74.90	75.10	69.03	71.30	72.70	67.18	67.80	68.88	61.97	41.66
7/8/2005 15:29	71.30	72.60	68.08	76.70	77.90	72.30	75.60	75.90	69.79	72.00	73.30	67.96	68.41	69.53	62.64	40.90
7/8/2005 15:59	71.80	73.20	68.59	77.30	78.60	72.90	76.30	76.60	70.30	72.60	74.00	68.54	68.90	70.00	63.07	41.31
7/8/2005 16:29	72.40	73.80	69.20	78.00	79.30	73.50	77.10	77.40	71.00	73.30	74.80	69.37	69.56	70.70	63.81	40.71
7/8/2005 16:59	73.00	74.40	69.75	78.60	80.00	74.20	77.80	78.10	71.70	73.80	75.50	69.96	70.10	71.30	64.28	40.05
7/8/2005 17:29	73.30	74.80	70.00	78.90	80.40	74.50	78.20	78.50	72.10	74.20	75.90	70.30	70.30	71.50	64.54	40.00
7/8/2005 17:59	73.30	74.70	69.97	79.00	80.40	74.60	78.20	78.60	72.10	74.20	75.90	70.40	70.20	71.50	64.48	37.77
7/8/2005 18:29	73.30	74.80	70.00	79.10	80.60	74.60	78.40	78.80	72.20	74.20	76.00	70.50	70.20	71.50	64.41	37.22
7/8/2005 18:59	73.00	74.60	69.70	78.90	80.40	74.40	78.20	78.60	72.00	74.00	75.80	70.10	69.79	71.20	63.99	36.32
7/8/2005 19:29	72.80	74.40	69.41	78.70	80.20	74.20	78.00	78.50	71.80	73.80	75.60	69.88	69.45	70.90	63.66	35.79
7/8/2005 19:59	72.40	74.10	69.05	78.40	80.00	73.90	77.70	78.20	71.50	73.40	75.30	69.50	69.00	70.40	63.18	35.42
7/8/2005 20:29	72.10	73.80	68.72	78.10	79.70	73.70	77.40	78.00	71.20	73.10	75.00	69.26	68.60	70.10	62.85	34.78
7/8/2005 20:59	72.10	73.80	68.70	78.10	79.80	73.70	77.40	78.10	71.20	73.10	75.00	69.19	68.53	70.10	62.73	34.71

Sheet 4 of 12

TANJUNG BIN, RAFT FOUNDATION OF CHIMNEY

THERMOCOUPLE TEMPERATURE MONITORING RECORD

Date & Time	Temperature in °C Location A			Location B			Location C			Location D			Location E			AMBIENT
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	
7/8/2005 21:29	71.90	73.60	68.47	78.00	79.60	73.60	77.30	78.00	71.10	72.90	74.90	69.06	68.30	69.89	62.52	34.30
7/8/2005 21:59	71.80	73.50	68.38	78.00	79.60	73.50	77.20	78.00	71.00	72.80	74.80	68.95	68.12	69.75	62.34	34.12
7/8/2005 22:29	71.80	73.50	68.27	77.90	79.60	73.40	77.30	78.00	71.00	72.70	74.80	68.89	67.99	69.67	62.24	33.84
7/8/2005 22:59	71.60	73.40	68.15	77.80	79.60	73.30	77.20	77.90	70.90	72.60	74.70	68.79	67.82	69.52	62.06	33.45
7/8/2005 23:29	71.60	73.30	68.06	77.80	79.60	73.30	77.20	78.00	70.90	72.60	74.70	68.75	67.70	69.38	61.95	33.53
7/8/2005 23:59	71.50	73.30	67.99	77.80	79.60	73.30	77.20	78.00	70.90	72.50	74.70	68.72	67.59	69.34	61.86	33.32
8/8/2005 0:29	71.40	73.20	67.85	77.70	79.60	73.20	77.10	78.00	70.80	72.30	74.50	68.60	67.40	69.20	61.67	33.55
