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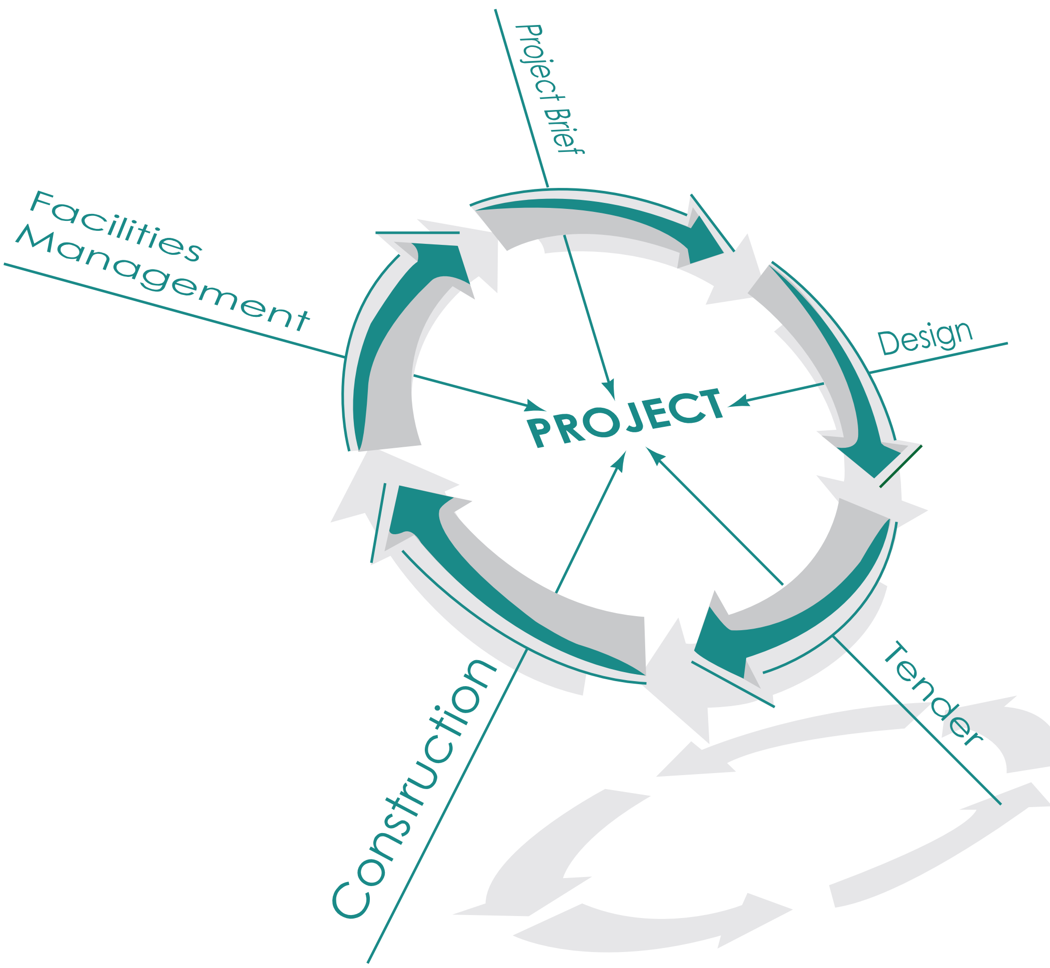

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CONSTRUCTION RESEARCH INSTITUTE OF MALAYSIA

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Contents

Editorial Advisory Board

Editorial

Welcome from the Editors

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

Kim S Elliott and Arnold Van Acker, shows the precast concrete industry is ideally placed to accommodate the higher demands by using experienced design teams and skilled labour in a quality controlled environment to produce high specification components for IBS. The key to success is the adoption of an off-site construction methodology from the outset, rather than trying to modify traditional solutions by converting existing cast in-situ concrete buildings to precast concrete IBS. Special materials, such as high strength and self compacting concrete, and the integration of building services, have special significance in IBS. Precast concrete structures need not be limited to rectangular shoe-box designs, and offer clients and architects many options for modern construction.

