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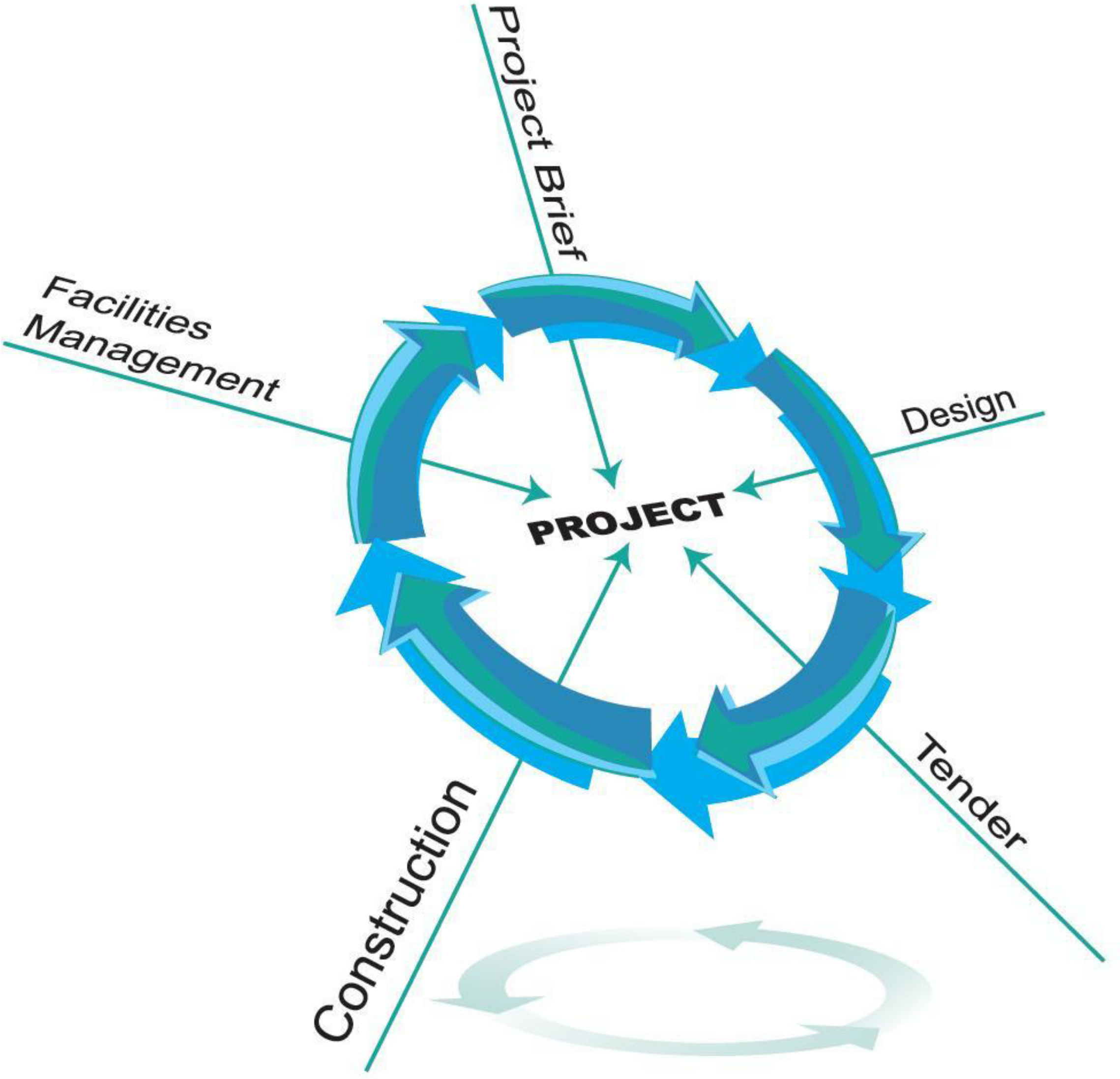

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Contents

Editorial Advisory Board

Editorial

Welcome from the Editors

Welcome to the fifth issue of Malaysian Construction Research Journal (MCRJ). The editorial team would like to extend our gratitude to all contributing authors and reviewers for their contributions, continuous support and comments. It is hope that the readers will find beneficial information from this edition of MCRJ. A total of 6 papers will be discussed further in this issue.

Mashitah Mat Don, et. al. studies the chemical and mineralogical of recycled aggregates from concrete based-waste materials. Recycled aggregates from concrete based-waste materials of demolition sites were found to be contaminated with hydrated cement paste and minor quantities of other substances.

H.Hamza, et. al. evaluates the alkali-silica reactivity (ASR) characteristics of aggregate samples from Sabah using simple chemical method. Petrographical studies and chemical tests were performed on sandstones and granite rocks obtained near Kota Kinabalu and results show that a number of specimens are potentially reactive.

Zuhairi et.al. discuss the strategic approach towards creating a sustainable construction in Malaysia. Sustainable construction looks several issues related to economic, social, environment and quality of life.

Sia Mal Kong and Christy Pathrose Gomez report on the survey conducted on 100 ISO 9001 certified companies in the Malaysian construction industry. The findings among others reveal that local companies adopt ISO 9001 certifications mainly to enhance their competitive processes and competitive performance to enable them to operate more efficiently.

Kurian V. John, et.al. present the methodology and implementation of hydraulic design and laboratory investigation on roof drainage system, based on parameters such as roof slope, roofing catchments profile, gutter cross section and gutter slope. The results of the study have been used to prepare recommended guidelines by CIDB for use by the architects, designers and builders in East Malaysia.

The last paper by ***Syamsuhaili Said et.al.*** studies the influence of unit strength on deformation behavior of fired-clay brickwork. The results indicate that creep and moisture movement is approximately inversely related to unit strength as theoretically stated that high-strength units tend to exhibits less creep and lowest expansion compared to lower-strength units.

Editorial Committee

CHEMICAL AND MINERALOGICAL STUDIES OF CONCRETE BASED-WASTE MATERIALS FROM DEMOLITION SITES

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Abstract
In developing countries, wastes management is becoming an acute problem as increase in urbanization and economic development leads to larger quantities of waste materials. Concrete based-waste materials that were generated usually delivered to landfills for disposal and in certain cases created air pollution problem due to open burning. Recycled aggregates from concrete based-waste materials of demolition sites were found to be contaminated with hydrated cement paste and minor quantities of other substances. After preliminary crushing and grain-size sorting, an investigation of its chemical and mineralogical properties were carried out to recognize particular granulometric classes that can be re-utilized as aggregates in new concrete production. Results of an X-ray fluorescence (XRF) and X-ray diffraction (XRD) showed that concrete based-waste materials behave as cementitious materials and gave rise to hydrated calcium silicate and aluminates to the reaction process. Scanning electron microscope (SEM) and Transmission electron microscope (TEM) micrographs revealed amorphous new formations of cement paste on the recycled aggregates. Fourier transform infra-red spectrometer (FTIR) showed the presence of functional groups in the waste materials.

Keywords: *Concrete based-waste materials, Recycled aggregates, Chemical, Mineralogical*

INTRODUCTION

Waste materials generated from construction and demolition sites are becoming a serious environmental problem in many large cities in the world. The management of waste materials required immediate attention especially in China, South Korea and Malaysia which have been categorized as emerging industrialized countries (Sangaralingam, 2003). In Malaysia, the construction industry generated lots of construction and demolition wastes which caused significant impacts on the environment and aroused growing public concern in the local community (Kamar and Zuhairi, 2008). With population of over 24 million in the country, more than 16,000 tones of domestic wastes were generated daily. At present, the per capita generation of waste materials in Malaysia varies from 0.45 to 1.44 kg/day depending on the economic status of that area (Lau, 2004).

Most of these wastes (75%) were disposed to landfill, despite its major recycling potential. They were left as stockpiles, landfill material or illegally dumped in selected areas. In fact, large quantities of these wastes cannot be eliminated. Roa *et al* (2007) reported that recycling turns materials that would otherwise become waste into valuable resources and generated a host of environmental, financial and social benefits. Previously, Begum *et al*., (2006) stated that construction materials at the construction sites contribute to the generation of construction wastes. Waste minimizations were common activities at the project sites where 75% of the waste materials were reused and recycled. Moreover, research into new and innovative application of waste materials are continuously advancing in Malaysia.

The environmental protection has to be considered seriously and should be integrated within the economical development. This great potential for minimizing wastes in construction industry should be geared forward so as to solve any environmental problems evolved. Besides that, the construction industries could reduce material purchasing and waste disposal costs through an increase emphasis on waste reduction, reuse and recycling. According to Pun *et al*. (2006), the increase in charges of landfill and scarcity of natural resources for virgin aggregates has encouraged the use of wastes from construction and demolition activities as a source of aggregates. Moreover, large quantities of these wastes were produced in urban areas, rising the recycling and reused of such types of wastes as an urgent and imperative environmental issue.

Prior recycling such wastes as aggregates in concrete production, greater attention should be paid to understanding of their chemical-mineralogical characteristics (Bianchini *et al.* 2005; Limbachiya *et al.* 2006). These might result in the detection of new potential applications for specific construction and demolition waste types (Bianchini et al., 2005). With that, development of more complete characterization procedures is desirable (Angulo et al., 2009).

The aim of this study is to identify the chemical and mineralogical composition of concrete based-waste materials to be used as recycled aggregates including its influence on engineering properties and durability of concrete.

MATERIALS USED

Concrete based waste materials from selected construction and demolition sites were clean and free from detrimental levels of chemical impurities and harmful constituents (Plate 1). Representative samples of concrete based waste materials were collected, dried, ground and sieve through a 75µm mesh sieve. Only fraction ≤ 75 µm were used for subsequent studies.

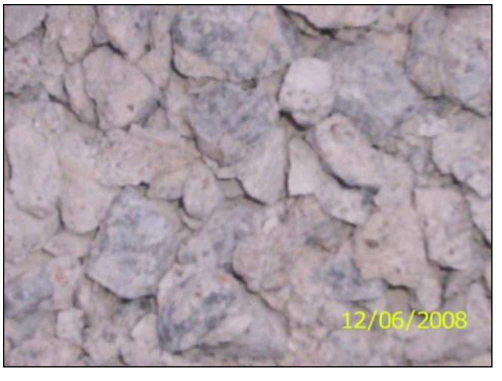

Plate 1. Concrete based waste materials

ANALYTICAL METHODS

Fractions of size ≤ 75 μm were analyzed for their chemical and mineralogical properties using an X-ray fluorescence (XRF), X-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), and Fourier transform infra-red spectrometer (FTIR), respectively.

For an X-ray fluorescence analyses (XRF), an ARL Advant XP sequential (wavelength dispersive) XRF were used.

X-ray powder diffraction patterns were obtained using a Siemens D5000 Diffractometer operation at 40 kV, 30 mA.

Mineralogical and morphological investigations of the waste materials were carried out using scanning electron microscopy (SEM, Leo supra scanning electron microscope model 35 VP Germany) and transmission electron microscopy (TEM, Philips CM 12 transmission electron microscope), respectively. IR absorption measurements were carried out using a Fourier transform infra-red (FTIR) spectrometer (Perkin Elmer 880). The FTIR spectra in the wavelength range from 400 to 4000 cm^{-1} were obtained with the use of the KBr pellet technique.

RESULTS AND DISCUSSION

Chemical characterization of natural and recycled aggregates

The striking feature observed first in the concrete based waste materials was deposition of cement paste onto the concrete with various colours due to longer exposure at the demolition sites. In order to verify the chemical composition of the wastes, a careful chemical analysis of the concrete wastes powder has been carried out. The results of the particle size distribution analysis revealed that all studied concrete wastes consist of finely grain materials of size ≤ 75 μm in accordance to BS 8500; Part 2.

Table 1 presents the XRF chemical results of both concrete based-waste materials and natural aggregates. The main oxides were SiO_2, CaO, Al_2O_3 and Fe_2O_3, followed by Fe_2O_3, MgO, K_2O, Na_2O, TiO_2, P_2O_5 and MnO. The SO_3 lies below 1.0 wt %. Higher amount of CaO was detected at 38 wt % for concrete based waste materials while only 2.7 wt % for the natural aggregates. This is closely related to the higher amount of cement paste that was left attached onto the surface of concrete based-waste materials during crushing. Portland cement is made up of limestone ($CaCO_3$) and higher CaO reflects its presence in waste aggregates. According to Limbachiya *et al*. (2007) when natural aggregates were blended with Portland cement, it will behave as cementitious materials and gave rise to calcium silicate hydrated, CSH ($CaO.SiO_2.H_2O$) and aluminates, and their reactions could contribute a considerable amount of CaO to the reaction processes.

Table 1. XRF analysis of natural aggregates and concrete based waste materials.

Element	Natural aggregates (wt %)	Concrete based waste materials (wt %)
SiO_2	64.00	43.00
CaO	2.70	38.00
Al_2O_3	15.00	10.00
Fe_2O_3	9.30	3.40
MgO	1.00	1.30
K_2O	4.70	2.00
SO_3	0.24	1.00
Na_2O	2.00	0..25
TiO_2	0.35	0.30
P_2O_5	0.37	0.11
MnO	0.05	0.08

Physio-chemical reactions of the cement paste around concrete based waste materials were investigated. As can be seen in Table 1, the concrete based waste materials had nearly the same amount of silicon and calcium. This coincides with the results reported by Tam *et al.* (2008) who stated that in principles, fours compound should exist in normal cement paste such as: (i) tricalcium silicate (C_3S), (ii) dicalcium silicate (C_2S), (iii) tricalcium aluminate (C_3A) and (iv) tetracalcium aluminoferrite (C_4AF). In these chemical reactions, C_3S and C_2S react with water (H_2O) to produce calcium silicate hydrated ($C_3S_2H_3$) and calcium hydroxide (CH). The reactions that took place were (1) $2C_3S + 6H \rightarrow C_3S_2H_3 + 3CH$ and (2) $2C_2S + 4H \rightarrow C_3S_2H_3 + CH$. The overall process of the hydration is $2Ca_3SiO_5 + 7H_2O \rightarrow 3CaO.2SiO_2.4H_2O + 3Ca(OH)_2$. These explained the presence of higher amount of silicon, calcium and alumina in the waste materials (Table 1).

The analysis of XRD patterns (Figure 1) indicated the presence of predominant elements, SiO_2 and $CaCO_3$ peaks for concrete base-waste materials. The natural components of the waste materials were quartz (SiO_2), microline ($KAlSi_3O_8$), calcium carbonate ($CaCO_3$) and calcium silicate (Ca_2SiO_4). This analysis showed that concrete based waste materials constituted of different amounts of hydration products such as afwillite ($Ca_3(SiO_3OH)_2.2H_2O$) and C-S-H-calcium silicate hydrates ($Ca_4Si_5O_{13.5}(OH)_2$) and binding materials, such as lime (CaO), periclae (MgO), calcium hydroxide-portlandite ($Ca(OH)_2$) and carbonate-calcite ($Ca(CO)_3$) (Figure 1). According to Limbachiya *et al*. (2007), recycled aggregates contained calcite, portlandite, and minor peaks of muscovite/illite. And XRD analysis was used to recognize a particular granulometric classes that can be re-utilized as a 1^{st} order material in the building activity.

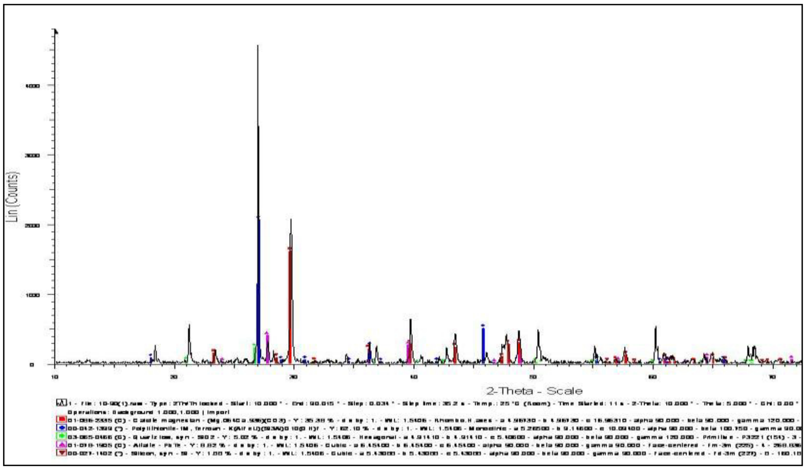

Figure 1. XRD pattern for concrete based waste materials

Mineralogical and morphological analysis

A scanning electron microscopy (SEM) analysis is a valuable step in the characterization of the aggregate. The distributions of CSH, calcium silicate hydrates in the microstructure were determined by SEM and some selected ones were presented as backscattered electron images in Figure 2 and 3.

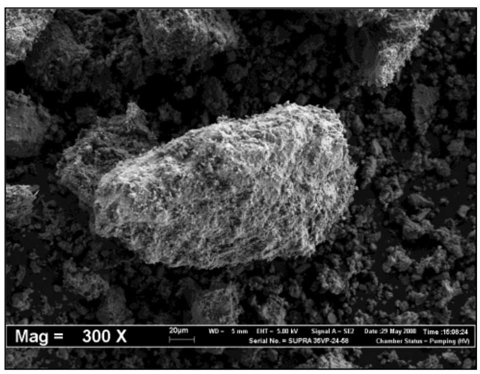

Figure 2. SEM micrograph of concrete based waste materials (300 X magnification)

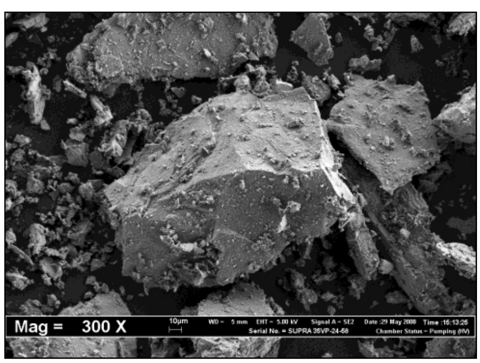

Figure 3. SEM image of natural aggregates (300 X magnification)

SEM micrographs revealed new amorphous formations. SEM observations highlighted differences in the surface of concrete based waste materials as shown in Figure 3, compared to natural aggregates where Figure 3 showed the formation of portlandite and CSH in aggregate. However, the thin section images of blended cement pastes showed that the microstructure has newly formed alite minerals. The SEM micrographs clearly showed that the concrete based waste materials structure containing inclusions of cement paste hydrates. Their surfaces were covered with amorphous formations and were devoid of crystal bodies. Tam *et al*., (2008) reported that in a fully cured cement paste, calcium hydroxide-portlandite, $Ca(OH)_2$ was highly crystalline and has a fixed composition, comprised of more than 20% of the hydration products. Hydration of silicate phases, C_3S, C_2S and free lime (CaO) can be described as:

$$2(3CaO.SiO_2) + 6H_2O \rightarrow 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2 \quad (1)$$

$$2(3CaO.SiO_2) + 4H_2O \rightarrow 3CaO.2SiO_2.3H_2O + Ca(OH)_2 \quad (2)$$

$$CaO + H_2O \rightarrow Ca(OH)_2 \quad (3)$$

Another type of crystal found in hydrated cement paste that was left at the surface of concrete based waste materials is known as ettringite ($Ca_6[Al(OH)_6]_2(SO_4)_3.26H_2O$), and the reaction is as follows:

$$6Ca^{2+} + 2Al(OH)_4^- + 4OH^- + 3SO_4^{2-} + 26H_2O \rightarrow Ca_6[Al(OH)_6]_2(SO_4)_3.26H_2O \quad (4)$$

Previously, Mymrin *et al.* (2007) observed similar forms on the surfaces of mixtures of clayey soils with ferrous slag in a study of their chemical interaction and structural formation. Later, Binici *et al*. (2008) reported that SEM micrograph of concrete based waste materials reveals the development of uniform pore spaces and products of hydration.