8/8/2005 0:59	71.30	73.10	67.65	77.60	79.50	73.10	77.00	77.90	70.70	72.20	74.50	68.45	67.20	69.02	61.51	33.23
8/8/2005 1:29	71.30	73.20	67.77	77.80	79.70	73.20	77.20	78.10	70.90	72.30	74.60	68.57	67.25	69.09	61.57	33.53
8/8/2005 1:59	71.40	73.20	67.74	77.80	79.80	73.30	77.20	78.20	70.90	72.30	74.60	68.59	67.22	69.07	61.56	33.50
8/8/2005 2:29	71.30	73.20	67.71	77.80	79.80	73.30	77.20	78.30	70.90	72.20	74.60	68.58	67.11	69.01	61.45	33.41
8/8/2005 2:59	71.30	73.10	67.65	77.70	79.80	73.20	77.20	78.30	70.90	72.10	74.60	68.58	67.04	68.93	61.38	33.33
8/8/2005 3:29	71.20	73.10	67.51	77.70	79.80	73.20	77.20	78.30	70.90	72.00	74.50	68.48	66.87	68.83	61.23	33.43
8/8/2005 3:59	71.20	73.00	67.47	77.70	79.80	73.20	77.10	78.30	70.90	72.00	74.50	68.44	66.79	68.75	61.13	34.67
8/8/2005 4:29	71.00	72.90	67.30	77.60	79.70	73.10	77.10	78.20	70.80	71.80	74.30	68.29	66.59	68.55	60.93	33.77
8/8/2005 4:59	70.80	72.80	67.13	77.40	79.60	73.00	76.90	78.10	70.70	71.60	74.20	68.17	66.37	68.36	60.73	35.40
8/8/2005 5:29	70.90	72.80	67.15	77.50	79.70	73.10	77.00	78.30	70.80	71.60	74.30	68.24	66.39	68.41	60.80	35.45
8/8/2005 5:59	71.00	72.90	67.24	77.70	79.90	73.10	77.10	78.50	70.90	71.70	74.40	68.35	66.38	68.47	60.84	33.82
8/8/2005 6:29	71.00	72.90	67.28	77.70	80.00	73.20	77.20	78.60	71.00	71.70	74.40	68.47	66.43	68.47	60.89	33.32
8/8/2005 6:59	71.00	72.80	67.20	77.70	80.00	73.20	77.20	78.60	71.00	71.60	74.40	68.40	66.32	68.36	60.80	33.42
8/8/2005 7:29	70.90	72.80	67.13	77.70	80.00	73.20	77.20	78.60	71.00	71.60	74.40	68.36	66.18	68.31	60.69	33.33
8/8/2005 7:59	70.10	72.10	66.42	77.00	79.30	72.50	76.40	77.90	70.30	70.80	73.70	67.61	65.38	67.51	59.89	33.38
8/8/2005 8:29	70.20	72.10	66.45	77.10	79.40	72.60	76.60	78.00	70.40	70.90	73.80	67.70	65.38	67.54	59.91	33.75
8/8/2005 8:59	70.20	72.10	66.40	77.10	79.40	72.60	76.50	78.10	70.40	70.80	73.70	67.65	65.28	67.49	59.81	34.87
8/8/2005 9:29	70.00	71.90	66.16	76.80	79.30	72.40	76.30	77.90	70.30	70.60	73.50	67.41	65.00	67.25	59.59	36.33
8/8/2005 9:59	69.75	71.70	65.97	76.70	79.10	72.20	76.10	77.80	70.10	70.30	73.30	67.25	64.71	66.99	59.33	36.53
8/8/2005 10:29	69.73	71.70	65.95	76.70	79.20	72.30	76.20	77.80	70.20	70.30	73.30	67.27	64.76	67.01	59.33	36.17
8/8/2005 10:59	69.54	71.40	65.66	76.50	79.00	72.10	75.90	77.70	69.95	69.99	73.00	67.01	64.41	66.73	59.07	38.09
8/8/2005 11:29	69.12	71.00	65.26	76.10	78.60	71.70	75.60	77.30	69.54	69.52	72.60	66.56	63.91	66.30	58.60	36.91
8/8/2005 11:59	68.93	70.80	65.07	75.90	78.50	71.50	75.40	77.20	69.40	69.31	72.40	66.40	63.75	66.09	58.44	38.31