Another study conducted by Mymrin *et al.* (2007) clearly showed that the SEM micrographs of concrete waste contained inclusions of stone and sand aggregates. Their surfaces were covered with amorphous formations and were devoid of crystal bodies. These findings confirmed that the XRD data was partly crystalline in nature with new formations that could strengthen the material's volume.

Figure 4 showed the TEM surface micrograph of concrete based waste materials with abundant amount of pores and cracks, making it having higher absorption of water. The pores were smaller and denser as compared to the natural aggregates (Figure 5). This showed that the structure of recycled aggregates were porous. In fact, the images of cement paste hydrates that were left on the surface of the waste materials can be seen clearly in the micrograph. The cement paste tend to hydrate by itself and gave rise to an abundant pores present in the surfaces, comprising of calcium silicate hydrates and the main compounds - quartz and calcite. However, during setting and hardening, the new cement paste will first react with the old cement paste attached to the concrete based waste materials, in which some of the water was used. According to Tam *et al*., (2008), this could be the cause that affected and reduced the formation of $C_3S_2H_3$, ettringite, CH and C_6S_3H; leading to poorer strength of concrete based waste materials such as in recycled aggregates. The major reason of the activeness of the physio-chemical reactions occurred in recycled aggregates were the larger amount of mini cracks that absorbed some of the required water and reduced the amount for mixing and at the same time hinder the development of $C_3S_2H_3$, ettringite, CH and C_6S_2H. As a result, the concrete strength reduced accordingly.

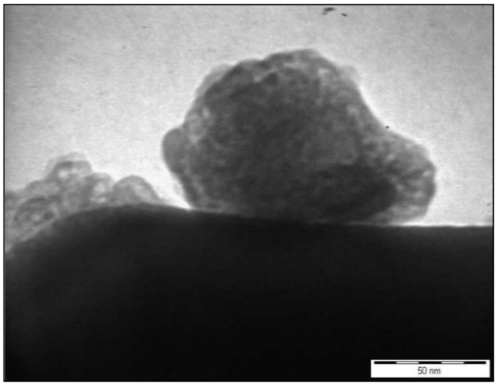

Figure 4. TEM image of concrete based waste materials

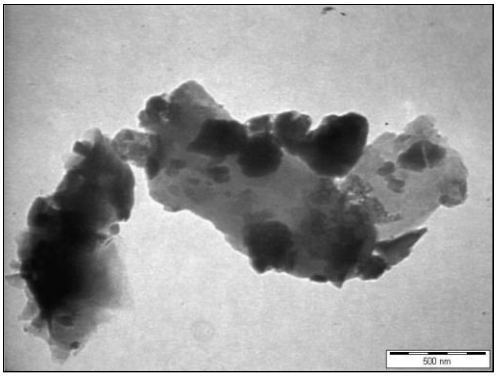

Figure 5. TEM image of natural aggregates

FTIR Study of concrete based waste materials

The FTIR absorbance measurements were performed on the recycled aggregate samples in order to characterize the mineralogical composition that could provide information for the paste typology. FTIR spectra can be very useful in obtaining information about structure, channel size and the cation substitution (Si^{4+}, Al^{3+} and Ca^{2+}) in the concrete based waste materials.

An FTIR spectrum of recycled aggregates is presented in Figure 6. The strongest vibration appeared at 1429 cm^{-1}. This band is significant for the estimation of silicon content in the crystalline framework. Another band that appeared was the carbonyl (C=O) group at 1796 cm^{-1}. Tam et al. (2008) reported that there was a gradual increased in the total absorbance of CO and CO_2 from the FTIR analysis for concrete aggregates. Theoretically, the cement paste taken from the internal part of aggregates should be exposed to a higher degree of carbonation. Due to that, the total absorbance of CO and CO_2 would gradually decrease from the layer of the cement paste.

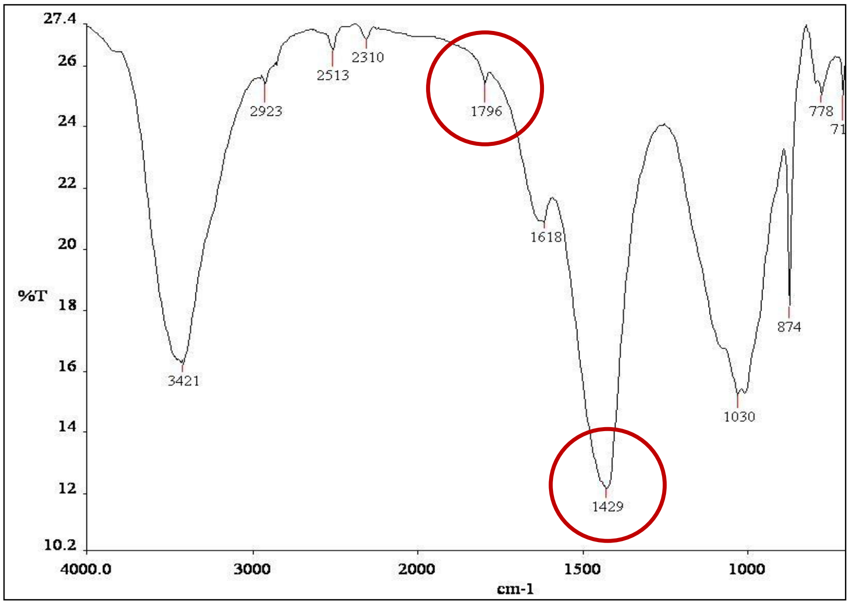

Figure 6. FTIR spectrum of concrete based waste materials

CONCLUSION

This paper described the chemical and mineralogical properties of concrete based waste materials suitable for use in new concrete production. X-ray fluorescent analysis indicated the presence of SiO_2, CaO, Al_2O_3 and Fe_2O_3, followed by Fe_2O_3, MgO, K_2O, Na_2O, TiO_2, P_2O_5 and MnO, respectively. Higher amount of CaO was detected for concrete based waste materials compared to the natural aggregates. The analysis of XRD patterns indicated the presence of predominant elements, SiO_2 and $CaCO_3$ peaks for concrete base-waste materials. This is closely related to the higher amount of cement paste that was left attached onto the surface of waste materials during crushing. In fact, the cement paste hydrates were clearly shown in SEM micrographs. This paste contained higher amount of pores on the surface which affected the development of $C_3S_2H_3$, ettringite, CH and C_6S_2H, thus influencing the strength of the concrete accordingly. Nevertheless, these concrete-based waste aggregates could help to induce the utilization of recycled aggregates in construction industries, decrease natural aggregate consumptions and reduce environmental problems.

ACKNOWLEDGEMENT

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DETERMINATION OF POTENTIAL ALKALI SILICA REACTIVITY OF AGGREGATES FROM SABAH, MALAYSIA

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Abstract
Aggregate makes up a significant portion of concrete. However, unlike cement, there are limited choices as to the composition and source of aggregate to be used. It has been shown in the field and in the laboratory that certain types of aggregate can cause deleterious expansion through a reaction known as alkali-silica reaction (ASR). It is known that alkaline components of cement chemically react with silica in certain forms found in certain aggregates. The reaction product is referred to as ASR gel. When the relative humidity in the vicinity of the gel exceeds about 80 percent, the gel absorbs water from its surroundings. This water absorption causes swelling that disrupts the structure of surrounding concrete. The concrete structures in Kota Kinabalu, Sabah, Malaysia, affected by the ASR have been found in many places and this has become a major problem. Therefore, it is necessary to clarify the reactivity level of different types of rocks used in local construction. The aim of this study is to evaluate the alkali-silica reactivity characteristics of aggregate samples collected near Kota Kinabalu using simple chemical method. The samples chosen in this study are three sandstone and two granite rocks. Petrographical studies showed that the sandstone consisted of 70% quartz, 8% chert, 15% feldspar and less than 10% rock fragments including sedimentary, metamorphic and igneous rock. It can be seen that most of the aggregates tested are categorized as reactive aggregate, except one sample of granite aggregate is non-reactive. The quick chemical test result concluded that the sandstone aggregates are potentially reactive. However additional mortar bar expansion test at longer duration is required to confirm the reactivity level.

Keywords: *Alkali silica reaction (ASR), Sandstone, Granite, Chemical test, Reactivity index value*

INTRODUCTION

Until recently, it was believed that the alkali-silica reaction (ASR) of concrete was very rare in Malaysia, and almost no aggregates in Malaysia were known to show the alkali–silica reaction When the concrete is affected by the ASR, map-like cracks take place in the concrete, and its serviceability and durability becomes low. The concrete structures in Kota Kinabalu, Sabah, Malaysia, affected by the ASR have been found in many places and this has become a major problem. Therefore, it is necessary to clarify what types of rocks are reactive.

In Sabah, Malaysia the average annual production of stone aggregates including river pebbles is about 12 million tones. The crushed sandstone aggregate itself is about 6.5 million tones, which is more than 54% of annual production (Kumar 2006, Tony and Hisam 2002). The commonly used aggregate for the construction near Kota Kinabalu city is sandstone and granite aggregate is used for specific projects. There are 19 quarries situated near Kota Kinabalu and the locations are shown in Figure 1. Sandstones are mainly found in most of the areas around Penampang, Inanam, Menggatal, Telipok and Tamparuli. The stone reserves are between 100,000 and 2,000,000 m^3. A small granodiorite stock at Kampung Kapa, near Tamparuli, beside the Tamparuli-Ranau Highway and the nearest igneous body to Kota Kinabalu, has been quarried for the past 15 years. A small granite stock is also available at certain area of Tamparuli-Ranau.

Aggregate makes up a significant portion of concrete. However, unlike cement, there are limited choices as to the composition and source of aggregate to be used. It has been shown in the field and in the laboratory that certain types of aggregate can cause deleterious expansion through a reaction known as alkali-silica reaction (ASR). It is generally believed that the concrete containing aggregates like sandstone are susceptible to ASR (Wakizaka 2000). The expansion behavior of a concrete element depends on the type, size, and amount of aggregates containing reactive silica present in the concrete.

Since the reaction was first discovered in by Stanton in 1940 (Stanton 1940), a few literature has reported the damage to concrete structures caused by this deterioration process. ASR is the reaction between the alkali hydroxide in cement and certain siliceous rocks and minerals present in the aggregates. However, not all siliceous aggregates are reactive. In general, the aggregates that cause harmful reactions in concrete are those containing amorphous silica (glasses and opal), unstable crystalline polymorphs of silica (cristobalite and tridymite), poorly crystalline forms of silica (andesite and rhyolite), and microcrystalline quartz-bearing rocks (quartzite and greywacke) (Felix 1989).

The highly alkaline pore fluids of concrete are able to depolymerize the reactive silica present in the aggregates, forming products of different compositions in the concrete pores. In the presence of moisture, the reaction products (gel products) change in volume and may expand to such a degree that the concrete tensile strength is reached and the material cracks. As soon as the material's integrity is affected, other processes of deterioration may take place. In order to ensure the durability of concrete structures, the susceptibility of aggregates and cements need to be investigated. The obvious solution for avoiding problems with ASR is simply to use a non-reactive rock type. Unfortunately there is no single test that can be utterly recommended as a perfect method for screening potential aggregates for which no historical performance records exist. Consequently a conservative engineering approach is suggested, checking the aggregate performance by more than one technique and taking appropriate measures where the test results indicate caution is justified.

The first step in the evaluation of any new aggregate source should be the commissioning of petrographic examination in accordance with ASTM C 295 (or an equivalent method). This determines whether the rock contains any of the reactive silica phases identified, which indicate potentially deleterious performance. Secondly, an accelerated test for ASR susceptibility should be used in which mortar bar length changes were measured and used to indicate the potential of being reactive. In most of the test methods (Duyou et al. 2006), potential alkali-silica reactivity of an aggregate is evaluated at elevated temperature. In these test methods, if the alkali hydroxide concentration is kept low then the risk of false negative is low. These methods can only evaluate the reactivity of the aggregate but cannot suggest an acceptance criterion.

Based on these requirements a simple chemical test method has been proposed by Chatterji to test directly the alkali-silica reactivity of aggregate (Chatterji and Jensen 1988). This method is very simple, fast and does not require any complicated instruments. The tests can be carried out in a quarry to control the quality of a chosen aggregate and the result is obtained generally within 24 hours. The size of the sample could be adjusted depending upon the size of the aggregate. The aim of this study is to evaluate the alkali-reactivity characteristics of aggregate samples collected near Kota Kinabalu using simple chemical method. The samples collected in this study were obtained from five different quarries near Kota Kinabalu as shown in Figure 1.

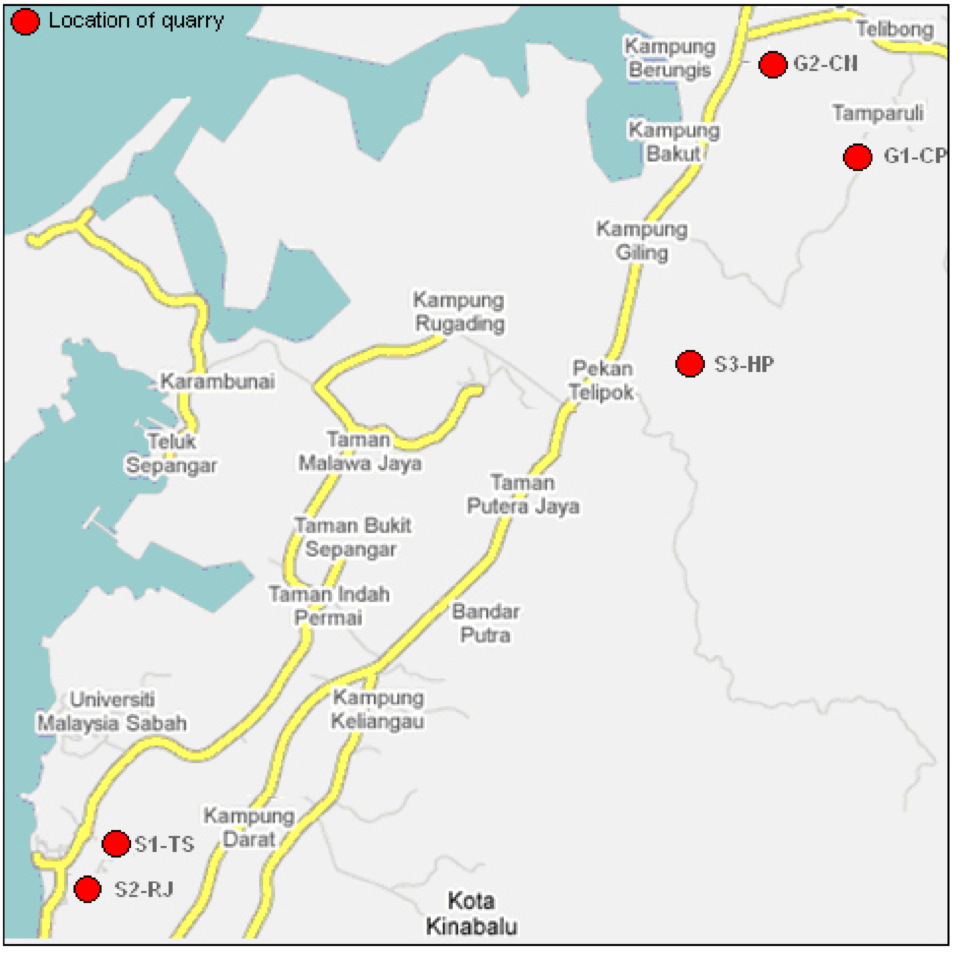
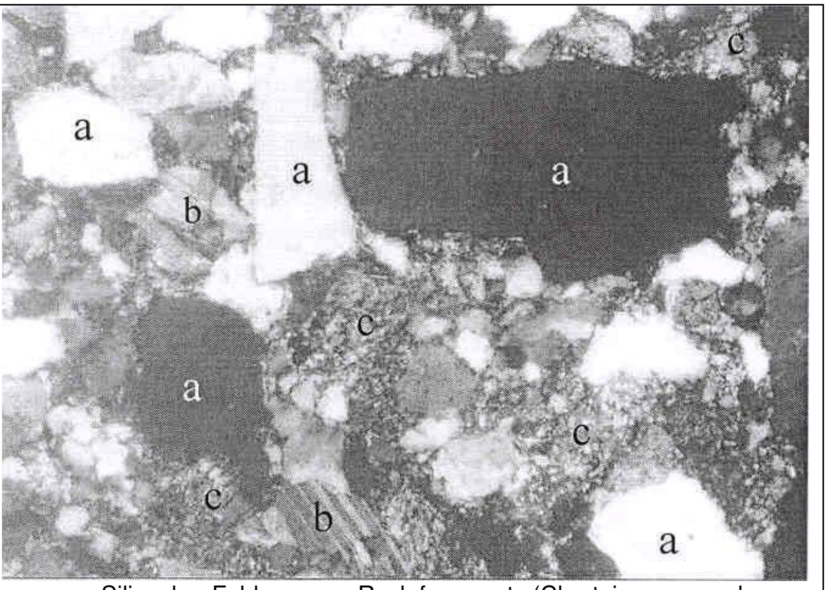


Figure1: Location of quarries near Kota Kinabalu, Sabah

PETROGRAPHIC EXAMINATION OF SANDSTONE AGGREGATE

Petrography is a comparatively quick way to predict aggregate reactivity based on microscopic examination of aggregate samples. Figure 2 showed the photomicrograph image of sandstone aggregate from Sabah (Kumar 2006). A study on petrographical, mineralogical and textural description of the different sources of sandstone aggregate quarried near Kota Kinabalu consisted of 70% quartz, 8% chert, 15% feldspar and less than 10% rock fragments including sedimentary, metamorphic and igneous rock (Felix 1989).

The sandstones are poorly sorted, that is, grain of various sizes occurs together (0.03-3 mm). The frame work is dominated by quartz grains which are generally rounded to subrounded. The interstitial matrix consists of silt-sized quartz, mica, and probably also sub-microscopic clay minerals at grain interfaces. Internal porosity of sandstone is clearly enhanced adjacent to mica. In general the sandstone is held together by phyllosilicate minerals (clay and altered rock fragments) as result of local compaction and rarely by chemical cement, and it is relatively soft and friable. Coarser granularity and better crystallinity suggest that sandstone is less liable to silica dissolution.



a– Silica; b – Feldspar; c – Rock fragments (Chert, igneous and metamorphic rock)

Figure 2: Photomicrograph image of sandstone aggregate (Kumar [8])

Besides, a petrographic examination of sandstone aggregate from a different source indicated that the mortar-bar expansion (ASTM C1260, Standard test for ASR in aggregate) with sandstones appear to vary widely between 0.032 and 0.25% (Gogte 1973). One sandstone containig 20% chert shows an expansion of 0.25% while another with 7% chert shows expansion up to 0.11%. Some of the sandstones containing a few grains of strongly undulatory quartz also show negligible expansions. The chemical compositions of the sandstone aggregates are shown in Table 1. The sandstone aggregate contains mainly silica 81.70% and alluvium 8.62% and all other compositions are marginal. Hence, the sandstone aggregate can be considered as reactive aggregate.

Table 1: Chemical composition of Sandstone aggregate

Chemical	Content (%)
SiO_2	81.70
Al_2O_3	8.62
Fe_2O_3	1.05
CaO	0.18
TiO_2	0.95
MgO	0.33
SO_3	0.17
Na_2O	0.02
K_2O	0.13
Loss on ignition (LOI)	1.17

SAMPLING

In total, five samples were taken from the different quarries and the details of source of samples from different locations are shown in Table 2. The aggregate was crushed and sieved according to the grading requirement (ASTM C 33-03) as shown in Table 3. The aggregate was washed to remove dust and small particle and then dried at about 105°C for 24 hours and weighed to attain constant weight.

Table 2: Quarry name, types of aggregate, and method of quarrying

No.	Sample	Types	Location	Methods
1	S1-TS	Sandstone	Menggatal	Demolition
2	S2-RJ	Sandstone	Menggatal	Drilling
3	G1-CP	Granite	Tamparuli-Ranau	Drilling
4	S3-HP	Sandstone	Telipok	Demolition
5	G2-CN	Granite	Tamparuli-Ranau	Demolition

Table 3: Grading requirement as per ASTM C 33

Size	Percentage Passing (%)
4.75 mm	95 to 100
2.36 mm	80 to 100
1.18 mm	50 to 85
600 μm	25 to 60
300 μm	10 to 30
150 μm	2 to 10

CHEMICAL TEST PROCEDURE

The test is based on a fundamental consideration of the reaction mechanism of alkali-silica reaction. In this method 100 g of aggregate, in its natural state, is digested at 70ºC in a suspension of Ca $(OH)_2$ in saturated KCl for 16 h. In the mixture the following reaction occurs

$$\text{Reactive silica} + Ca^{2+} + 2OH^{-} + K^{+} + Cl^{-} + H_2O \gg \text{Hydrated lime–alkali–silica complex} + Ca^{2+} + 2Cl^{-}$$

The detailed test procedures are explained in following paragraphs. A large stock solution of saturated solution of KCl in distilled water was prepared in certain proportion of KCl and water at about 50ºC. The saturated solution of KCl was stored for at least two days at 20°C ± 2°C before being used. To remove excess KCl, the solution was filtered using a membrane filter. Several dry samples of the aggregate and quartz sand as control were prepared as control. The samples were placed in an oven at 70°C ± 2°C for 24 hours.

One lot of CaO was added in each of the conical flasks containing saturated KCl solution and stored in the oven at 70°C for 16 hours. Then, the heated aggregate samples were added to the corresponding conical flasks and placed in the oven at 70°C ± 2°C for 24 hours. For the first 8 hours, the samples were re-suspended at every 2 hours and released pressure using the valve in the rubber plug. After that, the suspensions were cooled in a water bath maintained at 20°C ± 2°C for at least 3 hours. During the cooling period, the mix was re-suspended every 20 minutes.

The suspension was filtered through 0.4 or 0.45 μm size membrane filters under suction. The titration was started immediately after filtering to avoid carbonation after the solutions have been filtered. Approximately 10 mL of the filtrates should be taken out.

The OH^- concentration of each of the three filtrates was determined acidimetrically using 0.025 HCl and phenolphthalein as the indicator. A few drops of phenolphthalein were added to the filtrates. The start and end volume of the 0.025 N HCl was noted. A titration is considered complete when the filtrate solution remains colourless for 30 seconds or more. The concentration of OH^- in the solutions [mg/L] was calculated. The OH^- ion concentration (C) of the filtrate in mg/L is given in Eq.1 and the index value was calculated using Eq.2.

$$C = B*425/A \qquad \text{(Eq.1)}$$

$$\Delta = C_{control} - C_{test} \qquad \text{(Eq.2)}$$

Where,

A = ml of the filtrate requires
B = ml of 0.025 N HCl for complete neutralization

RESULTS AND DISCUSSION

The results obtained from the chemical test are shown in Tables 4 and 5. It can be seen that most of the aggregates tested are categorized as reactive aggregate, except one sample of granite aggregate (G1-CP) which is non-reactive. The most reactive aggregate among the aggregates tested is sample S1-TS with index value of 98, which can be categorized as highly reactive. The quick chemical test result concluded that the sandstone aggregate are potentially reactive. However additional mortar bar expansion test at longer duration is required to confirm the reactivity level.

In general, the granites are considered as non-reactive. But the test results showed that the index value of granite sample G2-CN was 88, which was categorised as highly reactive. This may be due to the higher amount of dissolved silica concentration in the rocks (Wakizaka 2000).

It is clear from the results that the reactivity of the aggregate is greatly influenced by the method of sampling. The extracted samples from demolition gave higher reactivity than drilling method. This may be due to the demolition method which produces very disturbed surface layer, which was more soluble in dilute alkaline solution (i.e. in dilute NaOH solution). Another possibility could be that during the demolition, the fracture naturally disturbed and weakened parts of the rock into microfractures and either disturbed or open structures may trigger reactivity of the aggregate (Chatterji 2005, Duncan et al. 1973).

Table 4: OH^- ion concentration of tested aggregate

No.	Sample name	OH ion concentration (mg/L)	
		Tested Sample	Control sample
1	S1-TS	504.53	602.10
2	S2-RJ	535.50	569.50
3	G1-CP	519.92	528.42
4	S3-HP	532.82	578.00
5	G2-CN	487.30	575.17

Table 5: Index value and potential reactivity of the tested aggregate

No.	Sample name	Index value	Reactivity
1	S1-TS	98	highly reactive
2	S2-RJ	34	slowly reactive
3	G1-CP	9	non-reactive
4	S3-HP	45	reactive
5	G2-CN	88	highly reactive

CONCLUSION

The result gave a clear view that almost all of the aggregates commonly used in construction industry at Kota Kinabalu are considered as reactive aggregate except for granite sample G1-CP. The level of alkali reactivity of the aggregate is high for sandstone sample, S1-TS and granite sample, G2-CN. The other sandstone samples, S2-RJ and S3-HP are slowly reactive and reactive aggregate respectively. As the conclusion, this research was successful to determine the level of alkali reactivity of the aggregate from East Malaysia. This process is beneficial in the beginning of a construction project to screen aggregates of unknown history with regard to potential reactivity as well as for optimizing the mix proportions of concrete with respect to water-cement ratio, mineral and chemical admixtures, which may prevent potential deterioration of concrete due to the ASR (Kumar 2006). Nonetheless, further test may have to be performed to confirm that the potentially reactive aggregates will pose harmful effects to concrete.

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STRATEGIC APPROACH TOWARDS SUSTAINABLE CONSTRUCTION IN MALAYSIA

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ABSTRACT
Sustainable has become a pertinent issues in the construction nowadays. The government through its Budget 2010 recently has given priority to environmental friendly products and services that comply with green technology and issues of climate change particularly in construction. As buildings and other structures are planned to last for 50 to100 years, future changes in climate change derived from these constructions should be given a high priority. Through anticipating future climatic developments, engineers can minimize their negative effects and benefit from their positive impacts. Construction sector could not be marginalized from the issues on environment. Creating a sustainable construction in Malaysia requires a strategic approach that will benefit the country's current and future consideration looking issues related to economic, social, environment and quality of life. Construction Industry Development Board (CIDB) Malaysia is obliged to take this issue on board through its Construction Industry Master Plan initiatives under Strategic Thrust 3: Strive for the highest standard of quality, occupational safety and health and environmental practices.

Keywords: *Construction Industry, Built Environment, Strategic, Sustainable, Challenges, Way Forward*

INTRODUCTION

In Budget 2010 that was tabled on 24th October, 2009 saw the government taking concerted effort to encourage Malaysian to embrace green and sustainable. This move is in tandem with global community in preserving resources and the environment in the future. The government had allocated RM 20 billion to intensify green and sustainable awareness to be more environmentally friendly. The construction industry and its related activities are responsible for a substantial amount that has been approved for. The manifestation of sustainable and built environment is generally associated with one another. Built Environment is a broad concept encompassing man-made artifacts and space at all levels from single items to urban regions (*Chalmers Architecture, 2008*). The world is at a crossroads between the old path of development at the price of environmental degradation and a new one combining growth with sustainability (*Newsweek, July, 2008*). In the scale of maximum score of 100 the Environmental Performance Index (EPI) aims to be a comprehensive assessment of the world's environmental challenges and how individual countries are responding to them. Switzerland and Sweden are the world's green leaders while Malaysia positioned 26th. in the ranking sharing with Denmark (*Newsweek, July, 2008*). This indicates that we as Malaysian are concerned of the environment.

The construction industry generates impetus to the Malaysian economy. For many years it has created important roles in improving the quality of life for Malaysian through multiplier effects to other industries. In this respect, physical development solely would not give the guarantee to pursuit the quality of life for future generations. It must also be able to develop and utilize resources with most effectively and competitive and sustainable economy.

This paper discusses the role played by CIDB Malaysia to set out an agenda and a strategy for action to attain current and future sustainability environment. The policy set by the government, R&D innovation, the domestic skills development and construction capability, are all fundamental to the infrastructure that will consolidate and drive the nation's economy forward.

ISSUES AND CHALLENGES IN MALAYSIAN CONSTRUCTION

In a developing country like Malaysia, the sustainable construction trend tends to focus on relationship between construction and human development and marginalizing environmental aspects. However, in light of the severe environmental degradation experienced by most of the developing countries, construction industry cannot continue to ignore the environment (*Begum, 2005*).

Environment encompasses physical and non physical medium such as air, water, solid waste/land and also noise pollution. Construction sector could not be put aside from the issues on environment. The construction with exploitation of natural resources such as forest for timber, housing and industry without proper control contributes to the environmental problems (*Ibarahim, 1999*). Many of environmental issues that occur in our country are due to lack of environmental considerations in the exploitation, development and management of resources as well as lack of control of pollution resources. These issues if not tackled strategically will further aggravate and exert challenges towards sustainable construction in the following way (*CIB, 2002*).

i) Major concern challenges on sustainable construction are the mobilization of resources in order to support research, technological changes and feasibility studies. The sharing of research and educational activities must be taken on board right from government, universities and other private sector related industries (*CIB, 2002*),

ii) Environmental issues on construction are becoming more complex. The pursuance of environmental protection must be balance with the need for economic development (*CIB, 2002*),

iii) The use of environmentally appropriate technologies with concern on energy efficiency and full commitment to waste recycling and pollution should be practiced by construction players (*CIB, 2002*) ,

iv) Emphasis also must be given to the integration of environmental in all project planning and implementation. In this respect, usage and application of information, communication and technology (ICT) in leveraging skills should be introduced to the construction players (*CIB, 2002*),

v) Construction also has to reduce usage of its resources through material consumption, construction costs and wastage rates (*CIB, 2002*). It can be successful being done by way of education, site planning, management and design practices and adoption of new technologies,

vi) In global environmental sustainability, there is need for construction players to leverage socio-economic through equitability which stipulated in Kyoto Protocol which requires a substantial reduction in greenhouse gas emissions (*CIB, 2002*).

vii) Improving the quality of the construction process and its products. A first step towards sustainable construction is to improve the quality of construction products and the efficiency and safety of the construction process.

Malaysian construction industry players need to take a holistic approach along the construction value chain activities in performing their duties. Wider spectrum coverage within construction fraternity itself including societies, workers must work together towards sustainable construction in future.

There are a lot of rooms for improvement in the Malaysian environment scene at large. We could learn from experience in Sweden that focuses to build sustainable communities by looking at four strategic challenges as follows (*Ministry of Sustainable Development, 2006*):

i) Balancing various interests in terms of physical planning, regional development and infrastructure, along with residential and city planning consistent with sustainable urban development. An overall challenge, both nationally and globally, is posed by demographic change as the result of migration, an ageing population, urbanisation (particularly in the metropolitan areas) and depopulation trends in most Swedish municipalities.

ii) Encouraging good health on equal terms requires laying the foundation for decent living conditions – access to gainful employment, decent workplaces, economic and social security, communities in which children can grow up safely, participation and codetermination.

iii) Prioritising broad-based initiatives aimed at eliminating health and mortality discrepancies among various social and economic groups. A clean environment and healthy lifestyles are also vital to improve public health that facilitates both national economic growth and more stable household finances.

iv) Encouraging sustainable growth implying economic expansion driven by dynamic markets, a forward-looking welfare policy and a progressive environmental policy. The Government's vision is for Sweden to eventually obtain its entire energy supply from renewable sources.

Issues on 3R (reduce, reuse and recycle) can be seen as a way forward for construction industry to move up in achieving sustainable development on the various environmental, social, economic and even cultural factors. In addressing these issues on construction and environment, efforts towards sustainable construction must be taken on board to restore between natural and built environments (*Tse, 2001, Shen and Tam, 2002*).

THE WAY FORWARD ON MALAYSIA’S GREEN STRATEGIES

The Malaysian Government announcement on the creation of the Energy, Green Technology and Water Ministry to spearhead the country’s sustainability agenda in the recent cabinet lineup is timely in tackling all related green issues. The emphasis on creating green or environmentally friendly buildings was also highlighted during the launching of Green Building Index (GBI) by the Minister of Work recently shows the commitment from the construction industry especially from organizations like Association of Consulting Engineers Malaysia (ACEM) and Pertubuhan Arkitek Malaysia (PAM). Buildings will be awarded the GBI Malaysia rating based on 6 key criteria below:

- Energy Efficiency
- Indoor Environmental Quality
- Sustainable Site Planning and Management
- Materials and Resources
- Water Efficiency
- Innovation

Government policies have been recognised as important instruments in driving the market for sustainable buildings. In Malaysia, there is currently no policy which mandates a sustainable building; the closest we have is the MS 1525:2007 which is the 'Code of Practice on Energy Efficiency and the Use of Renewable Energy for Non Residential Buildings (*Ooi, S., 2007*).

The National Policy on Environment seeks to integrate environment considerations into development activities and in all related decision-making processes, to foster long-term economic growth and human development and to protect and enhance the environment. The integrated considerations will lead to drive the Malaysia's Green Strategies towards the following seven key areas *(MOSTE, 2002; CIB, 2002)*:

i) *Education and awareness*
Inline with the recommendations of Agenda 21 *(CIB, 2002)*, a deeper and better understanding of the concepts of environmentally sound and sustainable development, and caring attitude towards nature, environmental education and awareness will be promoted across the board, in comprehensive formal and informal environmental education and training strategies and information dissemination programmes will be devised and introduced.

ii) *Effective Management of Natural Resources and the Environment*
The strategic area on effective management of natural resources and the environment are to protect and conserve the environment and natural resources to meet the needs and aspirations of the country's population, particularly with regard to the productive capacity of resources such as land, forests and biodiversity and water.

iii) *Integrated Development Planning and Implementation*
Environmental considerations will be integrated into all stages of development, programme planning and implementation and all aspects of policy making. Environmental inputs shall be incorporated into economic development planning activities, including regional plan, master plans, structure and local plan (*MOSTE, 2002*).

iv) *Prevention and Control of Pollution and Environmental Degradation*
Pollution and other adverse environmental impacts arising from development activities shall be minimised. Environmental quality monitoring surveillance programmes and environmental auditing systems will be expanded and strengthened to support enforcement programmes, planning and zoning and to enable a comprehensive and regular assessment of the state of environment. Within this context, CIDB has embarked programmes related to ISO 14001 certification focusing at construction companies that involved in larger projects which require Environmental Impact Assessment (EIA) (*CIDB, 2007a*). CIDB has also introduced the Environmental Management System (EMS) D.I.Y. Schemes. The aim of this

CIDB EMS D.I.Y. Scheme is to facilitate contractors in upgrading their environmental management performance.

v) *Strengthening Administrative and Institutional Mechanisms*
Integrated and effective cooperation and coordination among government and other sectors shall be enhanced in order to achieve efficient environmental management and protection. Environment-related legislation and standards shall be reviewed regularly and revised where necessary to ensure the continued effectiveness and coordination of laws. Particular attention will be paid to effective enforcement.

vi) *Proactive Approach to Regional and Global Environmental Issues*
Malaysia will corporate actively with other countries, particularly the ASEAN community of nations, and with relevant regional and international organisations, on global environmental concerns. In other word, Malaysia will adopt a proactive approach in addressing global environmental issues such as the depletion of the ozone layer, climate change, trans-boundary pollution, hazardous chemicals and toxic waste management, marine quality and resource conservation and trade in endangered species.

vii) *Formulation and Implementation of Action Plans*
Action plans, with adequate resource support for their implementation, will be formulated.

The way forward has to be a reactive and responsive among stakeholders. No one is to be in a state of denial but has to be progressively improved towards the betterment to ensure the earth is safe and sustainable for future generation.

CONSTRUCTION INDUSTRY MASTER PLAN 2006-2015 (CIMP) INITIATIVES

Construction Industry Master Plan 2006-2015 (CIMP) has identified the future challenges on environmental aspect as mentioned in Strategic Thrust 3: Towards highest standard of quality, occupational safety and health and environmental practices. The demand on environmental sustainability is necessary to achieve and sustain economic growth and social development (*CIDB, 2007a*). A systematic effort is required to avoid undesirable environmental impacts and enhance ecosystem management. Among the major impacts associated with the industry are soil erosion and sedimentation, flash floods, destruction of vegetation, dust pollution, depletion of natural resources and the usage of building materials which are harmful to the human health.

Table 1: Strategic Thrust 3 – Strive for the Highest Standard of Quality, Occupational Safety and Health and Environmental Practices (*CIDB, 2007a*)

No.	Action Plan	Programme
1	Foster a quality and environment-friendly culture	The need to increase customer demand in the global environment in construction. Necessary to achieve and sustain economic growth and social development.
1.1	Encourage external accreditation in quality and environmental management. • Incorporate ISO certification requirements as part of the contractors registration scheme (G7 and G8) • Organise communication plan to promote ISO certification	CIDB will play actively in participation local construction companies to attain ISO 9001 and ISO 14001 certifications.
1.2	Promote environment-friendly practices. • Recommend to the Ministry of Housing and Local Government to develop guidelines on stage construction • Propose to DOE to review conditional approval provision for EIA reports. • Enforce Tree Preservation Order (Act 1972). • Encourage "Green Reporting" by public listed companies • Introduce tax incentives for the adoption of ISO 14001	Initiatives of "Green Building Material" will be promoted to ensure impact activities can provide in order to spur economy and social benefits at large. Urgent need of self-regulation within construction industry as a minimum necessary to achieve performance required.

The envisioned of Malaysian Construction Industry Master Plan 2006-2015 (CIMP) is to be a progressive construction sector that lies on sustainable development. **Figure 1** shows the overall strategic thrusts in CIMP, its critical success factor (CSF) as well as its enabling recommendations.

The importance of standard of quality, occupational safety and health and environmental practices to foster a quality and environmentally culture among construction industry players as outlined in the Strategic Thrust 3 is depicted in **Table 1**. The table summarises some action plan and also the continuous programme to be planned to promote quality and environmentally culture among construction stakeholders. CIMP envisaged that sustainable on construction is vital to the construction players to achieve and sustain economic growth and social development (*CIDB, 2007a*).