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TANJUNG BIN, RAFT FOUNDATION OF CHIMNEY

THERMOCOUPLE TEMPERATURE MONITORING RECORD

Date & Time	Temperature in °C															
	Location A			Location B			Location C			Location D			Location E			AMBIENT
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	
8/8/2005 12:29	68.92	70.80	65.07	75.90	78.50	71.50	75.40	77.10	69.47	69.23	72.40	66.41	63.69	66.06	58.40	39.24
8/8/2005 12:59	68.70	70.60	64.82	75.70	78.40	71.40	75.20	77.00	69.25	69.01	72.20	66.20	63.43	65.82	58.16	40.95
8/8/2005 13:29	68.69	70.60	64.86	75.80	78.50	71.50	75.20	77.10	69.35	69.05	72.20	66.25	63.41	65.90	58.20	41.95
8/8/2005 13:59	68.44	70.30	64.54	75.50	78.20	71.10	75.00	76.80	69.08	68.68	71.90	65.93	63.02	65.51	57.87	42.22
8/8/2005 14:29	68.42	70.40	64.61	75.70	78.40	71.30	75.10	77.10	69.30	68.75	72.10	66.08	63.19	65.61	58.02	41.60
8/8/2005 14:59	68.94	70.80	65.11	76.10	79.00	71.80	75.70	77.60	69.86	69.22	72.60	66.64	63.64	66.12	58.54	41.12
8/8/2005 15:29	69.20	71.00	65.36	76.50	79.20	72.10	76.00	78.00	70.10	69.48	72.80	66.97	63.85	66.31	58.78	41.17
8/8/2005 15:59	69.32	71.20	65.54	76.60	79.40	72.40	76.20	78.30	70.40	69.65	73.00	67.17	63.97	66.41	58.95	41.51
8/8/2005 16:29	69.65	71.50	65.86	77.10	79.80	72.70	76.60	78.70	70.80	69.95	73.50	67.59	64.23	66.71	59.27	41.02
8/8/2005 16:59	69.86	71.70	66.14	77.30	80.20	73.00	76.90	79.00	71.10	70.20	73.70	67.92	64.46	66.93	59.49	40.11
8/8/2005 17:29	70.20	72.00	66.43	77.70	80.50	73.40	77.30	79.40	71.50	70.60	74.10	68.27	64.77	67.23	59.79	39.77
8/8/2005 17:59	70.30	72.20	66.56	77.90	80.80	73.60	77.50	79.60	71.80	70.70	74.20	68.48	64.83	67.37	59.97	38.59
8/8/2005 18:29	70.40	72.20	66.62	77.90	80.90	73.70	77.60	79.80	71.90	70.80	74.30	68.63	64.85	67.38	59.99	37.88
8/8/2005 18:59	70.50	72.30	66.67	78.00	81.00	73.80	77.80	79.90	72.00	70.80	74.40	68.71	64.92	67.41	59.99	36.95
8/8/2005 19:29	70.40	72.20	66.61	78.10	81.00	73.80	77.70	79.90	72.00	70.80	74.40	68.69	64.72	67.25	59.88	36.36
8/8/2005 19:59	69.99	71.90	66.25	77.70	80.70	73.50	77.40	79.60	71.70	70.40	74.00	68.33	64.28	66.82	59.43	36.04
8/8/2005 20:29	69.65	71.50	65.79	77.40	80.40	73.20	77.00	79.30	71.40	70.00	73.60	67.92	63.80	66.36	58.96	35.38
8/8/2005 20:59	69.34	71.20	65.53	77.10	80.10	73.00	76.80	79.00	71.10	69.69	73.30	67.61	63.40	66.00	58.61	34.95
8/8/2005 21:29	69.15	71.00	65.36	77.00	80.00	72.80	76.60	78.90	71.00	69.53	73.10	67.49	63.16	65.74	58.40	34.81
8/8/2005 21:59	69.13	71.00	65.35	76.90	80.00	72.80	76.60	78.90	71.00	69.51	73.10	67.43	63.10	65.68	58.38	34.69
8/8/2005 22:29	69.05	70.90	65.24	76.90	79.90	72.80	76.60	78.90	71.00	69.41	73.00	67.37	62.97	65.55	58.25	34.80
8/8/2005 22:59	69.03	70.90	65.20	76.90	80.00	72.80	76.60	78.90	71.00	69.39	73.00	67.38	62.90	65.51	58.21	34.42
8/8/2005 23:29	68.77	70.60	64.96	76.70	79.70	72.60	76.40	78.70	70.80	69.13	72.70	67.12	62.67	65.18	57.92	34.42
8/8/2005 23:59	68.66	70.50	64.83	76.50	79.70	72.50	76.30	78.60	70.70	68.97	72.60	66.98	62.46	64.99	57.76	34.05
9/8/2005 0:29	68.67	70.50	64.84	76.60	79.80	72.60	76.40	78.70	70.80	68.98	72.60	67.04	62.42	65.00	57.75	33.96
9/8/2005 0:59	68.56	70.40	64.73	76.50	79.70	72.50	76.20	78.60	70.80	68.87	72.50	66.95	62.26	64.87	57.64	33.85
9/8/2005 1:29	68.40	70.20	64.59	76.40	79.60	72.50	76.20	78.50	70.70	68.76	72.40	66.87	62.11	64.71	57.48	33.59
9/8/2005 1:59	68.31	70.10	64.47	76.30	79.50	72.30	76.00	78.40	70.60	68.57	72.20	66.72	61.91	64.52	57.34	33.33
9/8/2005 2:29	68.11	69.93	64.27	76.20	79.40	72.20	75.90	78.30	70.50	68.41	72.10	66.59	61.74	64.30	57.14	33.34
9/8/2005 2:59	68.05	69.85	64.22	76.10	79.30	72.20	75.90	78.30	70.50	68.31	72.00	66.54	61.61	64.22	57.05	33.50