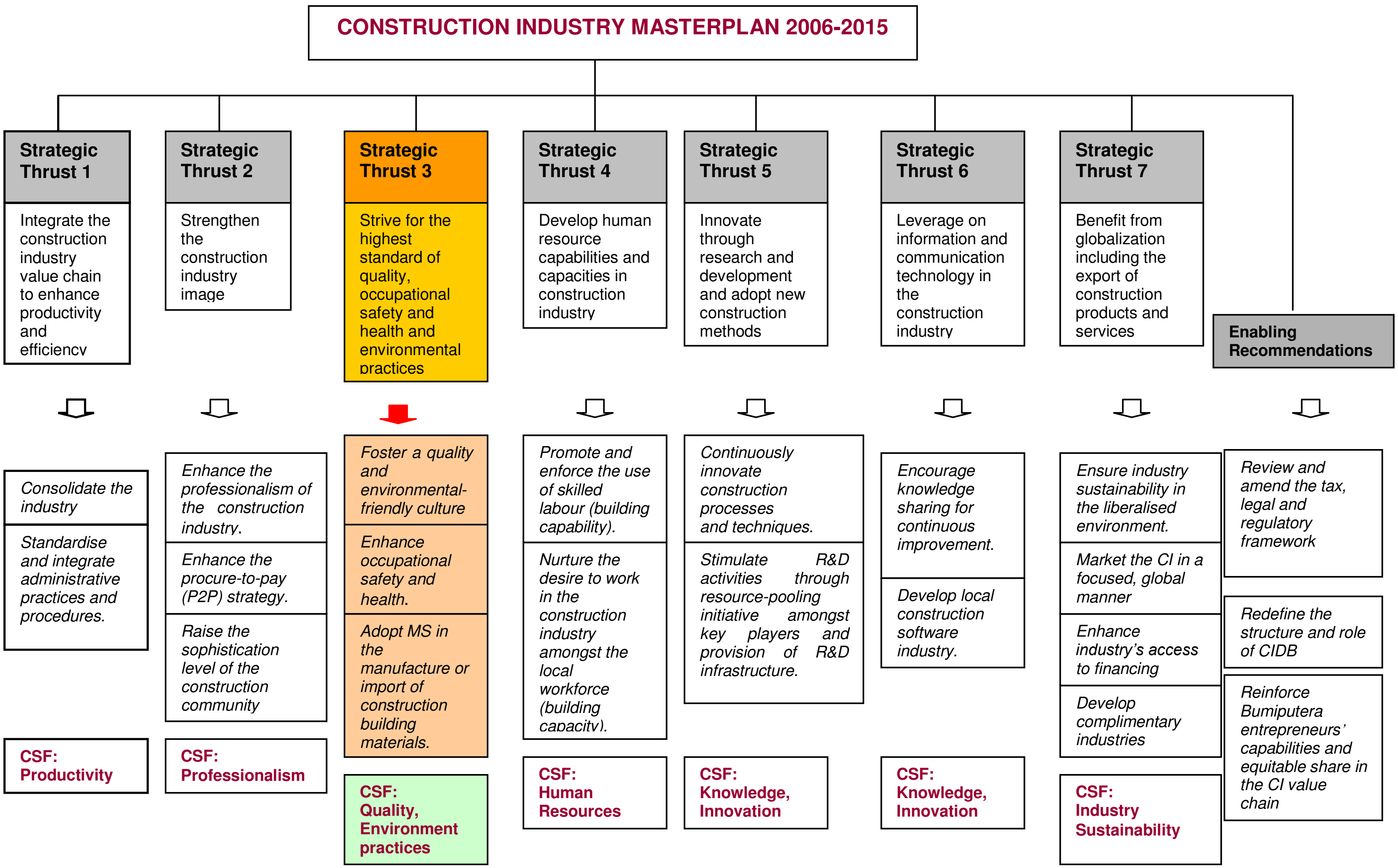

Figure 1: Construction Industry Master Plan 2006-2015 (CIMP) Initiatives (*CIDB, 2007a*)

IMPLEMENTING STRATEGIES ON SUSTAINABLE DEVELOPMENT: CIDB'S INITIATIVES

The sustainable development requires a balance between economic growth, social expansion and environmental protection. In order to pursue sustainable development, the construction industry itself has to be sustainable and give emphasis to environmental matter in addition to economic gains and social obligations.

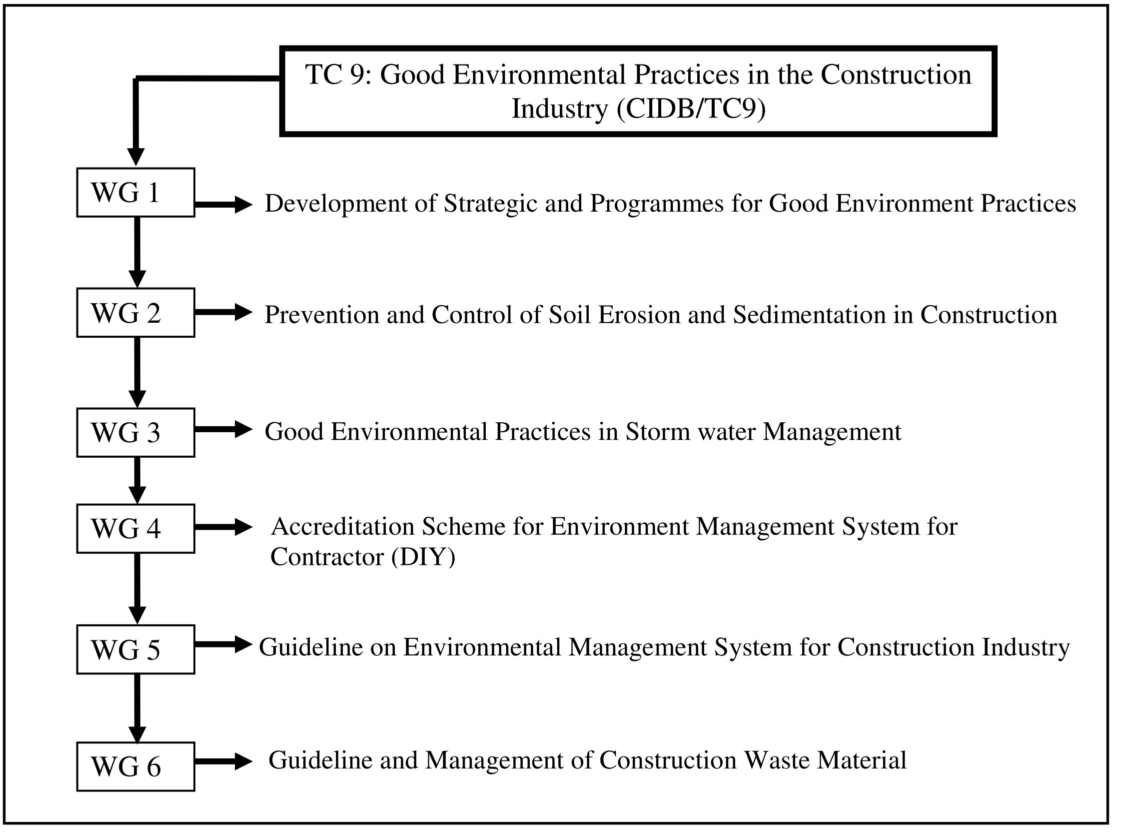

Figure 2: Strategic Recommendation Working Group under Technical Committee 9 (CIDB/TC9)

In 1999 CIDB had established a Technical Committee to look into developing good environmental practices in the construction industry. Technical Committee 9 on Good Environmental Practices in the Construction Industry (CIDB/TC9) comprises environmental experts from government agencies, professional bodies, academia and construction related associations.

The role of CIDB/TC9 is to develop standards to improve environmental in the construction industry and advise CIDB in the formulation of programmes to promote good environmental practices. The term of reference of TC9 is to identify, prepare and develop the Construction Industry Standard (CIS) and Good Environmental Practices in Construction Industry. CIDB/TC9 executes its mandate through the establishment of Working Group (WG). **Figure 2** shows the strategic recommendation working group under CIDB / TC9.

RESEARCH AND DEVELOPMENT INITIATIVES

Currently there are six research projects on Environment and Sustainability managed by Construction Research Institute of Malaysia (CREAM), a research arm of CIDB. The research topics are as follows:

i. Construction Practices for Storm Water Management and Soil Erosion Control for the Construction Industry,
ii. Achieving Sustainability of the Construction Industry via International Environmental Management Systems Standard, ISO 14001,
iii. Waste Minimisation and Recycling Potential of Construction Materials,
iv. Materials Security And Waste Management for Industrialised Building Systems (IBS): Towards Sustainable Construction,
v. Environmental Management Plan in the Contract Tender Document of Construction Projects and
vi. Utilisation of Waste Materials for the Production of Concrete Pedestrian Block (CPB).

Research on Construction Practices for Storm Water Management and Soil Erosion Control for the Construction Industry are focusing towards developing good practices in these areas. Data and output from this project are being used in the various Working Groups for further development and some of the findings have been disseminated to the stakeholders via seminars and workshops.

Achieving Sustainability of the Construction Industry via International Environmental Management Systems Standard, ISO 14001 is aligned to prepare the Guideline on Environmental Management System for Construction Industry (EMSCI). This guideline is prepared and aimed to assist contractors to be ISO 14001 certified and looking into the proper environment management systems in the construction industry.

Research on Waste Minimization and Recycling Potential of Construction Materials has been completed in 2005 and handed over to the Technical Committee (TC) 9 under CIDB. Some of the document have been published and disseminate to industry players. TC9 is in the midst of consolidating the research output and will assign Working Group 6 to assist CIDB to prepare Guideline and Training Modules on Good Practices on Waste Management at Construction Sites.

Three other research namely Environmental Management Plan in the Contract Tender Document of Construction Projects, Materials Security and Waste Management for Industrialised Building Systems (IBS): Towards Sustainable Construction and Utilization of waste materials for the production of concrete pedestrian block (CPB) are due to be completed in 2010. Upon completion, stakeholders are able to capture some of the local experiences as well as global practices on waste management and sustainable construction through lesson learned and technology transfer of best practices.

STRATEGIC RECOMMENDATIONS

The task to uphold sustainable construction in Malaysia is an enormous undertaking that require plenty of innovation and commitment from all concerned. Both through CIDB's initiatives, R&D initiatives and other action oriented industry strategies have identified tasks for immediate attention, as well as tasks for the medium and long term. It is vital that the strategic implementation plan continues to develop tools and technologies and other enablers to lessen the impact on environment and lead the Malaysian construction to be sustainable.

The commitment from stakeholders, government authorities and legislators can transform the Malaysian construction industry into one that is not threat to the environment, but meeting the human need for development in harmony with the nature. The combination of CIDB's initiatives and strategies documented in *Strategic Recommendations for Improving Environmental Practices in Construction Industry (CIDB, 2007b)* are recommended to be the strategic way forward to be adopted by all players. The strategies identified are summarised as follows:

i) Strengthening the Development Approval Process,
ii) Enhancing Law and Enforcement,
iii) Promoting Self-Regulation, reflecting the best regulatory practices which is necessary to achieve sustainable construction in future,
iv) Increasing Capacity and Public Awareness and
v) Addressing Knowledge Gaps.

The strategic direction, the implementation strategies and R&D participation have to be driven in congruent to ensure continuity and focused. It is envisioned that all initiatives mentioned need to be taken forward simultaneously at both the local and international level. Every stakeholder involved in the green initiatives must stand together and react as a team not as individual champion.

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COUNTRYWIDE SURVEY ON ISO 9001-CERTIFIED COMPANIES IN MALAYSIAN CONSTRUCTION INDUSTRY

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Abstract
This article reports part of the results collected from 100 ISO 9001-certified companies in the Malaysian construction industry for a PhD research. Construction industry has bad public image because of safety, delay and quality issues. This is due to extreme segmentation and fragmentation of the supply chain, which cause difficulties in managing quality in construction industry. Due to low quality and low productivity, there is a need to implement ISO 9001 quality management system. This article helps to address the lack of data and information identified by CIDB Malaysia by documenting the extent to which Malaysian construction companies are accredited with ISO 9001 certifications, summarising the motivations behind the pursuit for ISO 9001 certifications, investigating the reasons for firms to obtain and maintain ISO 9001 certifications status in their organisations, and reviewing the extent to which ISO 9001-certified companies have gained benefits through the implementation of ISO 9001 quality management system. The results reveal that companies in the Malaysian construction industry adopt ISO 9001 certifications mainly to enhance their competitive processes and competitive performance to enable them to operate more efficiently.

Keywords: *Benefits; Business performance; ISO 9001 certifications; Motivations, Quality*

INTRODUCTION

The construction industry is generally an adversarial business. This is because it is amorphous and diverse, and consists of multifarious professions, occupations and organisations in delivering a project. Construction industry has one of the worst public images among the industrial sectors (Samuelsson, 2003). This poor image is mainly due to problems caused by safety, delay and quality issues, which according to Oakland and Marosszeky (2006), are remarkably similar all over the world. They list the following specific issues that create difficulties for the construction industry, namely: a) extreme fragmentation of construction supply chain; b) short term nature of relationships within them; and c) discontinuity of individuals involved in the procurement process. These may be due to long time frame taken from conception to completion of construction products.

The Malaysian construction industry is also fraught with problems of time and cost overruns, and abounds with quality problems (Azmi, 2002; Zakaria, 2004). CIDB Malaysia (2004) lists seven critical issues faced by the Malaysian construction industry in its Master Plan Framework for 2005 – 2015. These are: low quality, low productivity, fragmentation, bureaucratic delays, lack of ethics in some parts of the industry, shortage of skilled manpower, and lack of data and information. The issues of low quality and low productivity in construction products are pervasive within the industry, permeating through the construction value chain from the design stage to the operation and maintenance stage (CIDB Malaysia and APEC, 2000). There is thus an urgent need for the management of quality in construction industry (Oakland & Marosszeky, 2006). Due to problems of low productivity and low quality (CIDB Malaysia, 2004), there is a need to reform the Malaysian construction industry through the ingenious application of engineering tools

(Azmi, 2002). One of the available tools and techniques is ISO 9001, which is process-oriented, can be used to improve the performance of construction companies (McCabe, 1998; Samuelsson, 2003).

Quality is an integral element in construction, from its inception to completion (Alcock, 1994). Due to its diverse and amorphous nature, the existence of adversarial relationship among the various parties within the construction industry as well as its poor image, there is a need to implement ISO 9001. It is necessary to identify the benefits and limitations of ISO 9001 certifications in the rush to gain accreditation to the quality management system. The extent to which quality-related knowledge is understood and appropriately applied needs to be investigated given the void in documented quality-related efforts in Malaysia (Ahmad and Zain, 2000; CIDB Malaysia, 2004). Because of this, Said et al. (2006) contend that there is a need for the academia to study the implementation of the ISO 9000 quality management system and business performance in the Malaysian construction industry. Although much effort has been put in by the industries in Malaysia to obtain ISO 9001 certification, there has been no attempt to verify whether implementation of ISO 9001 leads to any increase in company profitability (Jabnoun and Kanapathy, 1998). It is reported by Naser et al. (2004) in their paper that very few studies were undertaken to identify factors that influence corporate performance and to establish the relationship between performance and the ISO 9001 registration. To address the gaps identified above, the aims of this article are fourfold, namely: to document the extent to which Malaysian construction companies are accredited with ISO 9001 certifications; to summarise the motivators behind the pursuit for ISO 9001 certifications; to investigate the reasons for companies to obtain and maintain ISO 9001 certifications status in their organizations; and to review the extent to which ISO 9001-certified companies have gained benefits through the implementation of ISO 9001 quality management system.

MANAGING QUALITY IN CONSTRUCTION INDUSTRY

According to Griffith (1990), quality is applicable within the broad ranges of activities and parties involved in the construction industry. These are: client in the project brief; designer in the design and specification; manufacturers in the supply of materials, products and components; contractors and subcontractors in construction, supervision, and management; and users in the use of the new building, in its upkeep and repair. Hill (1985) specifies four stages of the procurement process in the construction life cycle in which quality must be defined, i.e. quality of the design process, quality of the construction process, quality of the products, and quality of maintenance (Griffith, 1990). This is supported by Atkinson (1995) who mentions that the quality of a building derives from the quality of its design and the process through which the design was developed, quality of the construction process and the care taken in translating the design into practical shape, quality of products used and equipment installed, and the way they are used, and quality of building management and maintenance. This is echoed by Alcock (1994), who argues for quality in the organisation of the various parties in the construction supply chain, namely, quality in contracts, quality in design, and quality in construction. Yeoh and Lee (1996) maintain that in construction, quality refers to both the quality of the end product, as well as the quality of process and practices and other factors of production that lead up to the end product. Barrett (2000:385) recommends an explicit project quality plan which links the relevant parts of all the supply chain participants' own quality systems together around the needs of the project.

Adoption of ISO 9000 Standards as MS ISO 9000

Malaysia is a full member nation in ISO, which stands for International Organisation for Standardisation. ISO is established to promote standards in international trade, communications, and manufacturing. It is a world-wide federation of national standard organisations from 141 nations, which consists mostly of government organisations. It has 80 standard-drafting technical committees. Malaysia is a participating member of Technical Committee 176 (TC 176), which is an international team representing 75 nations. Malaysia is represented on TC 176 by the Department of Standards Malaysia (DSM), the Malaysian national standards organisation. The Department of Standards Malaysia has appointed SIRIM (Standard and Industrial Research Institute of Malaysia) Berhad as the agent to develop Malaysian Standards. SIRIM and other Government bodies such as National Productivity Corporation (NPC) are entrusted with the task of promoting the ISO 9000 standards to the Malaysian industry through talks, short courses, workshops and consultancy services (Abdul-Aziz et al., 2000). A certification scheme for quality systems for the Malaysian industry, known as "Scheme for the Assessment and Registration of Quality Systems", was introduced by the Malaysian government via SIRIM in 1987 (Yeoh and Lee, 1996; Abdul-Aziz et al., 2000). The ISO 9000 standards were adopted as the Malaysian Standard MS ISO 9000 in 1991 (Abdul-Aziz et al., 2000; Yeoh and Lee, 1996). It became the basis of certification of quality systems in Malaysia (Lee, 1993).

ISO 9000, introduced in 1987, is an internationally recognized set of standards on quality management and assurance system that attempts to ensure a product is constantly being produced according to the required specifications. It has since been updated twice, in 1994 and December 2000. Construction companies throughout the world are now leaning towards third party certification of their quality systems based on ISO 9000 standards (Bray, 1996; Yeoh and Lee, 1996; Lam, et al., 1994). Table 1 gives the breakdown of ISO 9000-certified local construction companies which are registered with CIDB Malaysia from 1994 to 12th December 2005 (Sia and Zainal, 2006). The construction companies in Malaysia are on the bandwagon in the quest for the accreditation of ISO 9000 certifications. A check with the CIDB Malaysia Directory shows, however, there is no construction company with certification date earlier than 1994.

Table 1. ISO 9000-Certified Local Contractors Registered with CIDB Malaysia

Year of Certification	Total	Cumulative Total
1994	1	1
1995	2	3
1996	5	8
1997	7	15
1998	9	24
1999	12	36
2000	14	50
2001	11	61
2003	20	81
2004	49	130
2005	30	169

Source: CIDB Malaysia Directory @ http://www.cidb.gov.my. Accessed on 12/12/2005. CIDB Malaysia (2007:3-2) put the figure as 58 and 145 for year 2002 and 2004 respectively.

Establishment of CIDB Malaysia

The construction industry is segmented and fragmented due to the presence of too many players, with each performing their own independent activities without proper coordination and control. Prior to 1994, there is no national resource centre which can integrate and coordinate the formulation of policies, and to tackle the issues and problems faced by the construction industry (Yeoh and Lee, 1996). In tandem with rapid economic growth from 1989 – 1996, the Malaysian construction industry has experienced rapid growth. As a result, contractors were in a hurry for the timely completion in anticipation of growth of other projects. Due to uncontrolled growth, coupled with shortages of skilled workers and shortage of basic construction materials, there were signs of deterioration in quality of workmanship and safety on construction sites (CIDB Malaysia and Chan, 2004; Yeoh and Lee, 1996). A statutory body, known as the Construction Industry Development Board (CIDB) Malaysia was thus established under the Ministry of Works under the Parliamentary Act known as "Act 520 Lembaga Pembangunan Industri Pembinaan Malaysia Act" in July 1994.

The functions of CIDB Malaysia, among others, as given in sub-section 4(1) of the Act are: a) to promote and stimulate the development, improvement and expansion of the construction industry; b) to promote, stimulate and undertake research into any matter relating to the construction industry; c) to promote quality assurance in the construction industry; and d) to encourage the standardization and improvement of construction techniques and materials. The objective of CIDB Malaysia is to develop the construction industry as a major contributing sector to the national economy and capable of producing and delivering high quality construction works, with value for money and responsive to the nation's needs (CIDB and Chan, 2004). For this purpose, CIDB Malaysia has published the Malaysian Construction Industry Master Plan (2007). The main aim of CIDB Malaysia is the overall improvement of quality in the construction industry. For this purpose, CIDB has embarked the following programmes (CIDB and Chan, 2004):

a) Standard Development. On 22nd April 1997, Sirim Berhad appointed CIDB Malaysia as a Standard Writing Organisation to develop Malaysian Standards for building and civil engineering works. The Department of Standards Malaysia has also appointed CIDB as a member of its standard advisory committees.
b) Quality Assurance Development. To upgrade quality in the construction industry, CIDB Malaysia promotes the ISO 9000 certification scheme by conducting courses and embarking on the Do-It-Yourself Scheme (DIY) for ISO 9000 certification. The main purpose is to encourage industry players to develop their own quality assurance system for the certification towards ISO 9000 standards. This is to ensure quality during the construction process. In order to maintain their existing registrations, CIDB has made it mandatory for G7 contractors to be certified with ISO 9001:2000 by 1st January 2009.
c) Formulation of Quality Policy. The purpose of the quality policy is to ensure proper direction in the implementation of the quality upgrading programmes.
d) QLASSIC. QLASSIC is a quality assessment system used to measure the quality in the constructed product. Singapore is using CONQUAS for the same purpose (Lam, et al., 1994). QLASSIC measures construction quality and benchmarks the level of quality achieved in the construction project. QLASSIC evaluates the end product based on approved standards and specification.
e) Zero-Defect Programme. The "Zero-Defect Programme", implemented with the support and cooperation of the Ministry of Housing and Local Government, aims to provide

quality houses to owners. Currently the programme focuses on low-cost and medium low housing due to many complaints received on defects, poor workmanship and poor quality.

Impact of ISO 9000 Certifications

Many authors have written on the importance of achieving quality in the construction industry (Griffith, 1990; Lam et al., 1994; Yeoh and Lee, 1996; Chung, 1999; Thorpe and Summer, 2004). In practice, Tari (2005) mentions that firms may follow known, accepted or standard models as a guide to carry out quality improvement. Quality can be achieved through the implementation of quality assurance and quality management schemes. In order to remain competitive in an increasingly global environment, many construction companies have chosen to implement quality schemes (Europa, 2002). KPMG International, in its global construction survey 2005, finds that quality of reputation is the main key factor which enhances an organization's ability to secure new work. Oakland and Marosszeky (2006) list three key issues faced by organisations in the construction industry, namely, quality management, supply chain management and knowledge management. They contend that excellence in these three key aspects of business is the hallmark of great construction companies.

Griffith (1990) mentions that effective implementation of formal quality assurance scheme procedures for the building process and construction phase can bring better design, more effective planning, increased site management, efficient management of construction problems, improved quality, fewer delays and disruptions, lower cost of remedial and repeat works, provision of feedback for future projects, and enhanced reputation for good design and construction. Chung (1999) argues that there is a need to adopt and implement a quality system as there is a general movement towards making the implementation of a quality system a contractual requirement. This could be used as a marketing tool as the quality system helps to promote the image of the company and provides the competitive edge in a competitive market. In addition, legal costs could be minimised as the quality records will facilitate and strengthen the process of claims, and provides the potential line of defence in the case of counter claims.

Among the measures of construction project success in Malaysia which have been identified by Takim et al. (2004) are quality, process improvement programme, resource management, users' satisfaction, and operational assurance. ISO 9000:2000 is relevant in construction industry as it has a process-based structure, covering the areas of quality management system, management responsibility, resource management, product realisation, and measurement, analysis and improvement. This process approach, because of its flexibility, has made the new standard more applicable to construction industry (Zeng et al., 2005). Findings from various researchers in different parts of the world indicate that ISO 9000:2000 is suitable to construction industry. To remain competitive in an increasingly global environment, construction companies have chosen to implement quality systems based on the principles of TQM and ISO 9000 series of standards (EUROPA, 2002; Lindsey and Peoples, 2002). TQM has been used successfully by many construction companies in the US, Singapore, UK, and other European countries (Ahmed et al., 2001).

In their paper to determine the applicability and effectiveness of ISO 9000 in U.S. construction firms, Chini and Valdez (2003) conclude that ISO 9000 is an appropriate and effective tool for construction firms in the United States, although several obstacles affect its implementation and acceptance among construction organizations. Major inhibiting factors of implementing total quality management on construction sites are presented by Haupt and Whiteman (2004). To ensure continued quality performance, there is also a need to inculcate quality culture in the construction industry (Kanji and Wong, 1998; Thomas et al., 2002). Tan and Sia (2001) find that most companies agreed that gaining certification did improve the quality process as well as the product quality. In the survey carried out to examine and compare the TQM practices and organisational performances of small to medium enterprises with or without ISO 9000 certification in Malaysia (where ten construction and engineering organisations are included), Sohail and Teo (2003) find that ISO 9000 certification contributed to a higher organisational performance. In their study on the financial effects of ISO 9000 registration, from a sampled 162 public listed Malaysian companies, Naser et al. (2004) find that accredited companies outperformed the non-accredited ones during the period of study.

METHODOLOGY

Questionnaire survey is used as the method of primary data collection as it is not resource intensive and yet reliable (Raghunathan et al., 1997) to gather information from the whole of Peninsular Malaysia, Sabah and Sarawak. The survey questionnaire is developed based upon the information from: literature review on quality assurance, ISO 9001 and total quality management; the questionnaire developed by Pan (2003); and the questionnaire developed by Dissanayaka et al. (2001). This research employs the mailed survey method to collect primary data. The population of this study is the ISO 9001-certified companies in the Malaysian construction industry. They include mainly of: a) construction companies of various trades registered with CIDB Malaysia; b) selected local construction companies from the Construction, Infrastructure, and Properties sectors listed on Bursa Malaysia; c) construction companies registered with the Master Builders Association Malaysia (MBAM); d) Civil and Structural (C&S) consulting engineering firms which are members of Association of Consulting Engineers Malaysia (ACEM); e) quantity surveying firms registered with the Institution of Surveyors Malaysia (ISM); f) Architectural firms which are registered with the Persatuan Arkitek Malaysia (PAM); g) foreign construction companies having construction jobs in Malaysia; and h) local property developers.

The names and addresses of these ISO 9001-registered companies are obtained from the CIDB Malaysia directory, membership directories of MBAM, ACEM, ISM, PAM, and trawled from the search engine Google for those ISO 9001-certified companies which have website addresses. The key respondent of the research is chosen to be the "person to contact" as listed in the CIDB Malaysia directory, or quality management representative, managing director, director, or general manager of the ISO 9000-certified companies since these key personnel are considered as the most knowledgeable people who are directly involved with the quality management system of the company.

RESULTS AND ANALYSIS

The survey was carried out from February to May 2008. The details of respondents for the survey are summarised in Table 2. A total of 456 questionnaires were sent out, with the breakdown as follows: a) 303 questionnaires to the 338 ISO 9001-certified contractors registered with the CIDB Malaysia (as on 14th April 2008), who are mostly Grade G7 contractors; b) 99 questionnaires to ISO 9001-certified companies, consisting of contractors of various trades and property developers, which are not found in the CIDB Directory, but trawled from the search engine Google; and c) 54 questionnaires to other players with ISO 9001-certifications in the construction industry which are trawled from Google, consisting of 28 C&S consulting engineering firms, 17 quantity surveying firms, and 9 architectural firms. The respondents are located throughout the whole of Peninsular Malaysia, as well as Sabah and Sarawak. A total of 100 usable questionnaires for data analysis were received. 12 questionnaires were returned unanswered, due to various reasons such as companies shifted and resignations of respondents. Two telephone calls were received, informing the first author that their companies were not ISO 9001-certified. 8 questionnaires were rejected because they were incomplete with more than 10% missing data. The response rate was about 22.6%, which is not unusual for an extensive survey which requires at least 40 minutes completing the eight-page length questionnaire (Skrabec, 1999:79).

Table 2. Details of Questionnaire Survey

<table>
<tr><td colspan="3">Survey Period</td><td>February to May 2008</td></tr>
<tr><td colspan="3">Locations</td><td>Peninsular Malaysia, Sabah and Sarawak</td></tr>
<tr><td colspan="3">Number of Questionnaires Sent</td><td>456</td></tr>
<tr><td colspan="3">Number of Questionnaires Returned Unanswered</td><td>12</td></tr>
<tr><td colspan="3">Telephone calls received on non-certification status</td><td>2</td></tr>
<tr><td rowspan="5">ISO 9001-Certified Companies</td><td>CIDB Malaysia Directory</td><td>Contractors of all trades</td><td>303</td></tr>
<tr><td rowspan="4">Trawled from Google</td><td>Contractors and developers</td><td>99</td></tr>
<tr><td>C&S Engineering</td><td>28</td></tr>
<tr><td>Quantity Surveying</td><td>17</td></tr>
<tr><td>Architectural</td><td>9</td></tr>
<tr><td colspan="3">Number of Questionnaires Received</td><td>108</td></tr>
<tr><td colspan="3">Incomplete Questionnaires</td><td>8</td></tr>
<tr><td colspan="3">Useable Questionnaires for Data Analysis</td><td>100</td></tr>
<tr><td colspan="3">Response Rate (%)</td><td>22.6</td></tr>
</table>

The designations of the respondents in their organisations for the survey are given in Table 3. 25% of the respondents are directors or of higher designations, 33% are managers, quality management representatives or QA/QC executives who are directly involved with the quality management systems, and 23% are in the managerial or higher positions. From these percentages, it can be concluded that the management of these companies place a high emphasis on the ISO 9001 certifications in their organisations. 99% of the respondents (99 responses) highlight that their organisations are ISO 9001-certified, with the remaining one not highlighted even though the company is in fact ISO 9001-certified, as shown in Table 4(a). Out of 100 respondents, 93 respondents (93%) mention that they have personal experience in ISO 9001 quality management systems. The lead time to get ISO 9001 certifications is given in Table 4(b). 90 respondents (90%) opine that ISO 9001 certification is important to their companies' success, as shown in Table 4(c), with a mean value of 3.95, which is consistent with the value reported by Corbett and Luca (2002). 7 respondents do not answer this question.

Table 3. Designations of Respondents in Their Organisations

Designations in Organizations	Number	Percentage (%)
Vice President	1	
Managing Directors (MDs)	5	
Directors (of various designations)	18	25.0
Director (Quality Assurance or Management)	1	
Managers (QA/QC)	11	
Quality Management Representatives	16	33.0
QA/QC Executives	6	
Head of Operation	1	
General Managers (GMs)	10	23.0
Managers (of various designations)	12	
Senior Quantity Surveyors	2	
Engineers	4	
Document Controllers	1	
Secretaries	2	16.0
Others (Executives, Clerk, etc.)	7	
*Not Available (Responded that they have experience in ISO)	3*	3.0
* The respondents highlighted that their organisations are ISO 9001-certified, but the names of the organisations were not mentioned.		

Table 4(a). Types of Quality Management System and Personal Experience

	Responses	Not Available
Complying with ISO 9001:2000	99	1#
Personal Experience in ISO 9001 QMS	93	7*
# Design Engineer. The respondent has experience in ISO9001. A check on the organisation, which was mentioned, confirmed that the organisation is ISO 9001-certified. * MD = 2; Director = 1; Managers = 2; ISO Management Representative = 1; GM = 1.		

Table 4(b). Lead Time to Obtain ISO 9001

Total number of Respondents N =100		Below 1 year	1 – 2 year	2 – 3 years	Above 3 years	Not Available
Lead Time to get ISO 9001	Frequency	59	28	2	9	2
	Percentage (%)	59	28	2	9	2

Table 4(c). Importance of ISO 9001 Certification to Company's Success

Total number of Respondents N =100		Not important at all (1)	Not Important (2)	Somewhat important (3)	Important (4)	Extremely important (5)	Not Available
Importance to Company's Success	Frequency	0	3	23	43	24	7
	Percentage (%)	3			90		7

Extent of Construction Companies with ISO 9001 Certifications

Table 5 is obtained from the periodic tracking on the number of ISO 9001-certified local construction companies which are registered with CIDB Malaysia since the announcement on 21st June 2008 in The Star newspaper of the mandatory requirement. A check with the CIDB Malaysia directory shows that the number of ISO 9001-certified contractors countrywide as on 25/07/2009 is 1783, about 2.7% of the total number of contractors registered with CIDB Malaysia, which is at 66045 on even date. There is a noticeable increase in the number of G7 contractors getting ISO 9001 certifications. This is clearly due to the mandatory requirement by CIDB Malaysia for G7 contractors to obtain ISO 9001 certification by the extended dateline on 1st July 2009 in order to maintain their existing registrations.

Motivations for ISO 9001 Certifications

The respondents are asked to indicate the reasons which motivated their organisations to establish ISO 9001. The results are summarized in Table 6. The top six common motivations for ISO 9001 certifications from the formal survey are, in descending order: the desire to improve the quality of work done (87%); the intention to increase efficiency and productivity in all areas of operation (86%), the need to meet customer expectations (85%); as part of a larger improvement strategy (80%); to gain competitive advantage (77%); and to qualify to tender for public projects (54%). More than 50% of the respondents highlighted these reasons as motivations to establish ISO 9001 certifications.

Table 5. Malaysian Contractors Accredited with ISO 9001 Certifications

Years	Total Number of Contractors (All Grades)	ISO 9001- Certified Contractors							
		Cumulative Total of Certifications	Breakdown According to Grades						
			G1	G2	G3	G4	G5	G6	G7
2001	41500	61	Breakdown is not obtained						
2003	Not Obtained	81							
2004		130							
On 12/12/2005	63835	169	0	4	9	3	14	6	133
On 01/08/2007	Not Obtained	212	0	3	10	3	15	7	174
On 03/01/2008		323	0	4	11	3	18	7	280
On 14/04/2008		338	Breakdown is not obtained						
On 15/07/2008		379							
On 21/07/2008	65647	402	0	4	11	4	20	7	356
On 31/07/2008	Not Obtained	415	Breakdown is not obtained						
On 09/09/2008		455							
On 26/09/2008		481							
On 07/10/2008		484							
On 05/11/2008		499							
On 27/11/2008	65404	537	0	9	11	8	25	9	475
On 18/12/2008	Not Obtained	577	Breakdown is not obtained						
On 22/12/2008		594							
On 24/12/2008		843	10	10	17	7	27	12	760
On 13/02/2009	Not Obtained	1097	1	11	19	6	44	16	1000
On 22/02/2009	65663	1101	1	11	19	6	44	15	1005
On 24/02/2009	65735	1120	1	12	19	7	44	15	1022
On 28/02/2009	65719	1133	1	12	19	7	45	15	1034
On 31/03/2009	65785	1167	2	13	20	7	50	16	1059
On 30/04/2009	65863	1278	3	13	21	7	55	22	1157
On 07/05/2009	65781	1281	3	12	21	6	55	23	1161
On 30/05/2009	65901	1377	4	12	24	8	59	23	1247
On 04/05/2009	65820	1387	4	12	24	9	59	23	1256
On 13/05/2009	65873	1395	4	12	23	8	64	23	1261
On 20/06/2009	65899	1423	4	12	23	8	64	27	1285
On 26/06/2009	66002	1443	4	13	24	8	64	27	1303
On 03/07/2009	66081	1460	4	13	26	7	63	28	1319
On 11/07/2009	66036	1463	4	12	26	7	63	29	1322
On 17/07/2009	66044	1763	5	19	36	13	74	33	1583
On 25/07/2009	66045	1783	5	19	36	12	76	33	1602

Source: CIDB Malaysia Directory. CIDB Malaysia introduced a new method of searching for ISO 9001-certified companies somewhere on 12th February 2009

Table 6. Motivators for ISO 9001 Certifications

Motivating Factors		Feb – May 2008 Survey, where N = 100	
		Percentage of responses (%)	**Rank**
To improve the quality of work done		87	1
To increase efficiency and productivity in all areas of operations		86	2
To meet customer expectations		85	3
As part of a larger improvement strategy		80	4
To gain competitive advantage		77	5
To qualify to tender for public projects		54	6
To satisfy top management's corporate directive		46	7
To compete more effectively for overseas projects		36	8
To reduce costs of operation		33	9
Others: Please specify	- To satisfy the requirement of CIDB Malaysia for G7 contractors	6	10
	- Better filing system and traceability	---	---
	- Value adding	---	---
	- For standardisation of system , procedures and processes	3	11
	- To increase staff morale	2	12
	- Others (12 reasons, one response each)	1	13
Note: Each respondent could highlight more than one motivator.			

The respondents are also asked to indicate the reasons to obtain and maintain ISO 9001 certifications status in their organisations. The results were given in Table 7. The top five reasons chosen, in descending order, are: quality improvements (100%); corporate image (99%); customer pressure / customer demands (94%); marketing advantage (92%); and capturing workers' knowledge (92%). The results obtained from ISO 9001-certified companies in Malaysian construction industry are consistent with the results reported by Corbett and Luca (2002).

Table 7. Reasons for Seeking and Maintaining ISO 9001 Certifications

Reasons to Seek and Maintain ISO 9001 Certifications	Mean values	Ranking based on Mean	Ranking based on Frequency	Number of Responses	Importance of each Reason					
					NA	**NIAA (1)**	**NI (2)**	**SWI (3)**	**I (4)**	**EI (5)**
Cost reduction	3.42	9	7	Frequency	2	1	16	32	39	10
				Percentage (%)	2	17		81		
Quality improvements	4.36	2	1	Frequency	0	0	0	5	54	41
				Percentage (%)	0	0		100		
Marketing advantage	3.94	3	4	Frequency	1	0	7	20	44	28
				Percentage (%)	1	7		92		
Customer pressure/ customer demands	3.84	4	3	Frequency	0	0	6	30	38	26
				Percentage (%)	0	6		94		
Many competitors were already ISO 9001 certified	3.63	5	6	Frequency	0	0	17	23	40	20
				Percentage (%)	0	17		83		
Benefits experienced by other certified companies	3.44	8	7	Frequency	1	2	16	30	38	13
				Percentage (%)	1	18		81		
Avoid potential export barrier	3.24	10	8	Frequency	2	4	17	36	33	8
				Percentage (%)	2	21		77		
Capturing workers' knowledge	3.56	6	4	Frequency	1	2	5	40	40	12
				Percentage (%)	1	7		92		
Relations with authorities	3.48	7	5	Frequency	0	3	10	34	42	11
				Percentage (%)	0	13		87		
Corporate image	4.38	1	2	Frequency	1	0	0	10	41	48
				Percentage (%)	1	0		99		
Note: NA = Not Available; NIAA = Not Important At All; NI = Not Important; SWI = Somewhat Important; I = Important; EI = Extremely Important.										

Benefits from ISO 9001 Certifications

The respondents are asked to make their subjective assessments to identify the perceived outcomes of implementing ISO 9001 in their organisations, by rating these outcomes on a five-point scale from 'strongly agreed' to 'strongly disagreed'. Table 8 shows the number of positive/beneficial outcomes selected for investigation. By examining the results as summarized in Table 8, the principal positive outcomes from ISO 9001-certifications (with percentage greater than 80%) are, in descending order: continual improvement of operation (98%); more systematic record keeping (98%); greater client satisfaction (97%); stronger customer focus (94%); higher efficiency in operation (94%); improved internal communication (94%); client perceives higher quality of work done (93%); improvement in internal performance appraisal systems (93%); enhanced competitiveness of company (91%); improved external communication (91%); having a valuable marketing tool (89%); higher productivity (89%); increased staff motivation (86%); less rework or repair (86%); improved supplier relations (84%); better risk management (84%); less problems in defects liability period (83%); and better access to domestic markets (80%).