Sheet 6 of 12

TANJUNG BIN, RAFT FOUNDATION OF CHIMNEY

THERMOCOUPLE TEMPERATURE MONITORING RECORD

Date & Time	Temperature in °C															
	Location A			Location B			Location C			Location D			Location E			AMBIENT
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	
9/8/2005 3:29	67.93	69.77	64.12	76.10	79.30	72.20	75.90	78.20	70.40	68.26	71.90	66.44	61.51	64.09	56.93	33.52
9/8/2005 3:59	68.03	69.80	64.17	76.10	79.30	72.20	75.90	78.40	70.50	68.26	72.00	66.51	61.49	64.05	56.98	33.30
9/8/2005 4:29	68.06	69.83	64.20	76.20	79.40	72.30	76.00	78.40	70.60	68.30	72.00	66.59	61.48	64.11	56.99	33.46
9/8/2005 4:59	68.00	69.75	64.19	76.20	79.40	72.30	76.00	78.50	70.60	68.24	72.00	66.56	61.42	64.00	56.93	33.52
9/8/2005 5:29	68.00	69.75	64.12	76.20	79.40	72.30	76.00	78.50	70.60	68.21	71.90	66.53	61.35	63.93	56.86	33.45
9/8/2005 5:59	67.77	69.52	63.93	76.00	79.30	72.10	75.80	78.30	70.50	67.93	71.70	66.35	61.09	63.69	56.65	33.11
9/8/2005 6:29	67.67	69.45	63.86	75.90	79.30	72.20	75.80	78.30	70.40	67.89	71.60	66.30	60.95	63.58	56.58	33.35
9/8/2005 6:59	67.57	69.30	63.74	75.90	79.20	72.00	75.70	78.20	70.40	67.72	71.50	66.20	60.83	63.43	56.46	33.35
9/8/2005 7:29	67.46	69.14	63.62	75.80	79.00	71.90	75.60	78.10	70.30	67.57	71.40	66.06	60.66	63.27	56.27	33.52
9/8/2005 7:59	67.43	69.11	63.60	75.80	79.10	72.00	75.60	78.10	70.30	67.60	71.40	66.11	60.61	63.22	56.20	34.05
9/8/2005 8:29	67.14	68.84	63.28	75.50	78.80	71.70	75.30	77.80	70.10	67.23	71.00	65.79	60.24	62.87	55.92	34.59
9/8/2005 8:59	66.86	68.57	63.03	75.30	78.60	71.50	75.10	77.60	69.87	66.96	70.70	65.49	59.97	62.62	55.62	35.27
9/8/2005 9:29	66.61	68.29	62.75	75.00	78.40	71.30	74.80	77.40	69.67	66.66	70.50	65.26	59.70	62.35	55.42	35.19
9/8/2005 9:59	66.36	68.06	62.49	74.70	78.20	71.10	74.50	77.10	69.43	66.38	70.20	64.93	59.39	62.02	55.09	36.29
9/8/2005 10:29	65.90	67.56	62.00	74.20	77.70	70.50	74.00	76.60	68.88	65.81	69.67	64.36	58.84	61.50	54.54	38.05
9/8/2005 10:59	65.93	67.68	62.33	74.50	77.60	70.60	74.30	76.90	69.03	65.90	69.97	64.86	58.96	61.81	55.14	36.20
9/8/2005 11:29	66.39	68.00	62.46	74.80	78.20	71.20	74.60	77.20	69.54	66.30	70.20	64.97	59.38	62.08	55.20	40.84
9/8/2005 11:59	66.20	67.81	62.34	74.60	78.10	71.00	74.50	77.10	69.42	66.08	69.96	64.78	59.14	61.87	55.01	43.14
9/8/2005 12:29	65.42	67.05	61.56	73.90	77.30	70.30	73.60	76.30	68.62	65.18	69.09	63.93	58.31	61.04	54.15	43.26
9/8/2005 12:59	65.29	66.90	61.46	73.80	77.20	70.10	73.50	76.20	68.51	65.06	68.99	63.87	58.23	60.91	54.10	46.21
9/8/2005 13:29	65.02	66.65	61.25	73.50	77.00	69.92	73.30	76.00	68.35	64.78	68.76	63.62	57.95	60.66	53.91	44.09
9/8/2005 13:59	65.08	66.67	61.27	73.60	77.10	69.98	73.40	76.20	68.44	64.82	68.82	63.78	58.00	60.70	54.03	43.73
9/8/2005 14:29	65.40	66.94	61.59	74.00	77.40	70.40	73.80	76.50	68.81	65.12	69.17	64.13	58.32	61.02	54.35	45.34
9/8/2005 14:59	65.51	67.10	61.74	74.20	77.60	70.60	74.00	76.70	69.04	65.25	69.30	64.28	58.42	61.13	54.48	43.49
9/8/2005 15:29	65.66	67.22	61.89	74.40	77.80	70.70	74.10	76.90	69.23	65.35	69.44	64.47	58.57	61.25	54.63	42.54
9/8/2005 15:59	66.28	67.77	62.56	75.00	78.60	71.40	74.90	77.70	70.10	66.04	70.20	65.21	59.26	61.92	55.39	42.30
9/8/2005 16:29	67.10	68.63	63.40	75.90	79.40	72.30	75.80	78.70	71.00	66.91	71.00	66.22	60.13	62.76	56.31	41.29
9/8/2005 16:59	67.49	69.02	63.82	76.40	79.90	72.80	76.30	79.20	71.50	67.32	71.50	66.73	60.47	63.13	56.65	39.96
9/8/2005 17:29	67.43	68.95	63.76	76.40	79.90	72.90	76.30	79.10	71.50	67.27	71.50	66.67	60.35	63.00	56.55	38.94
9/8/2005 17:59	67.36	68.90	63.74	76.30	79.80	72.80	76.30	79.10	71.50	67.22	71.40	66.63	60.21	62.86	56.43	37.27