Table 8. Perceived Positive Outcomes/Benefits from ISO 9001 Implementations

Outcomes	Number of Responses						(%) Total (SWA/A/SA)	Rank
	Not Available	Strongly disagreed (1)	Disagreed (2)	SWA (3)	Agreed (4)	Strongly Agreed (5)		
Continual improvement of operation	2	0	0	24	48	26	98	1
More systematic record keeping	1	0	1	11	37	50	98	1
Greater client satisfaction	2	0	1	21	55	21	97	2
Stronger customer focus	1	0	5	24	49	21	94	3
Higher efficiency in operation	1	0	5	23	50	21	94	3
Improved internal communication	1	0	5	32	47	15	94	3
Client perceives higher quality of work done	3	0	4	27	49	17	93	4
Improvement in internal performance appraisal systems	3	0	4	23	59	11	93	4
Enhanced competitiveness of company	1	0	8	28	40	23	91	5
Improved external communication	1	0	8	27	48	16	91	5
Having a valuable marketing tool	3	0	8	24	48	17	89	6
Higher productivity	1	0	10	41	33	15	89	6
Increased staff motivation	1	1	12	40	37	9	86	7
Less rework or repair	1	1	12	26	45	15	86	7
Improved supplier relations	2	2	12	35	38	11	84	8
Better risk management	3	0	13	36	39	9	84	8
Less problems in defects liability period	3	0	14	29	40	14	83	9
Better access to domestic markets	2	1	17	36	37	7	80	10
Better access to overseas market	2	1	19	33	33	12	78	11
Better flexibility in operation	3	1	20	32	35	9	76	12
Lower overall project cost	3	1	24	46	22	4	72	13
Shorter project completion time	4	1	31	40	18	6	64	14
* SWA = Somewhat Agreed, A = Agreed, SA = Strongly Agreed								

CONCLUSION

Table 5 shows that there is a noticeable increase in the number of G7 contractors getting ISO 9001 certifications since the announcement on 21st June 2008 by CIDB Malaysia of the mandatory requirement for G7 contractors to obtain ISO 9001 certification by the extended dateline on 1st July 2009 in order to maintain their existing registrations. Table 6 shows that the two top motivators to obtain ISO 9001 certifications are to improve the quality of work done and to increase efficiency and productivity in all areas of operations. This is confirmed by the main reason for companies to obtain and maintain ISO 9001 certifications, namely, quality improvements as shown in Table 7. The main perceived benefits from ISO 9001 certifications are continual improvement of operation and more systematic record keeping. The benefits obtained from ISO 9000 certifications can be classified into four categories (Casadesús and Karapetrovic, 2003), namely: operational results; financial results; and the benefits related to customers and workers. Based on this classification, the reasons which motivated organisations to establish ISO 9001, to obtain and maintain ISO 9001 certifications status and the perceived benefits from ISO 9001 implementation are reclassified into the following categories, i.e. company competitiveness, customer satisfaction and business performance. The results, shown in Table 9, reveal that companies adopt ISO 9001 certifications mainly to enhance their competitive processes and competitive performance to enable them to operate more efficiently. In conclusion, ISO 9001-certified companies can use ISO 9001 certifications as an innovative administration tool to enhance their competitiveness.

Table 9. Categorization of Motivations, Reasons and Perceived Benefits of ISO 9001 Certifications

		Company Competitiveness			Customer Satisfaction	Business Performance
		Competitive Assets	Competitive Processes	Competitive Performance		
		Worker Related	Operational Results		Customer Related	Financial results
Motivations to establish ISO 9001 certifications	Improved quality of work done			√		
	Increased efficiency and productivity in all areas of operation		√	√		
	Meet customer expectations				√	
	As part of a larger improvement strategy		√	√		
	To gain competitive advantage			√		
	Qualify to tender for public projects		√			
Reasons to seek and maintain ISO 9001 certifications	Cost reduction					√
	Quality improvements		√			
	Marketing advantage			√		
	Customer pressure/demands				√	
	Many competitors were already ISO 9001 certified			√		
	Benefits experienced by other certified companies		√	√		
	Avoid potential export barrier		√	√		
	Capturing workers' knowledge	√				
	Relations with authorities			√		
	Corporate image			√		
	Continual improvement of operation		√			
	More systematic record keeping		√			

Perceived benefits from implementing ISO 9001 certifications	Greater client satisfaction				√	
	Stronger customer focus				√	
	Higher efficiency in operation		√			
	Improved internal communication		√			
	Client perceives higher quality of work done			√		
	Improved internal performance appraisal systems		√			
	Enhanced competitiveness of company			√		
	Improved external communication		√			
	Valuable marketing tool			√		
	Higher productivity			√		
	Increased staff motivation	√				
	Less rework or repair		√			√
	Improved supplier relations		√			
	Better risk management			√		
	Less problems in defects liability period			√		
	Better access to domestic markets			√		
	Better access to overseas market			√		
	Better flexibility in operation		√			
	Lower overall project cost					√
	Shorter project completion time		√	√		

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HYDRAULIC DESIGN AND EXPERIMENTAL INVESTIGATION OF ROOF DRAINAGE SYSTEM

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Abstract
Developing countries generally lack long-term data and have limited terms of reference or empirical data on many areas including the field of engineering design and construction. At present, design of roof drainage system are addressed subjectively, on ad-hoc basis, by individual designers using guidelines adopted and adapted from different standards of practice or based on experience. Optimisation of design criteria for roof drainage system is the main objective of this study. The paper presents the methodology and implementation of hydraulic design and laboratory investigation on roof drainage system, based on parameters such as roof slope, roofing catchment profile, gutter cross section and gutter slope. The details and results of laboratory tests are also presented. The results of this study have been used to prepare recommended guidelines by CIDB for use by the architects, designers and builders in East Malaysia.

Keywords: *Hydraulic Design, Roof Drainage, Rainfall Simulator, Model Roof, Gutter Slope*

INTRODUCTION

Roof drainage systems fulfil a very important function in preventing damage to buildings by rainwater. However, less attention is often given to the design of these systems than their importance warrants. There are several reasons for this. Firstly, although annual expenditure on rainwater components is very substantial, each system normally represents only a small proportion of the total cost of the building that it drains. Since design fees tend to be related to the costs of the components, the amount of time spent on design is often small, even though flooding could easily cause damage worth many times the cost of the system itself.

Secondly, the basic simplicity of rainwater components such as gutters, outlets and pipes suggests that their hydraulic design should be equally simple. In terms of the hydraulic principles involved, flow conditions in a gutter are similar in complexity to those in a side-channel spillway of a dam. Complicated roof drainage calculations are not normally justified for domestic housing because the systems are small and can often be sized from experience and past practice. However, more detailed design work and specialist skills are needed to ensure that rainwater systems for large high-value buildings will provide the specified degree of safety against damage by flooding. Thirdly, it is common practice to provide gutters for large commercial and industrial buildings from sheet metal. This allows the sizes and shapes of the gutters to be tailored to the drainage requirements of individual buildings. In terms of design, there are therefore two possible choices. One is to provide a highly simplified design method that is safe in nearly all practical situations but which will necessarily result in considerable overdesign in the majority of cases. The other choice is to provide a more detailed design procedure that takes correct account of the hydraulic factors and which produces more economic and consistent results.

This study was undertaken as part of a project to prepare recommended guidelines by CIDB to be followed by the architects, designers and builders in Malaysia with respect to the design of roof drainage system. Even though the study included statistical analysis of rainfall data also, this paper presents the experimental investigations only.

ROOF DRAINAGE DESIGN

European Standard (BS EN 12056:2000)

The rate of flow of rainwater to be drained away from a roof under steady state conditions shall be calculated from Equation 1

$$Q= r.A.C \tag{1}$$

where Q is the rate of flow of water, in litres per second *(l/s);*
r is the rainfall intensity, in litres per second per square metre [l/(s . m^2)];
A is the effective roof area, in square metres (m^2);
C is a runoff coefficient (taken as 1,0 unless national and local regulations and practice state otherwise), dimensionless.

Where there is adequate statistical rainfall data related to the frequency of recurrence of storms of specific intensity and duration, the rainfall intensity used in the above equation shall be chosen with due regard to the nature and use of the building and appropriate to the degree of risk that can be accepted. The European Standard (BS EN 12056:2000) recommends that drainage systems for impermeable roofs should normally be designed for critical storm duration of 2 minutes. The isopleth maps for the rainfall intensities for a 2 minute duration storm event with return periods of 1 year, 5 years, 50 years and 500 years are given in the above European Standard and using these and the steps given, the design rainfall intensity for the gutter can be obtained.

No allowance shall be made for the effects of wind when calculating the effective roof area, unless national and local regulations and practice state otherwise. Where no allowance is made for wind, the effective roof area shall be calculated from Equation 2:

$$A = L_R \, . \, B_R \tag{2}$$

where A is the effective roof area, in square metres (m^2);
L_R is the length of roof to be drained, in metres (m);
B_R is the width of roof from gutter to ridge, in metres (m).

Gutters may be laid level or to a gradient, unless stated otherwise by local or national regulation. A gutter laid to a nominal gradient of 3 mm/m or less (referred to as "nominally level") shall be designed as a level gutter. For eaves gutters of semi-circular and similar shape, designed as level and with outlets capable of allowing free discharge, the capacity shall be calculated using its cross-sectional area and shape, from Equation 3:

$$Q_L = 0{,}9. \, Q_N \tag{3}$$

where Q_L is the design capacity of "short" gutter laid level, in litres per second (l/s);
0,9 is a factor of safety, dimensionless;
Q_N is the nominal capacity of the gutter, calculated as $2.78 \times 10^{-5} \times A_E{}^{1.25}$ or determined by test, in litres per second (l/s);

A_E is the full cross-sectional area of gutter, in square millimetres (mm^2).

For eaves gutters of rectangular, trapezoidal and similar shapes, designed as level and with outlets capable of allowing free discharge, the capacity shall be calculated again from Equation 3:

Where Q_N is the nominal capacity of the gutter, calculated as Q_{SE} x F_d x F_s or determined by test, in litres per second (l/s);
Q_{SE} is the capacity of an equivalent square eaves gutter, calculated as 3,48 x 10^{-5} A_E x. $^{1.25}$, in litres per second (l/s);
F_d is the depth factor, dimensionless;
F_s is the shape factor, dimensionless.
F_d and F_s depend on the dimensions of the gutter and can be obtained from the European Standard (BS EN 12056:2000). The design requirement is that the total capacity of the gutters should be equal to or more than the rate of flow of rainwater to be drained away from a roof. The Manual (May, 2003) gives the details of the design procedure.

Australian Standard

As per Australian / New Zealand Specification (AS/NZS 3500, 2003), ARI (Average Recurrence Interval) values of 20 years for eaves gutter and 100 years for box gutter are used. Isopleths for storm duration of 5 minutes for the above ARIs are available. The rainfall intensities for a particular location can be directly read from figures available or can be obtained from the authority concerned if the latitude and longitude of the location are submitted.

The steps can be summarised as follows. The ARI and rainfall intensity are determined. The dimensions and other relevant data are obtained from physical observations, plans or both. Catchment areas A_h and A_c are calculated. A gutter gradient not flatter than 1/250 to 1/500 is selected depending upon the soils. The eaves gutter is selected from manufacturers specification and the value of A_e is noted. The catchment area per downpipe is determined for the affected gutter. The minimum number of downpipes is calculated. The downpipe locations and gutter high points are selected and then the catchment area for each downpipe is calculated. If the catchment area for each sub-catchment is less than or equal to the maximum area per downpipe, then the design is suitable and the downpipe size is determined based on gradient and size of eaves gutter. If not, the steps from selection of gutter gradient are to be repeated till the design becomes suitable.

Urban Stormwater Management Manual for Malaysia (USMMM)

The design procedure of the Urban Stormwater Management Manual for Malaysia (USMMM, 2000), follows AS/NZS 3500.3.2 in recognising that wind causes the rain to slope, and because of this there is a horizontal component of rainfall. This horizontal component becomes significant on vertical walls or sloping roofs. The direction of wind, which results in the maximum catchment area, should be selected. A maximum rainfall slope of 2 vertical to 1 horizontal is assumed. This leads to the following Equation 4 for catchment area A_c:

$$A_c = A_h + \frac{A_v}{2} \tag{4}$$

where the meaning of terms is as shown in Figure 1.

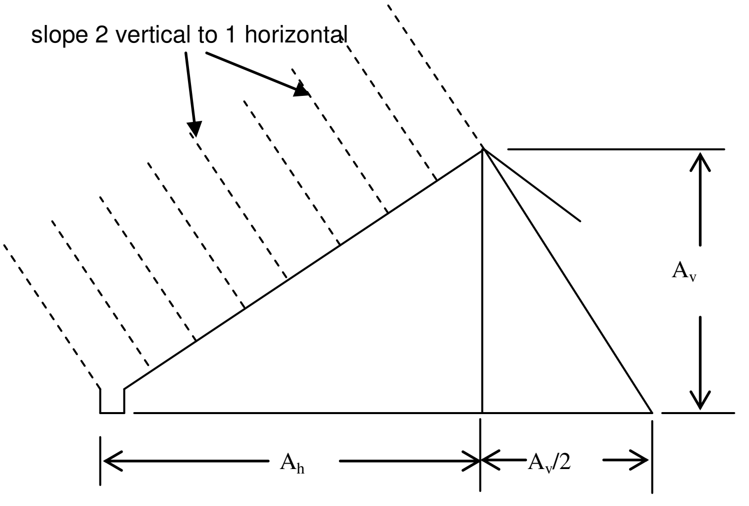

Figure 1: Single Sloping Roof Freely Exposed to the Wind

For normal buildings, a design storm of 5 minute duration for 20 year return period shall be used for eaves gutter and of 100 years return period should be used for box gutter. For special buildings, a design storm of 5 minute duration for 20 year return period shall be used for eaves gutter and of 500 years return period should be used for box gutter. The 500 year value is to be obtained by increasing the 50 year value by 20%.

The total storm rainfall depth at a point, for a given rainfall duration and return period or ARI, is a function of the local climate. Rainfall depths can be further processed and converted into rainfall intensities, which are then presented in IDF curves. The three variables, frequency, intensity and duration, are all related to each other. The data are normally presented as curves displaying two of the variables, such as intensity and duration, for a range of frequencies. These data are then used as the input in most storm water design processes. A typical IDF curve for a rainfall station called 'Tangkulap' in East Malaysia is shown in Figure 2.

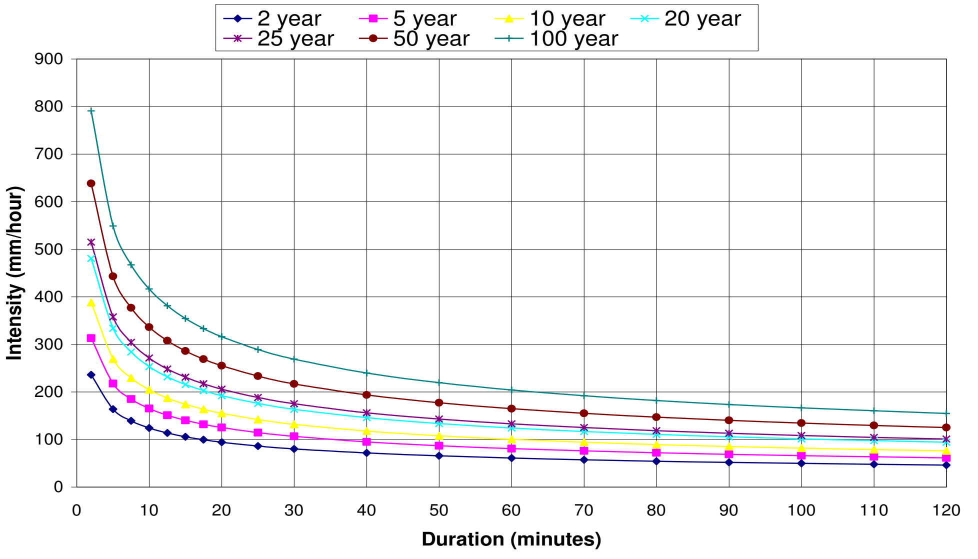

Figure 2: IDF Curves for Station 'Tangkulap' in East Malaysia

For a simple sloping roof, the eaves gutter design is straightforward. It should slope from one end to the downpipe location at the other end. The required size of eaves gutter shall be determined from the Manual USMMM. The downpipe size is determined from a table given in the Manual to match the eaves gutter size.

DETAILS OF TEST RIG

The test rig consisted of a model roof and a rainfall simulator. The rainfall station Inanam is very close to the Universiti Malaysia Sabah (UMS) campus and according to the statistical analysis, the 5 minute rainfall intensity at Inanam was 350 mm/hour. The rainfall simulator was designed to give a maximum rainfall intensity of 350 mm/hour.

The width of the rainfall simulator was 3 m and the maximum width of the model roof was 2 m. The model roof provided with rollers was placed under the simulator so that uniform rainfall conditions over the entire roof surface was reproduced. The rainfall simulator and model roof with the components are shown in Figures 3 & 4. The rainfall simulator was 6.5 m long, 3 m wide and 3 m high fabricated using pipe posts 75 mm dia. The water that was used to simulate actual rain falling on the roof was collected and used again so that wastage was reduced. For this purpose two tanks were used as shown in the Figure 3. The main tank had a capacity of 1800 litres and from this tank, water was pumped into the spraying pipes using a pump of 750 Watt power. The spraying pipings were 18 mm diameter and were spaced at 100 mm centres as shown. The water came down through holes 0.5 mm diameter spaced at 100 mm centres under pressure. This was able to simulate a uniform rainfall of maximum intensity 350 mm/hour. A flow meter measured the quantity of water. A filter filtered out the water flowing into the pipings. The water drained into the gutter and the out-flowing water from the downpipe was collected into a secondary tank of capacity 900 litres. A smaller pump of 330 Watt pumped back water from the secondary tank to the main tank.

The model roof frame was 6 m long, 1.5 m wide and 1 m high. The width of the sloping roof was 2 m and could be adjusted to any angle from zero to 45 degrees using an electric hydraulic jack. Three heavy-duty rollers were provided for each leg of the main support so that the model roof could be mobile. The gutter slope could be adjusted from 1/240 to 1/48 in stages. Using a magnetic angle finder, the model roof could be adjusted to any desired roof slope. The details are given in the paper by Febik (Febik, 2004).

ROOF SHEETS AND GUTTERS

Five types of roof sheets with different profiles were used. The effective width ranged from 406 mm to 760 mm, the depth of rib ranged from 20 mm to 41 mm and the base metal thickness ranged from 0.48 mm to 0.52 mm. All these products specified a minimum roof slope of 3 degrees. Five different sizes of gutters were used as shown in Figure 5. According to Article 3.5.5. of the AS/NZS, for an eaves gutter with external brackets, the effective cross-sectional area is the area beneath a line not less than 10 mm below the overflow. As per this clause, the effective areas of the gutters used were 11250 mm^2, 6125 mm^2, 12830 mm^2, 20000 mm^2 & 11650 mm^2 in the order 1, 2, 3, 4 & 5.

Figure 3: Model Roof and Rainfall Simulator

Figure 4: Water Tanks for the Test Rig

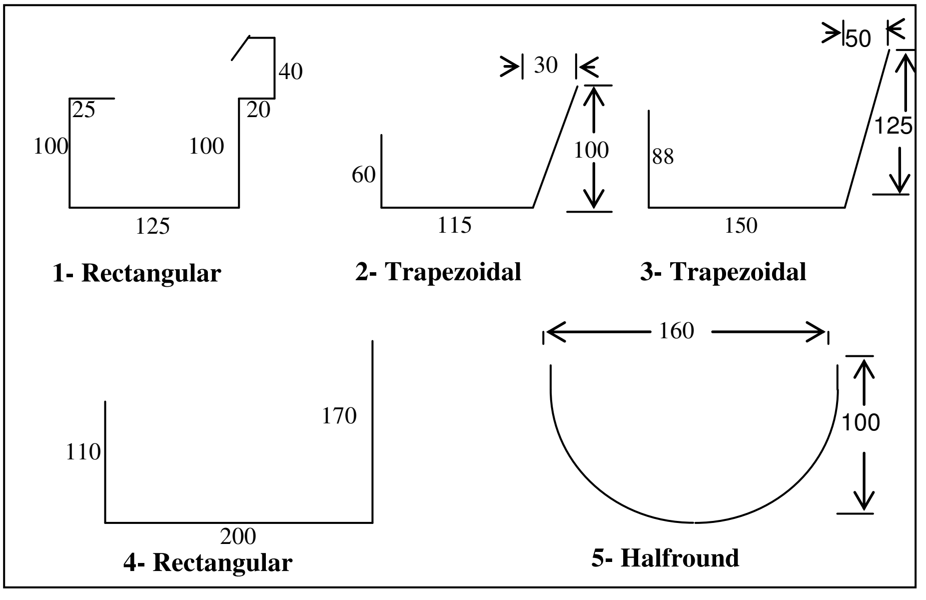

Figure 5: Gutter Cross Sections (dimensions in mm)

TESTING PROCEDURE

The main pump was run and water was allowed to flow through the complete system and all the air entrapped was removed by opening the outlet valves at the two ends of the rainfall simulator. The exit valves were closed and the pump stopped. The flow meter reading was noted. Using the electric hydraulic jack, the roof slope was adjusted to 45 degrees and the power to the jack switched off. The main pump was switched on and the water was allowed to run for 5 minutes. The water depths at the beginning, centre and the end of the gutter length were measured using a water depth probe. The flow meter reading was noted after switching off the pump. A stopwatch was started at the time of switching off the pump. The stopwatch was stopped when the water in the gutter was completely drained off. The above steps were repeated for roof slopes of 30, 15, 10, 5 and 2 degrees. The gutter slopes used were 1/240, 1/120, 1/80, 1/60 and 1/48. The tests were completed for all the five roof sheets. Figure 6 shows the model roof during testing.

Figure 6: Model Roof during Testing

RESULTS OF LABORATORY TESTS

Effect of Gutter Slope

The tests were done with gutter slopes of 1/240, 1/120, 1/80, 1/60 & 1/48. The water depth pattern showed considerable change with change in roof slope. The depth was smaller at the beginning of the gutter, increased to a larger value at the centre and further increased slightly at the end near the vertical downpipe outlet. Based on the maximum water depth, the actual used up effective cross sectional area of the gutter was determined.

USMMM uses the same design charts as the AS/NZS Code. For the catchment area of 12 m^2 of the model roof and for a 20 year 5 minute design rainfall intensity of 350 mm/hour for Inanam, the required effective cross sectional area for the gutter was determined as 4600 mm^2 from the USMMM. AS/NZS does not specify minimum gutter slope whereas USMMM specifies a minimum gutter slope of 1/500. For incorporating the rain water harvesting option into our guidelines, a lower slope of 1/200, a medium slope of 1/100 and a high slope of 1/50 could be considered (Still & Thomas, 2002). It is desirable to specify a minimum gutter slope of 1/200 for rain water harvesting possibility. Naturally steeper gutter slopes would drain the water faster resulting in reduced water depth and thus reduced cross sectional area. From the results of the tests, Table 1 has been tabulated

Table 1: Used up Areas (mm^2) corresponding to Gutter Slopes

Gutter Type → / ↓ Gutter Slope	1	2	3	4	5	Percentage of 4600 mm^2
1/240	3250	3215	3240	3400	3120	73.9
1/120	2875	2724	2920	3000	2850	65.2
1/80	2500	2480	2610	2600	2610	56.7
1/60	2250	2240	2295	2400	2365	52.1
1/48	2000	2000	1985	2200	2125	47.8

Table 1 shows the calculated values of effective cross sectional areas corresponding to the maximum water depths in the gutter. The percentage in the last column was corresponding to the maximum among the values for all the gutters. For example, for the gutter slope of 1/240, the percentage taken was 3400 mm^2 out of 4600 mm^2. It can be observed that the variation of areas for different gutters were not substantial.

Brater et. Al, (1996) observed that most practical problems fall in the fully turbulent range of flow at high values of the Reynolds number, where the Manning equation gives satisfactory results. The gutter flow could not be strictly taken as an open channel flow because of the lateral inflow of water along the full length. But, at the end of the gutter, the full discharge was available. Therefore, it was decided to calculate the cross sectional areas of gutter required using Manning equation for a comparison. A roughness coefficient of 0.012 was assumed because the gutters were all smooth metal gutters. The results are tabulated in Table 2.

Table 2: Areas (mm^2) Calculated Using Manning Equation

Gutter Type → / ↓ Gutter Slope	1	2	3	4	5	Percentage of 4600 mm^2
1/240	3159	3106	3289	3553	2969	77.2
1/120	2503	2457	2623	2851	2325	62.0
1/80	2190	2146	2301	2509	2016	54.5
1/60	1992	1951	2097	2293	1822	49.8
1/48	1853	1814	1953	2138	1685	46.5

From Table 2, it could be observed that the areas calculated using Manning equation (Equation 5) were very close to the values obtained from the tests.

$$Q = \frac{1}{n} A_e r_h^{2/3} \sqrt{\theta} \qquad (5)$$

where (Q) is the flow, (n) is the roughness of the gutter material, (A_e) is the gutter cross-section area, (r_h) is the hydraulic radius and (θ) is the gutter slope.

The percentage in the last column of Table 2 was corresponding to the maximum among the values for all the gutters. For example, for the gutter slope of 1/240, the percentage taken was 3553 mm^2 out of 4600 mm^2. It can be observed that the variation for different gutters were not substantial.

Tables 1 & 2 show that as the gutter slope became steeper, only smaller gutter cross sections were needed having percentages of areas as tabulated. The results of this laboratory investigation could be incorporated as a design guideline with sufficient margin of error. It was recommended to take a reduction factor of 80% for a lower gutter slope of 1/200, a reduction factor of 70% for a medium gutter slope of 1/100 and a reduction factor of 60% for a high gutter slope of 1/50. This percentage was for a wide rectangular section and could still be reduced for other sections.

As an example, a catchment area of 40 m^2 having a rainfall intensity of 350 mm/hour would require 12450 mm^2 as per USMMM now. This area became 9960 mm^2 when we used a gutter slope of 1/200. The vertical downpipe could be designed using the Table given in USMMM itself and the saving in gutter area would automatically reduce the downpipe size also.

Effect of Roof Sheets

It was observed that the type of roof sheets did not have any significant effect on the roof drainage both in the water depths in the gutter as well as in the time required for complete drainage.

Effect of Roof Slope

It was observed that within a roof slope of 45 degrees to 5 degrees, the time of drainage showed only a marginal increase of about 1.5 seconds for all the roof sheets. From 5 degrees to 2 degrees, the time increased further by about 1.5 seconds. After the flow stabilised, the water depths in the gutter remained nearly same for all the roof slopes.

CONCLUSIONS

For the design of an eaves gutter, it is recommended to use a minimum gutter slope of 1/200 for the purpose of incorporating the rain water harvesting option. It is recommended that after estimating the required cross sectional area needed for the gutter as per USMMM, a reduction factor of 80% for a lower gutter slope of 1/200, a reduction factor of 70% for a medium gutter slope of 1/100 and a reduction factor of 60% for a high gutter slope of 1/50 may be permitted. This percentage is for a wide rectangular section and can still be reduced for other sections.

A minimum width of 75 mm would be alright for the eaves gutter. It is preferable and economical to get gutter sizes fabricated to our required needs rather than going for the next higher available size in the market.

The type of roof sheets do not have any significant effect on the roof drainage both in the water depths for the gutter as well as in the time required for complete drainage. Within the roof slope of 5 degrees to 45 degrees, there is no significant deviation for the water depths in the gutter as well as for the time required for complete drainage.

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INFLUENCE OF UNIT STRENGTH ON DEFORMATION BEHAVIOUR OF FIRED-CLAY BRICKWORK

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ABSTRACT
This paper discusses on the deformation behaviour of 1½ -brick wide x 5-course high single leaf walls constructed from three types of Malaysian fired-clay brick using OPC : lime : sand of 1 : ½ : 4 ½ mortar designation. The strength of the units used to construct the masonry wall ranged from 20 to 70 N/mm^2. The tests were conducted in ambient condition as it was intended to simulate the condition on site. The results show that creep and moisture movement is approximately inversely related to unit strength as theoretically stated that high-strength units tend to exhibits less creep and lowest expansion compared to lower-strength units.

Keywords: Masonry, fired-clay brick, compressive strength, moisture expansion, shrinkage, creep

INTRODUCTION

All building materials including masonry tend to deform when they are subjected to a constant load. Masonry is a visco-elastic material, which when subjected to sustained applied load, undergoes an instantaneous deformation or elastic deformation followed by a time-dependent deformation i.e. creep and moisture movement. The rate of creep decreases with time and ceases entirely after a time that varies according to the type of brick and mortar being used (Lenczner, 1972). Failure to allow for long term movements in the design of unreinforced masonry may cause serviceability problems i.e. spalling and buckling, or cracking in the case of restraint to movement (Abu Bakar, 1998).

It can be seen that the material and the strength of the bricks affect the total creep movement as well as the shrinkage. Marzahn (2000) concluded that a high strength unit tends to have less creep movement than a lower strength unit. The reason is because stronger bricks are generally more rigid and allow less spread of the mortar under vertical load. This in turn reduces the vertical strain in the mortar where most of the creep occurs (Lenczner, 1986). Thus, the stiffer the unit, masonry will be more restraint to the creep and shrinkage of mortar and therefore the less the movement of the masonry (Brooks and Abu Bakar, 2004).

Time dependent movements of brick masonry can be critically influenced by an interaction between the bonded brick and mortar element primarily due to the unit water absorption. This interaction results from the transfer of moisture between the two elements of the masonry leading to a reduction in the water content of the bonded mortar, thereby decreasing its potential for creep and shrinkage (Forth et al., 2000). The resulting effect on the nature of creep in brickwork can be viewed by considering two extremes; a very porous brick which allows the mortar to reach equilibrium with the environment before loading expected to show a minimal creep and the opposite case of a very dense brick where the mortar is kept wet for a long period of time before and after loading expected to have a large creep (Johnson, 1984). Strength and absorption of the brick affect creep in different ways. The effect of absorption of the brick is more complex. On the one hand, bricks absorb water from the mortar and thus increase its strength, leading to a lower creep. Too much absorption however, leaves insufficient water in the mortar for complete hydration, leading to a lower strength and higher creep. Therefore, there appears to be optimum value of water content within the bricks and mortar for minimum creep (Lenczner, 1986).

Although creep can cause problem during the life of load bearing or composite structure, unless it has been properly allowed for at the design stage, it is wrong to think of it as an undesirable property (Lenczner, 1981). According to Shrive and Reda Taha (2007), the effects of creep can be beneficial (positive), neutral, or detrimental (negative) for a structure. The effects can be beneficial, for example through the relief of stress concentrations, and detrimental through increasing deformations that latter can lead to a structure to be no longer meeting serviceability criteria. Stress redistribution can cause cracking, especially in cases where there is deterioration in strength over time due to environmental factors in that element of the structure that carries increasing load due to creep effects.

The influence of unit type on the deformation of masonry structure is very important owing to different type unit available in the local market. The perception that local bricks are of low quality is a wrong perception as reveals by Abdullah and Wan Omar (2007), none of the manufacturers in Malaysia produce bricks with strength less than 5 N/mm^2 and more than 90 percent produce bricks with strength more than 10 N/mm^2. More than 5 percent produced bricks of more than 50 N/mm^2. This finding indicates that although most of Malaysia bricks are common bricks, they acquire the level of strength to be use as load bearing bricks (Abdullah et al., 2009). Besides of this misleading perception, lack of data available on local brick also could be the reason why brick not be used as a load bearing and become unpopular building materials compared to reinforced concrete.

Due to these factors, it is important to investigate and understand the mechanical properties of the local brick, so that the effect of deformation behaviour on the strength of masonry can be studied further. Therefore, the findings of this research will help the better understanding of fired-clay brick unit and different patterns of deformation behaviour of masonry structures constructed with different types of fired-clay brick produced by local manufacturer.

EXPERIMENTAL WORK

The strength of Brick type 1, Brick type 2 and Brick type 3 were 23.78, 35.52 and 63.52 N/mm^2, respectively and used to construct 1½-brick wide x 5-course high single-leaf walls with an ordinary Portland cement : lime : sand of 1 : ½ : 4½ mortar designation. Table 1 shows the types and properties of masonry units.

For each batch of wall, 100 mm mortar cubes were tested for their strength and the overall properties result are shown in Table 2. Strength of the mortar at 14 days was between 8.08 - 14.83 N/mm^2. The water-cement (w/c) ratio was that required to give a standard consistence of 10 mm penetration in the dropping ball test of BS4551 (1980). Although the same mix proportions were used in all tests, the strength of mortar for Wall-Brick 2 was much higher than compared to Wall-Brick 1 and Wall-Brick 3. This was probably due to the difference in water content of the building sand used thus resulting in different w/c ratios. This was agreed by Samarasinghe and Lawrence (1992) which mentioned that the compressive strength of mortar decreases with an increase of water or air content.

Three single-leaf walls were constructed with the same batch of mortar. Wall 1 was used to test for the compressive strength at age of 14 days, Wall 2 as a controlled wall (unloaded) used for measuring shrinkage/moisture expansion and Wall 3 as a loaded wall for testing elasticity and creep. Immediately after construction the walls were covered with polythene sheet for 14 days before testing in ambient environment but at the same time the changes were recorded using thermo-hygrograph. For the creep tests, the walls were loaded constantly with a stress of 1.5 N/mm^2 using the creep frame shown in Figure 1 and were allowed to creep under ambient conditions as it was intended to simulate the condition on site. The application of load to the masonry was performed by tensioning the two tie-rods located on both sides of the wall. The load applied monitored using a digital data indicator.

The modulus of elasticity was determined from the instantaneous strain after loading the creep specimens. For each creep specimen, an identical control specimen was also built and placed in the same environment. Measurement of strain was taken before and after loading on the controlled wall and the loaded wall at the same time to ensure if there was any shrinkage or expansion movement during the elasticity measurements. The strain changes in the control specimen were assumed to be equivalent to the moisture strain in the masonry. It may be relevant to note that in the past, majority of investigators have used unloaded control specimens, which were believed to be the same, and thus the total movement of loaded specimens adjusted by the shrinkage of unloaded companions was assumed to represent "true" creep.

The fluctuating of temperature and humidity recorded shown in Figure 2, there was considerable fluctuation of daily temperature, sometimes by as much as 11 ºC and a correspondingly high variation in the relative humidity, which was typically above 25 %. The strains were measured using a 150 mm and 200 mm demountable gauge readings to 10.6 x 10^{-6} and 7.98 x 10^{-6}, respectively. The load was sustained until no movement detected in period of 3 weeks before the creep ceased. Figure 3 shows the loaded and unloaded specimen tested under ambient condition.

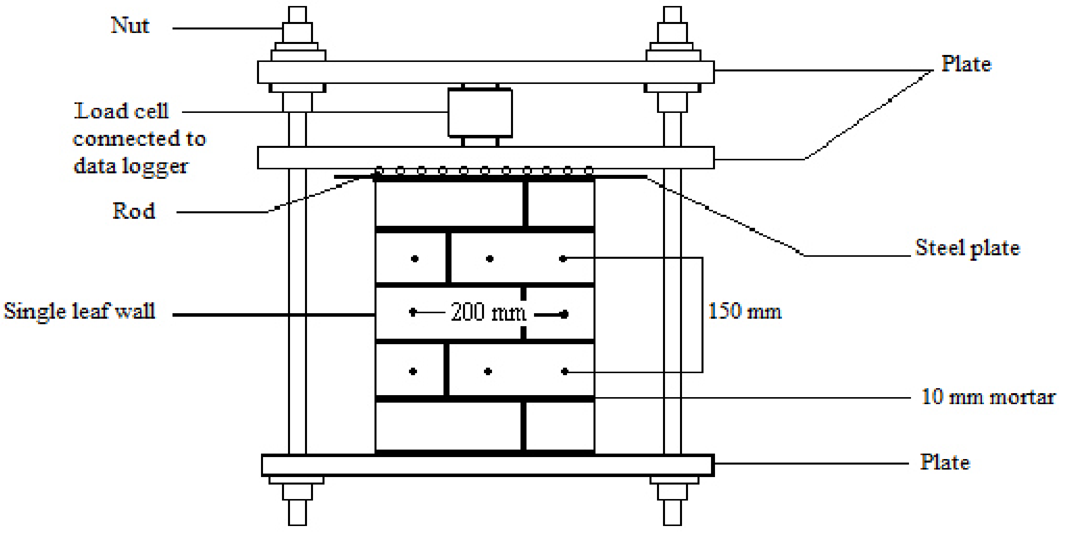

Figure 1: Creep Frame Designation

Table 1: Types and properties of masonry units

Unit		Strength (N/mm^2)	Elastic Modulus (KN/mm^2)	Water absorption (%)	Initial rate of suction ($kg/m^2/min$)
Code	Type	Mean	Mean	Mean	Mean
Brick type 1	Solid	23.78	7.42	22.80	4.96
Brick type 2	Perforated	35.52	7.81	12.11	1.64
Brick type 3	Perforated	63.52	16.03	9.76	0.79

Table 2: Mortar cubes properties

Testing conditions	Mortar Specimen	Compressive strength at 14 days (N/mm^2)	Density (kg/m^3)	Water / cement ratio	Dropping ball test (mm)
Ambient environment	Wall-Brick 1	9.27	888.02	1.20	9.5
	Wall-Brick 2	14.83	1118.68	1.10	9.5
	Wall-Brick 3	8.08	1075.92	1.20	10.5

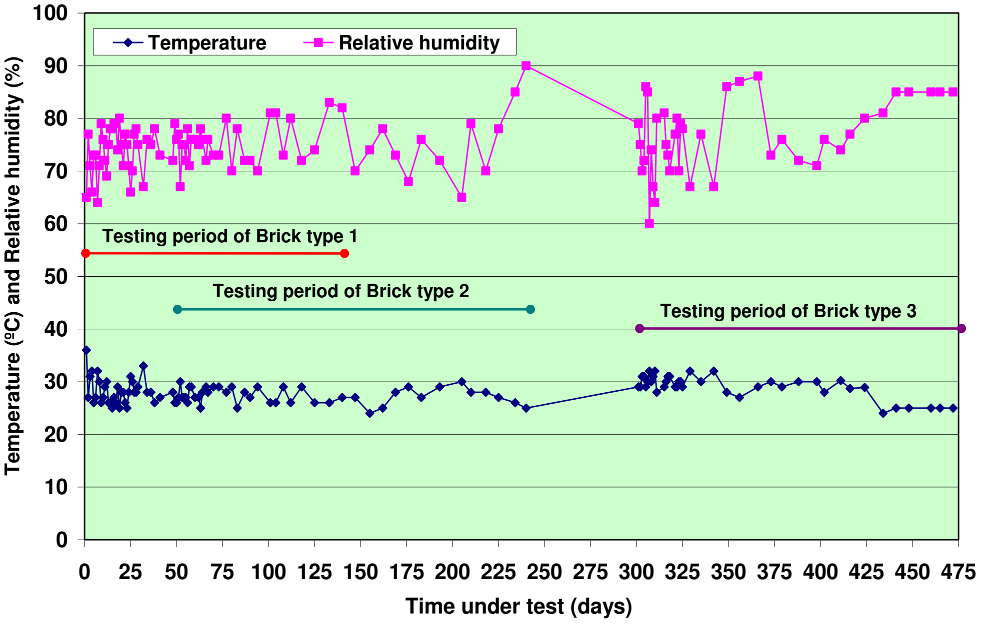

Figure 2: Records of test temperature and humidity with time (ambient condition)

Figure 3: Creep and moisture movement test walls

RESULTS AND DISCUSSIONS

Elasticity

The elastic strain was measured from the loaded wall immediately after applying a stress level of 1.5 N/mm^2 at the age of 14d and the detailed results is given in Table 3. The removal of load after the creep test periods were depends on the brick types which were for Wall-Brick 1, Wall-Brick 2 and Wall-Brick 3 creep ceased after 15 weeks, 20 weeks and 25 weeks, respectively. Wall-Brick 3 takes a longer period to be ceased but with lower elastic modulus if compared to Wall-Brick 2. The range of elastic modulus for three types of fired-clay bricks were between 4.56 KN/mm^2 to 16.65 KN/mm^2 as shown in Table 3. The elastic strains for Brick type 1 and Brick type 3 are greater than Brick type 2 probably because of lower mortar strength which were 9.27 and 8.08 N/mm^2 compared to 14.83 N/mm^2, consequently a lower modulus elasticity of the wall. The concave shape of the total strain curve under load can be explained by the closure of voids and microcracks generated at the interface between the brick and mortar.