Sheet 7 of 12

TANJUNG BIN, RAFT FOUNDATION OF CHIMNEY

THERMOCOUPLE TEMPERATURE MONITORING RECORD

Date & Time	Location A			Location B			Location C			Location D			Location E			AMBIENT
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	
9/8/2005 18:29	67.39	68.90	63.72	76.40	80.00	72.90	76.30	79.20	71.60	67.24	71.40	66.70	60.21	62.84	56.46	36.52
9/8/2005 18:59	67.17	68.71	63.50	76.20	79.70	72.80	76.20	79.00	71.40	67.05	71.20	66.48	59.87	62.55	56.15	35.73
9/8/2005 19:29	66.99	68.48	63.29	76.00	79.60	72.60	76.00	78.80	71.20	66.80	71.00	66.25	59.62	62.25	55.84	35.20
9/8/2005 19:59	66.66	68.22	63.03	75.80	79.40	72.40	75.70	78.60	71.00	66.51	70.70	65.95	59.22	61.90	55.49	34.85
9/8/2005 20:29	66.44	67.96	62.80	75.50	79.10	72.20	75.50	78.30	70.80	66.28	70.40	65.69	58.98	61.59	55.23	34.46
9/8/2005 20:59	66.25	67.76	62.58	75.40	79.00	72.00	75.30	78.20	70.60	66.04	70.20	65.56	58.71	61.35	55.01	34.24
9/8/2005 21:29	66.16	67.65	62.49	75.20	78.90	72.00	75.20	78.10	70.50	65.92	70.10	65.45	58.50	61.21	54.87	34.03
9/8/2005 21:59	65.82	67.36	62.17	75.00	78.60	71.70	74.90	77.80	70.30	65.65	69.77	65.11	58.21	60.84	54.53	33.58
9/8/2005 22:29	65.57	67.06	61.90	74.70	78.40	71.50	74.70	77.60	70.00	65.33	69.50	64.86	57.89	60.57	54.26	33.26
9/8/2005 22:59	65.53	67.00	61.86	74.70	78.30	71.50	74.60	77.50	70.00	65.32	69.43	64.80	57.83	60.46	54.22	33.12
9/8/2005 23:29	65.48	66.97	61.81	74.70	78.30	71.50	74.70	77.60	70.10	65.24	69.43	64.84	57.78	60.41	54.21	33.10
9/8/2005 23:59	65.34	66.81	61.69	74.60	78.30	71.40	74.50	77.40	70.00	65.10	69.32	64.70	57.59	60.22	54.02	32.81
10/8/2005 0:29	65.21	66.75	61.63	74.50	78.20	71.30	74.50	77.40	69.94	65.00	69.21	64.64	57.51	60.14	53.92	32.85
10/8/2005 0:59	65.38	66.84	61.73	74.70	78.30	71.50	74.60	77.50	70.10	65.12	69.31	64.74	57.55	60.19	54.06	32.94
10/8/2005 1:29	65.11	66.61	61.51	74.50	78.10	71.30	74.40	77.30	69.94	64.88	69.04	64.55	57.34	59.97	53.77	32.77
10/8/2005 1:59	64.95	66.41	61.32	74.30	78.00	71.20	74.30	77.20	69.80	64.66	68.85	64.33	57.12	59.76	53.61	32.84
10/8/2005 2:29	64.98	66.43	61.31	74.30	78.00	71.20	74.30	77.20	69.83	64.65	68.81	64.34	57.11	59.70	53.59	32.86
10/8/2005 2:59	64.99	66.41	61.36	74.40	78.00	71.30	74.30	77.30	69.89	64.66	68.85	64.40	57.09	59.71	53.63	32.86
10/8/2005 3:29	64.79	66.21	61.19	74.20	77.90	71.10	74.20	77.10	69.76	64.49	68.65	64.20	56.88	59.46	53.43	32.79
10/8/2005 3:59	64.65	66.10	61.08	74.20	77.80	71.00	74.10	77.00	69.69	64.35	68.51	64.13	56.76	59.37	53.31	32.64
10/8/2005 4:29	64.66	66.12	61.03	74.10	77.80	71.10	74.10	77.00	69.74	64.33	68.56	64.14	56.76	59.35	53.29	32.53
10/8/2005 4:59	64.67	66.14	61.12	74.20	77.90	71.10	74.20	77.10	69.78	64.31	68.53	64.15	56.73	59.34	53.30	32.68
10/8/2005 5:29	64.50	65.89	60.90	74.00	77.70	71.00	74.00	76.90	69.63	64.14	68.33	63.95	56.51	59.07	53.11	32.34
10/8/2005 5:59	64.34	65.73	60.76	73.90	77.60	70.80	73.80	76.80	69.50	63.91	68.17	63.82	56.30	58.91	52.95	31.96
10/8/2005 6:29	64.29	65.69	60.69	73.80	77.50	70.80	73.80	76.80	69.52	63.84	68.08	63.77	56.25	58.84	52.88	32.08
10/8/2005 6:59	64.18	65.58	60.58	73.80	77.40	70.80	73.70	76.70	69.48	63.75	67.99	63.66	56.14	58.68	52.79	32.04
10/8/2005 7:29	64.11	65.46	60.51	73.70	77.40	70.70	73.70	76.60	69.46	63.66	67.92	63.64	56.02	58.59	52.72	32.21
10/8/2005 7:59	64.02	65.42	60.42	73.70	77.40	70.70	73.60	76.60	69.42	63.55	67.81	63.53	55.91	58.50	52.61	32.89
10/8/2005 8:29	63.78	65.16	60.23	73.40	77.10	70.50	73.40	76.40	69.16	63.26	67.55	63.29	55.62	58.21	52.27	33.71
10/8/2005 8:59	63.45	64.85	59.85	73.00	76.80	70.20	73.00	76.00	68.80	62.86	67.12	62.86	55.27	57.83	51.94	36.35