There is no consistent pattern for horizontal strain compared with vertical load strain and the strain values were also small. This could be due to anisotropy behaviour of clay bricks and also the uneven distribution of horizontal load strain. At the same time, unit water absorption also could be another factor that could influence the porosity in the unit brick which allowed the water to transfer from the fresh mortar to the unit during wall construction process. Brick type 1 with higher water absorption makes the mortar shrink and become more porous, thus increasing the elastic strain when the load is applied as shown in Figure 4. Therefore, this process could have been more influential in the bed face direction as mentioned by Abu Bakar (1998).

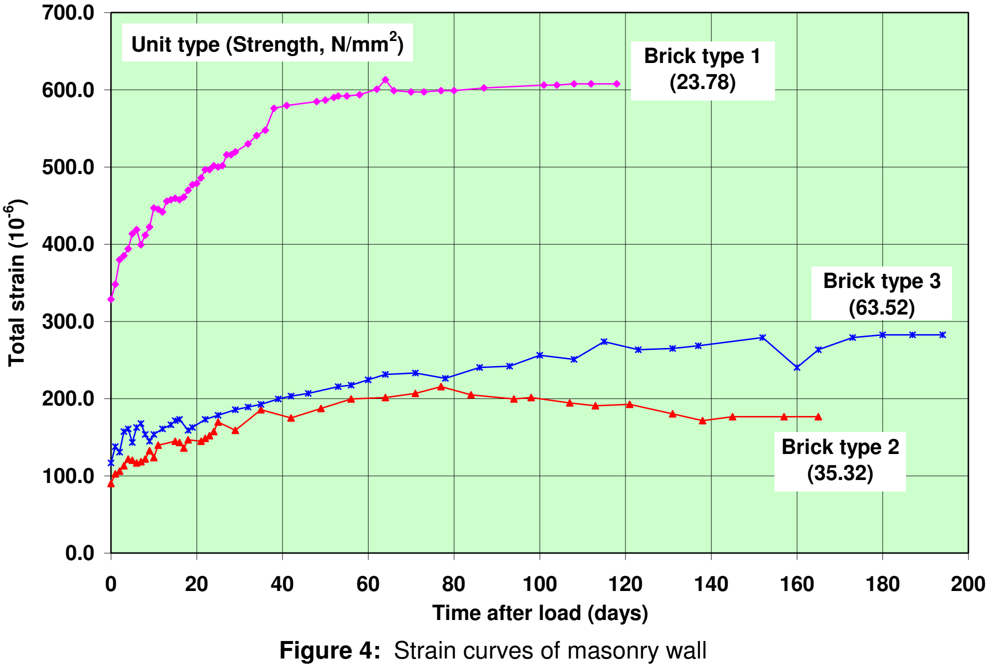

Figure 4: Strain curves of masonry wall

Moisture movement strain

Figure 5 illustrates moisture movement strain of fired-clay brick masonry and as given by the vertical strain on the controlled wall, the masonry can be manifested as one of the following; long-term shrinkage, shrinkage followed by expansion or long-term expansion as previously mentioned by Forth and Brooks (1995). Final expansion of Wall-Brick 1 and Wall-Brick 2 which shows a moisture expansion were -81 and -83 x 10^{-6}, respectively. However, Wall-Brick 3 showed long-term shrinkage amounting to an average of +124 x 10^{-6} strain.

At early ages, the masonry walls exhibited shrinkage because of the fresh mortar undergoing shrinkage and dominates the movement, which exceeded the value of expansion in the brick units. However, later the contribution of the brick expansion is more influential and result in overall long-term expansion. It can be seen that at approximately age of 30 – 50 days the majority of the shrinkage has occurred, and beyond that time the masonry shrinkage slowly decreases owing to the expansion of the brick taking place as occurred for Wall-Brick 1 and Wall-Brick 2. After that, the brick slowly expand until moisture condition in brick is at equilibrium with ambient condition. As reported by Forth and Brooks (2008), small control walls built from low strength bricks having high water absorption can undergo an enlarged moisture expansion.

It is apparent that the general trend of moisture movement strain of the masonry used in this investigation also exhibited shrinkage as in case of Wall-Brick 3 and thus, confirms the finding of Forth and Brooks (1995) where long term shrinkage was also be found. As a conclusion, it shows that the weaker unit wall tended to show long term moisture expansion, while the stronger unit wall showed long term shrinkage as agreed by Brooks and Forth (1994).

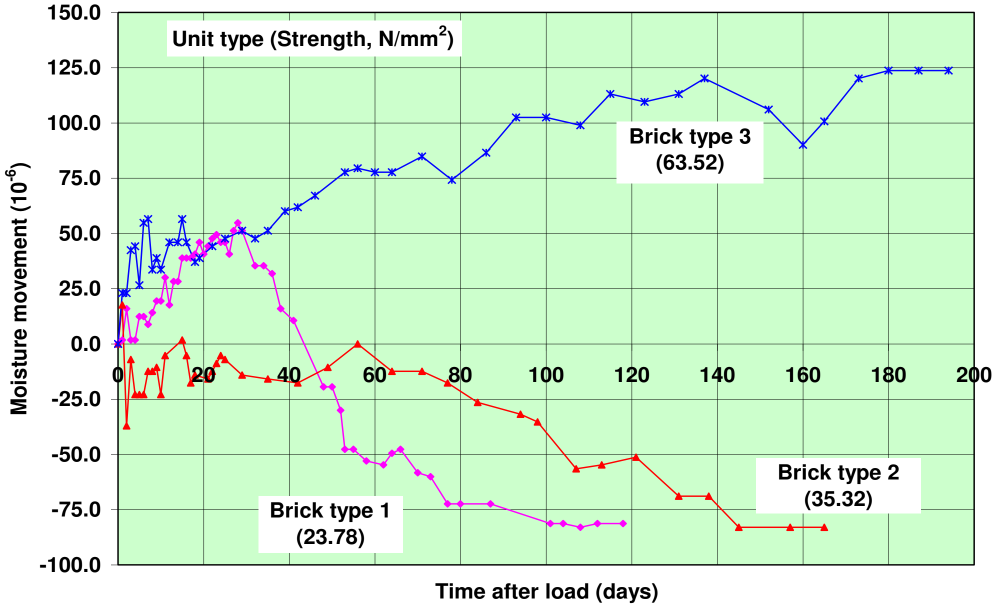

Figure 5: Moisture movement strain-time characteristics

Creep

Creep was calculated after subtracting the average strain of the controlled walls (shrinkage/expansion) and instantaneous (elastic) strains from the total measured strain of the loaded walls. The creep strain of the single leaf walls for three types of brick plotted against time after loading at intervals between 108 to 180 days depends on the type of brick. Results of creep time characteristics under constant stress of 1.5 N/mm^2 is shown in Figure 6.

As the creep behaviour of the concrete, all masonry walls in this investigation exhibited similar behaviour, i.e a rapid increase at initial stage but then the rate slowed down progressively with time. The maximum creep strain for Brick type 1, Brick type 2 and Brick type 3 were 360 x 10^{-6}, 170 x 10^{-6} and 42 x 10^{-6}, respectively. The unit strength could be the factor that has affected this trend. It shows that high-strength units tend to have less creep movement than a lower-strength unit as illustrated in Figure 5. It can be seen that, the creep results for single leaf walls correlate well with unit strength as reported by Brooks (1994). Earlier, Lenczner (1986) claimed that stronger brick are generally more rigid and allow less spread of the mortar under vertical load. This in turn, reduces the vertical strain in the mortar where the most of the creep occurs. Results also suggest that creep in brickwork increases with a reduction in relative humidity and possibly with slightly higher and fluctuating temperature. But as mentioned by Lenczner (1976), it is not easy to separate the effects of temperature and humidity.

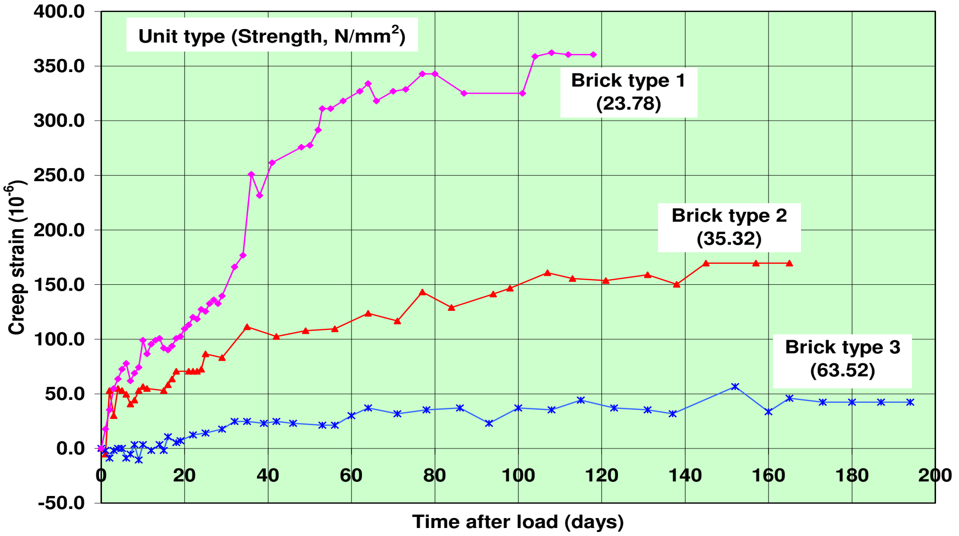

Figure 6: Creep-time characteristics of single leaf wall

Compressive strength

For each of brick type, the strength of single leaf wall was tested before loading at age 14 days. In order to investigate the effects of deformation on the strength of the wall, loaded walls and controlled walls were tested for their strength after deformation period and the results given in Table 3.

For the case of Wall-Brick 1, strength for the wall at the age of 14d (wall 1) was 5.76 N/mm^2 (lowest strength) and strength for controlled wall (wall 2) is 8.64 N/mm^2. The strength for the loaded wall (wall 3) shows the highest value at 9.51 N/mm^2. This is probably because the wall is already stable and the existence pores and voids in the mortar and brick was reduced due to sustained load approximately about 118 days. Lenczner (1981), stated that, indeed in some instances, creep may have beneficial effects. For examples, it relieves stress concentration which could otherwise lead to cracking or local failure. Therefore, it can be concluded that stage of the creep occurred in this study can be categorized in the primary creep range that given a beneficial effects in masonry.

However, the situations were different for another two brick type, Brick type 1 and Brick type 2. Controlled wall for Brick type 2 shows a higher strength at 14.84 N/mm^2 compared to loaded wall with 13.67 N/mm^2, while for Brick type 3, the same strength obtained for both of the wall with strength at 12.98 N/mm^2. According to recent paper, Cook and Chindaprasit (1980) also observed an increase in strength due to a sustained load but, after removal of the load followed by creep recovery, the strength decreased and become similar to that of a companion specimen not previously subjected to load.

Wall before deformation which is the strength tested at age 14 days shows the lowest strength because of immaturity of wall at loading age and the trend was similar for all the cases. For overall results, Wall-Brick 2 wall shows a higher strength compared to Wall-Brick 3 (high unit strength) could be due to higher strength obtained for the mortar unit for Wall-Brick 2.

Table 3: Properties of masonry wall

Type of Wall	Average strength of mortar at 14d (N/mm^2)	Instant. strain x 10^{-6}	Modulus of elasticity (KN/mm^2)	Max. load strain x 10^{-6}	Specific creep x 10^{-6}	Final Moisture movement x 10^{-6}	Strength at 14d (N/mm^2)	Strength of loaded wall (N/mm^2)	Strength of controlled wall (N/mm^2)
Wall-Brick 1	9.27	329	4.56	608 (after 15 weeks)	360	- 81 (expand)	5.76	9.51	8.64
Wall-Brick 2	14.83	90	16.65	177 (after 20 weeks)	170	- 83 (expand)	11.19	13.67	14.84
Wall-Brick 3	8.08	117	12.86	283 (after 25 weeks)	42	+124 (shrink)	9.60	12.98	12.98

CONCLUSIONS

By comparing different types of fired-clay unit, there was variability in the relationship between elasticity of clay brickwork and unit strength due to different modulus of elasticity strength characteristics of each type of units.

There is a relationship between moisture movement of masonry and unit strength where, low unit strength tends to show an initial shrinkage followed by a long term moisture expansion while for high unit strength shows long term shrinkage.

The unit strength affected the trend of the creep behaviour. Through this investigation, it shows that high-strength units tend to have less creep movement than a lower-strength unit.

It can be concluded, stage of the creep occurred can be categorized in the primary creep range that given a beneficial effect in masonry through the relief of stress concentrations. This was due to timing range of testing period was not longer enough for the long-term deformation detrimental effects.

There were no significant differences have been observed between the strength of unloaded specimens and specimens previously subjected to stress. However, these results might not be consistent because of other factor such as workmanship and etc. could affect the results of compressive strength of the brickwork.

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GUIDE TO AUTHORS

Aims and Scope:

The Malaysian Construction Research Journal (MCRJ) is the journal dedicated to the documentation of R&D achievements and technological development relevant to the construction industry within Malaysia and elsewhere in the world. It is a collation of research papers and other academic publications produced by researchers, practitioners, industrialists, academicians, and all those involved in the construction industry. The papers cover a wide spectrum encompassing building technology, materials science, information technology, environment, quality, economics and many relevant disciplines that can contribute to the enhancement of knowledge in the construction field. The MCRJ aspire to become the premier communication media amongst knowledge professionals in the construction industry and shall hopefully, breach the knowledge gap currently prevalent between and amongst the knowledge producers and the construction practitioners.

Articles submitted will be reviewed and accepted on the understanding that they have not been published elsewhere. The authors have to fill the Declaration of the Authors form and return the form via fax to the secretariat. The length of articles should be between 3,500 and 8,000 words or approximately 8 – 15 printed pages (final version). The manuscripts should be written in English. The original manuscript should be typed one sided, single-spacing, single column with font of 10 point (Times New Roman). Paper size should be of Executive (18.42 cm x 26.67 cm) with 2 cm margins on the left, right and bottom and 3 cm for the top. Authors can submit the manuscript:

- By e-mail to maria@cidb.gov.my / hazim@cidb.gov.my
- By hardcopy and softcopy in Microsoft-Word format to MCRJ Secretariat:

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Type of fonts: All text, drawing, graph must be written using Times New Roman
Language: Follow the spelling of the Oxford English Dictionary.
Size/Page Setup: Executive (18.42 cm x 26.67 cm)
Paper title: Arial, 16.

CODIFICATION AND APPLICATION OF SEMI-LOOF ELEMENTS FOR COMPLEX STRUCTURES

Author's name (full name): Arial, 9pt. should follow below the title.

Jamalodin Noorzaei[1], Mohd. Saleh Jaafar, Abdul Waleed Thanoon, Wong Jern Nee

Affiliation (including post codes): Arial, 9pt. Use numbers to indicate affiliations.

[1]*Department of Civil Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia*
Abstract: Arial Bold, 9pt. Left and right indent 0.25 inch.

Abstract: it should be single paragraph of about 100 – 250 words.

Keywords: Times New Roman Bold, 9pt (Italic). Left and right indent 0.25 inch.

Keywords: *Cooling tower; Finite element code; Folded plate; Semiloof shell; Semiloof beam*

Body Text: Times New Roman, 11 pt. All paragraph must be differentiate by 0.25 inch tab.

Heading 1: Arial Bold + Upper Case, 11pt.
Heading 2: Arial Bold + Lower Case, 11pt.
Heading 3: Arial Italic + Lower Case, 11pt.

Units: All units and abbreviations of dimensions should conform to SI standards.

Figures: Figures should be in box with line width 0.5pt. All illustrations and photographs must be numbered consecutively as it appears in the text and accompanied with appropriate captions below them.

Figures caption: Arial Bold + Arial, 9pt. should be written below the figures.

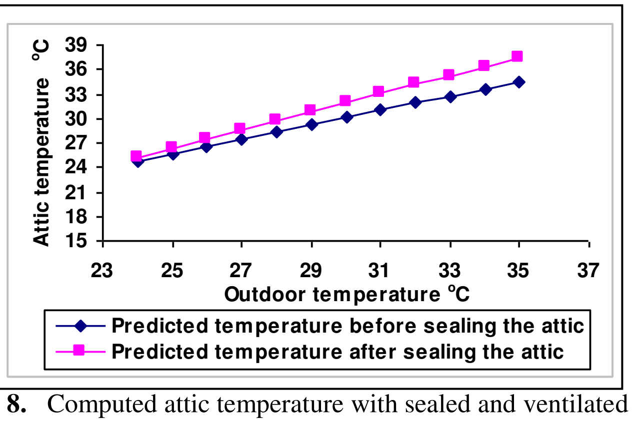

Figure 8. Computed attic temperature with sealed and ventilated attic

Tables: Arial, 8pt. Table should be incorporated in the text.

Table caption: Arial Bold + Arial, 9pt. Caption should be written above the table.

Table Line: 0.5pt.

Table 1. Recommended/Acceptable Physical water quality criteria

Parameter	Raw Water Quality	Drinking Water Quality
Total coliform (MPN/100ml)	500	0
Turbidity (NTU)	1000	5
Color (Hazen)	300	15
pH	5.5-9.0	6.5-9.0

(Source: Twort et al. 1985; MWA,1994)

Reference: Times New Roman, 11pt. Left indent 0.25inch, first line left indent – 0.25inch. Reference should be cited in the text as follows: "Berdahl and Bretz (1997) found…" or "(Bower et al. 1998)". References should be listed in alphabetical order, on separate sheets from the text. In the list of References, the titles of periodicals should be given in full, while for books should state the title, place of publication, name of publisher, and indication of edition.

Journal

Sze, K. Y. (1994) Simple Semi-Loof Element for Analyzing Folded-Plate Structures. *Journal of Engineering Mechanics*, 120(1):120-134.

Books

Skumatz, L. A. (1993) Variable rate for municipal solid waste: implementation, experience, economics and legislation. Los Angeles: Reason Foundation,157 pp.

Thesis

Wong, A. H. H. (1993) *Susceptibility to soft rot decay in copper-chrome-arsenic treated and untreated Malaysian hardwoods*. Ph.D. Thesis, University of Oxford. 341 pp.

Chapter in book

Johan, R. (1999) Fire management plan for the peat swamp forest reserve of north Selangor and Pahang. In Chin T.Y. and Havmoller, P. (eds) *Sustainable Management of Peat Swamp Forests in Peninsular Malaysia* Vol II: Impacts. Kuala Lumpur: Forestry Department Malaysia, 81-147.

Proceedings

Siti Hawa, H., Yong, C. B. and Wan Hamidon W. B. (2004) Butt joint in dry board as crack arrester. *Proceeding of 22nd Conference of ASEAN Federation of Engineering Organisation* (CAFEO 22). Myanmar, 55-64.

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