Temperature in °C

Sheet 8 of 12

TANJUNG BIN, RAFT FOUNDATION OF CHIMNEY

THERMOCOUPLE TEMPERATURE MONITORING RECORD

Date & Time	Location A			Location B			Location C			Location D			Location E			AMBIENT
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	
10/8/2005 9:29	63.05	64.40	59.44	72.60	76.40	69.77	72.60	75.60	68.44	62.41	66.65	62.38	54.84	57.43	51.48	36.61
10/8/2005 9:59	62.74	64.09	59.07	72.30	76.10	69.49	72.20	75.20	68.12	62.05	66.29	62.01	54.51	57.12	51.18	39.35
10/8/2005 10:29	62.74	64.13	59.20	72.30	76.10	69.55	72.30	75.30	68.25	62.10	66.34	62.12	54.60	57.19	51.36	37.40
10/8/2005 10:59	63.41	64.74	59.85	73.10	76.80	70.30	73.00	76.00	68.95	62.77	67.03	62.84	55.27	57.81	52.01	39.91
10/8/2005 11:29	62.64	64.02	59.16	72.50	76.00	69.51	72.30	75.30	68.18	61.91	66.26	62.14	54.48	57.09	51.34	38.87
10/8/2005 11:59	61.89	63.24	58.33	71.50	75.20	68.73	71.30	74.30	67.38	61.08	65.32	61.10	53.67	56.29	50.41	41.70
10/8/2005 12:29	61.51	62.87	57.96	71.10	74.90	68.31	70.90	74.00	67.03	60.64	64.88	60.78	53.32	55.96	50.11	41.06
10/8/2005 12:59	61.96	63.33	58.47	71.60	75.40	68.80	71.40	74.60	67.62	61.10	65.39	61.27	53.86	56.48	50.70	42.73
10/8/2005 13:29	62.24	63.54	58.73	72.00	75.70	69.18	71.80	74.90	67.99	61.36	65.67	61.62	54.19	56.73	51.05	41.60
10/8/2005 13:59	62.82	64.12	59.38	72.70	76.40	69.83	72.50	75.60	68.67	62.01	66.37	62.39	54.87	57.41	51.87	43.45
10/8/2005 14:29	62.78	64.05	59.34	72.60	76.30	69.81	72.50	75.60	68.62	61.95	66.28	62.32	54.75	57.30	51.80	41.30
10/8/2005 14:59	62.26	63.54	58.82	72.20	75.90	69.31	71.90	75.10	68.13	61.33	65.74	61.81	54.19	56.78	51.24	41.47
10/8/2005 15:29	62.51	63.77	59.15	72.50	76.20	69.64	72.30	75.50	68.53	61.64	66.07	62.13	54.54	57.06	51.61	40.29
10/8/2005 15:59	62.75	63.99	59.39	72.70	76.50	69.93	72.60	75.70	68.79	61.85	66.28	62.45	54.73	57.23	51.78	41.28
10/8/2005 16:29	63.51	64.72	60.17	73.60	77.30	70.70	73.40	76.60	69.69	62.68	67.13	63.32	55.56	58.03	52.66	40.06
10/8/2005 16:59	64.02	65.22	60.75	74.20	77.90	71.40	74.10	77.30	70.30	63.24	67.69	63.95	56.09	58.54	53.19	38.75
10/8/2005 17:29	64.08	65.34	60.79	74.30	78.00	71.50	74.20	77.40	70.50	63.33	67.80	64.08	56.07	58.56	53.19	38.31
10/8/2005 17:59	63.95	65.21	60.66	74.20	77.90	71.40	74.10	77.30	70.30	63.19	67.69	63.93	55.89	58.36	52.96	36.98
10/8/2005 18:29	63.90	65.13	60.65	74.10	77.80	71.40	74.00	77.30	70.30	63.12	67.61	63.90	55.76	58.23	52.93	36.20
10/8/2005 18:59	63.84	65.04	60.49	74.10	77.70	71.40	74.00	77.20	70.30	63.05	67.58	63.81	55.61	58.07	52.78	35.37
10/8/2005 19:29	63.66	64.87	60.39	73.90	77.60	71.30	73.90	77.10	70.20	62.90	67.42	63.66	55.43	57.92	52.55	34.64
10/8/2005 19:59	63.36	64.60	60.07	73.70	77.40	71.10	73.50	76.80	69.94	62.61	67.06	63.36	55.04	57.53	52.21	34.17
10/8/2005 20:29	63.07	64.30	59.78	73.40	77.10	70.80	73.30	76.50	69.63	62.29	66.76	63.05	54.72	57.17	51.86	33.63
10/8/2005 20:59	62.90	64.16	59.63	73.30	76.90	70.70	73.10	76.40	69.53	62.12	66.57	62.95	54.50	56.95	51.67	33.68
10/8/2005 21:29	62.61	63.82	59.34	73.00	76.70	70.40	72.90	76.10	69.28	61.80	66.28	62.58	54.18	56.63	51.38	33.14
10/8/2005 21:59	62.47	63.73	59.22	72.80	76.50	70.30	72.70	75.90	69.15	61.67	66.12	62.45	54.00	56.45	51.19	33.00
10/8/2005 22:29	62.37	63.62	59.17	72.80	76.50	70.20	72.70	75.90	69.09	61.61	66.04	62.39	53.89	56.36	51.11	32.94
10/8/2005 22:59	62.33	63.61	59.13	72.80	76.50	70.20	72.70	75.90	69.13	61.58	65.98	62.36	53.86	56.29	51.10	32.98
10/8/2005 23:29	62.32	63.55	59.12	72.80	76.50	70.30	72.60	75.80	69.11	61.51	65.92	62.30	53.82	56.22	51.06	32.97
10/8/2005 23:59	62.14	63.35	58.84	72.60	76.30	70.10	72.40	75.60	68.96	61.29	65.69	62.11	53.62	56.02	50.88	32.69

Temperature in °C

Sheet 9 of 12

TANJUNG BIN, RAFT FOUNDATION OF CHIMNEY

THERMOCOUPLE TEMPERATURE MONITORING RECORD

Date & Time	Temperature in °C															
	Location A			Location B			Location C			Location D			Location E			AMBIENT
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	
11/8/2005 0:29	62.07	63.30	58.87	72.50	76.30	70.10	72.40	75.70	68.94	61.29	65.67	62.09	53.55	55.95	50.86	32.69
11/8/2005 0:59	62.12	63.33	58.92	72.60	76.40	70.20	72.50	75.70	69.03	61.29	65.67	62.19	53.57	56.00	50.88	32.69
11/8/2005 1:29	61.96	63.15	58.71	72.40	76.20	70.00	72.40	75.60	68.90	61.11	65.49	61.99	53.37	55.79	50.70	32.48
11/8/2005 1:59	61.94	63.12	58.71	72.50	76.10	70.00	72.40	75.60	68.87	61.06	65.44	61.94	53.32	55.72	50.68	32.60
11/8/2005 2:29	61.74	62.98	58.57	72.30	76.10	69.93	72.20	75.40	68.80	60.91	65.30	61.84	53.22	55.60	50.51	32.24
11/8/2005 2:59	61.79	63.00	58.63	72.40	76.10	70.00	72.20	75.50	68.84	60.96	65.29	61.86	53.24	55.62	50.58	32.43
11/8/2005 3:29	61.63	62.86	58.47	72.30	76.00	69.89	72.10	75.30	68.78	60.82	65.18	61.72	53.10	55.46	50.42	32.17
11/8/2005 3:59	61.57	62.78	58.42	72.20	75.90	69.83	72.10	75.30	68.75	60.70	65.10	61.67	53.03	55.38	50.34	31.99
11/8/2005 4:29	61.52	62.75	58.41	72.20	75.90	69.83	72.00	75.20	68.74	60.66	65.05	61.66	52.99	55.32	50.30	32.03
11/8/2005 4:59	61.58	62.81	58.50	72.30	75.90	69.91	72.10	75.30	68.83	60.73	65.09	61.72	53.04	55.34	50.37	32.17
11/8/2005 5:29	61.62	62.80	58.49	72.30	76.00	69.95	72.10	75.40	68.84	60.72	65.10	61.69	53.00	55.33	50.41	32.13
11/8/2005 5:59	61.54	62.79	58.48	72.30	75.90	69.94	72.10	75.30	68.83	60.63	65.02	61.68	52.94	55.27	50.35	32.03
11/8/2005 6:29	61.37	62.55	58.24	72.10	75.80	69.77	71.90	75.20	68.68	60.44	64.85	61.46	52.72	55.08	50.15	31.88
11/8/2005 6:59	61.17	62.33	58.06	71.90	75.60	69.59	71.70	75.00	68.51	60.17	64.60	61.28	52.50	54.85	49.93	31.63
11/8/2005 7:29	61.08	62.22	57.98	71.90	75.50	69.56	71.70	74.90	68.50	60.14	64.52	61.25	52.44	54.75	49.85	31.91
11/8/2005 7:59	60.89	62.08	57.83	71.70	75.40	69.41	71.50	74.80	68.33	59.92	64.35	61.03	52.22	54.55	49.67	32.31
11/8/2005 8:29	60.61	61.82	57.53	71.40	75.10	69.19	71.20	74.50	68.07	59.59	63.98	60.76	51.95	54.25	49.35	32.87
11/8/2005 8:59	60.38	61.54	57.32	71.10	74.90	68.90	70.90	74.20	67.84	59.36	63.72	60.45	51.66	53.99	49.09	33.36
11/8/2005 9:29	60.00	61.18	56.91	70.80	74.50	68.52	70.50	73.80	67.46	58.91	63.27	60.00	51.30	53.59	48.68	34.27
11/8/2005 9:59	59.82	60.98	56.76	70.50	74.30	68.39	70.30	73.60	67.33	58.68	63.07	59.79	51.15	53.43	48.60	34.83
11/8/2005 10:29	59.93	61.09	56.87	70.70	74.40	68.53	70.40	73.70	67.49	58.81	63.15	59.88	51.30	53.59	48.73	37.78
11/8/2005 10:59	60.04	61.41	57.64	71.40	74.50	68.87	71.10	74.40	67.57	59.04	63.78	60.72	51.36	53.98	49.60	35.41
11/8/2005 11:29	59.50	60.73	56.53	70.40	74.00	68.14	70.00	73.40	67.05	58.31	62.74	59.57	50.87	53.23	48.42	39.31
11/8/2005 11:59	59.31	60.45	56.34	70.10	73.80	67.93	69.78	73.10	66.91	58.05	62.44	59.31	50.70	53.01	48.27	39.31
11/8/2005 12:29	60.16	61.35	57.24	71.10	74.80	68.92	70.80	74.20	67.95	59.00	63.46	60.40	51.73	54.06	49.39	37.99
11/8/2005 12:59	60.28	61.47	57.37	71.30	74.90	69.09	70.90	74.30	68.10	59.12	63.56	60.47	51.80	54.11	49.42	40.87
11/8/2005 13:29	59.84	61.02	56.92	70.80	74.40	68.62	70.40	73.80	67.56	58.63	63.04	60.00	51.35	53.66	48.97	39.05
11/8/2005 13:59	60.27	61.40	57.42	71.30	75.00	69.10	71.00	74.40	68.20	59.08	63.56	60.60	51.88	54.19	49.59	38.62
11/8/2005 14:29	60.39	61.52	57.49	71.40	75.10	69.29	71.10	74.50	68.34	59.18	63.68	60.74	51.98	54.26	49.62	39.51
11/8/2005 14:59	59.39	60.58	56.52	70.50	74.10	68.30	70.10	73.50	67.28	58.18	62.62	59.63	50.86	53.19	48.57	41.36

Sheet 10 of 12

TANJUNG BIN, RAFT FOUNDATION OF CHIMNEY

THERMOCOUPLE TEMPERATURE MONITORING RECORD

Date & Time	Temperature in °C															
	Location A			Location B			Location C			Location D			Location E			AMBIENT
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	
11/8/2005 15:29	58.97	60.20	56.15	70.10	73.70	67.90	69.68	73.10	66.91	57.74	62.17	59.16	50.44	52.82	48.15	40.33
11/8/2005 15:59	59.39	60.55	56.59	70.50	74.20	68.37	70.10	73.60	67.42	58.14	62.64	59.68	50.91	53.22	48.72	39.13
11/8/2005 16:29	60.08	61.22	57.33	71.30	74.90	69.13	70.90	74.40	68.23	58.88	63.38	60.49	51.70	53.98	49.51	39.30
11/8/2005 16:59	60.63	61.77	57.88	71.90	75.50	69.72	71.60	75.00	68.87	59.47	63.97	61.15	52.29	54.50	50.12	37.93
11/8/2005 17:29	61.00	62.16	58.34	72.30	76.00	70.20	72.10	75.50	69.36	59.91	64.44	61.64	52.71	54.92	50.50	37.68
11/8/2005 17:59	61.10	62.22	58.40	72.40	76.10	70.30	72.10	75.60	69.46	59.97	64.52	61.70	52.67	54.91	50.48	37.00
11/8/2005 18:29	60.96	62.13	58.26	72.30	76.00	70.20	72.00	75.50	69.39	59.85	64.38	61.60	52.51	54.77	50.34	36.09
11/8/2005 18:59	60.84	62.00	58.16	72.20	75.90	70.20	71.90	75.40	69.34	59.72	64.28	61.50	52.31	54.57	50.17	35.51
11/8/2005 19:29	60.63	61.77	57.98	72.00	75.70	70.00	71.70	75.20	69.13	59.52	64.02	61.25	52.06	54.29	49.89	35.15
11/8/2005 19:59	60.43	61.61	57.74	71.80	75.50	69.85	71.50	75.00	68.95	59.31	63.84	61.04	51.85	54.06	49.64	34.39
11/8/2005 20:29	60.07	61.24	57.39	71.50	75.10	69.57	71.20	74.70	68.62	58.94	63.44	60.69	51.43	53.62	49.26	33.96
11/8/2005 20:59	59.89	61.10	57.25	71.30	75.00	69.41	71.00	74.50	68.48	58.77	63.25	60.53	51.19	53.47	49.09	33.67
11/8/2005 21:29	59.70	60.93	57.09	71.20	74.80	69.27	70.80	74.30	68.32	58.58	63.07	60.32	51.00	53.24	48.86	33.46
11/8/2005 21:59	59.56	60.77	56.95	71.10	74.70	69.12	70.70	74.20	68.18	58.44	62.90	60.17	50.84	53.07	48.72	33.34
11/8/2005 22:29	59.48	60.64	56.84	70.90	74.60	69.07	70.60	74.10	68.15	58.31	62.80	60.07	50.68	52.92	48.56	33.28
11/8/2005 22:59	59.50	60.71	56.91	71.00	74.70	69.16	70.70	74.10	68.24	58.38	62.87	60.12	50.78	53.02	48.68	33.28
11/8/2005 23:29	59.49	60.70	56.88	71.00	74.70	69.17	70.60	74.10	68.23	58.35	62.81	60.13	50.72	52.96	48.67	33.39
11/8/2005 23:59	59.36	60.54	56.74	70.80	74.60	69.07	70.50	74.00	68.12	58.22	62.63	59.97	50.63	52.80	48.49	32.99
12/8/2005 0:29	59.48	60.62	56.85	70.90	74.70	69.19	70.70	74.10	68.20	58.27	62.73	60.05	50.72	52.91	48.62	32.93
12/8/2005 0:59	59.40	60.61	56.79	70.90	74.60	69.18	70.60	74.10	68.21	58.24	62.70	60.07	50.71	52.85	48.58	32.80
12/8/2005 1:29	59.15	60.33	56.56	70.70	74.40	68.95	70.30	73.80	67.96	57.98	62.39	59.76	50.42	52.54	48.30	32.37
12/8/2005 1:59	59.01	60.22	56.42	70.60	74.30	68.84	70.20	73.70	67.87	57.87	62.26	59.65	50.29	52.48	48.22	32.33
12/8/2005 2:29	58.94	60.08	56.35	70.50	74.20	68.77	70.10	73.60	67.82	57.75	62.16	59.60	50.17	52.29	48.07	32.16
12/8/2005 2:59	59.03	60.21	56.44	70.60	74.30	68.86	70.20	73.80	67.96	57.82	62.23	59.69	50.28	52.43	48.21	32.30
12/8/2005 3:29	59.10	60.31	56.53	70.70	74.40	69.02	70.30	73.80	68.08	57.91	62.30	59.79	50.38	52.47	48.30	32.37
12/8/2005 3:59	58.89	60.10	56.38	70.50	74.20	68.87	70.20	73.70	67.92	57.76	62.14	59.63	50.17	52.29	48.12	32.21
12/8/2005 4:29	58.78	60.02	56.27	70.50	74.20	68.80	70.10	73.60	67.86	57.65	62.03	59.50	50.06	52.18	48.03	32.00
12/8/2005 4:59	58.73	59.89	56.22	70.40	74.00	68.75	69.98	73.50	67.78	57.57	61.89	59.40	49.98	52.08	47.93	31.88
12/8/2005 5:29	58.49	59.68	56.00	70.20	73.90	68.54	69.79	73.30	67.59	57.26	61.67	59.18	49.74	51.84	47.67	31.68
12/8/2005 5:59	58.42	59.63	55.93	70.20	73.80	68.51	69.72	73.30	67.59	57.24	61.62	59.13	49.72	51.82	47.72	31.66

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TANJUNG BIN, RAFT FOUNDATION OF CHIMNEY

THERMOCOUPLE TEMPERATURE MONITORING RECORD

Date & Time	Temperature in °C															
	Location A			Location B			Location C			Location D			Location E			AMBIENT
	A1	A2	A3	B1	B2	B3	C1	C2	C3	D1	D2	D3	E1	E2	E3	
12/8/2005 6:29	58.46	59.62	55.96	70.20	73.90	68.52	69.78	73.30	67.62	57.27	61.61	59.17	49.73	51.83	47.70	31.84
12/8/2005 6:59	58.37	59.50	55.90	70.10	73.70	68.46	69.64	73.20	67.53	57.11	61.50	59.03	49.59	51.69	47.61	31.77
12/8/2005 7:29	58.18	59.36	55.68	69.97	73.60	68.39	69.50	73.10	67.42	56.96	61.31	58.89	49.43	51.50	47.42	32.13
12/8/2005 7:59	58.03	59.22	55.56	69.85	73.40	68.19	69.33	72.90	67.30	56.77	61.16	58.72	49.28	51.35	47.25	32.46
12/8/2005 8:29	57.78	59.02	55.31	69.55	73.20	67.97	69.06	72.70	67.07	56.52	60.89	58.52	49.03	51.10	47.00	33.32
12/8/2005 8:59	57.47	58.68	55.05	69.22	72.90	67.66	68.73	72.30	66.72	56.17	60.56	58.14	48.67	50.79	46.69	34.36
12/8/2005 9:29	57.19	58.37	54.76	68.91	72.60	67.42	68.46	72.00	66.48	55.88	60.22	57.85	48.43	50.55	46.43	34.21
12/8/2005 9:59	57.16	58.35	54.69	68.91	72.60	67.40	68.37	72.00	66.48	55.86	60.18	57.78	48.43	50.55	46.45	36.56
12/8/2005 10:29	56.62	57.81	54.10	68.28	72.00	66.81	67.74	71.30	65.87	55.17	59.49	57.14	47.86	50.01	45.86	38.44

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