Maisarah Ali, et. al. assess the quality of selected school buildings in Malaysia constructed using the Industrialised Building System (IBS) method of construction and comparing it with the quality of buildings constructed using conventional construction methods. This study involves the physical inspection of buildings, an analysis of the defect lists obtained from the relevant authorities and a questionnaire survey circulated to end users to obtain a feedback on their perception on the quality of the completed buildings. The results of this study demonstrate that the quality of IBS-constructed buildings had substantially better quality as compared to those constructed by the conventional methods.

Mukhtar Che Ali , et. al., review the current implementation of QLASSIC, identifies any shortfalls for it to become continual improvement tool, explore the potential areas for improvement and subsequently proposes recommendation areas for improvement. Taking into consideration that IBS is steadily gaining its importance in the future thus this research is focusing on IBS projects.

Zuhairi Abd. Hamid, et. al. encourage the adoption of sustainable and green construction in Malaysia. The challenges of the adoption are lack of skill and capacity, overlapping of roles among the government agencies, slow industry follows through on government programs, lack of research and innovation, and cost versus benefits in term of implementation of green technology. The paper in particular will discuss the issue on sustainability through IBS adoption, green technology strategy and Green PASS program. Both are true potential catalyst forward sustainable and green construction in Malaysia.

Nor Hayati Abdul Hamid, et. al. discuss a full-scale of the house is constructed on pad footing and seated on strong floor in Heavy Structural Laboratory, CREAM,Kuala Lumpur was tested under reversible lateral cyclic loading. Visual observations were recorded and their classification of damage states are in accordance to drift limits. Damage states limit of these two walls are followed by the definitions and descriptions as given in HAZUS 99-SR2. Colour-coded system is fully utilized in order to identify performance level, damage level, drift damage and ductility factors. Fragility curve for this house is developed based on the probabilistic hazard level, cumulative probability function and classification damage-states. This house has 40% of Confident Interval (CI) for green colour-coding and 95% of Confident Interval (CI) for yellow colour-coding under Design Basic Earthquake (DBE) with PGA=0.12g.

M. A. A. Aldahdooh, et. al. investigate on the usage of Acoustic Emission (AE) technique for testing the effect of beam depth on the damage mechanism of the Reinforced Concrete (RC) beams resulted from flexural failure mode. MICRO - SAMOS (μ-SAMOS) Digital AE system was used to conduct the test. Cumulative absolute energy was used to analyse the integrity of the beams. The results showed good agreement between visual observation and AE results in determining the damage mechanism of the RC structure. As the level of damage increased, the cumulative absolute energy increased with increasing beam depth. This study demonstrated that AE technique can be a useful tool in monitoring the structural health performance of RC beams.

Editorial Committee

BEST PRACTICE IN PRECAST CONCRETE STRUCTURES & MATERIALS FOR INDUSTRIALISED BUILDING SYSTEMS

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Abstract
Precast concrete is widely regarded as an economic, durable, structurally sound and architecturally versatile form of IBS. The precasting industry is continuously making efforts to keep on line with the demands of modern society: economy, efficiency, technical performance, safety, labour circumstances and environmental friendliness. This paper shows that the precast concrete industry is ideally placed to accommodate the higher demands by using experienced design teams and skilled labour in a quality controlled environment to produce high specification components for IBS. The conclusions are that key to success is the adoption of an off-site construction methodology from the outset, rather than trying to modify traditional solutions by converting existing cast insitu concrete buildings to precast concrete IBS. Special materials, such as high strength and self compacting concrete, and the integration of building services, have special significance in IBS. Precast concrete structures need not be limited to rectangular shoe-box designs, and offer clients and architects many options for modern construction. In conclusion, the requirement for off-site fabrication will continue to increase as the rapid growth in management contracting, with its desire for reduced on-site occupancy and high quality workmanship, will favour controlled prefabrication methods.

Keywords: *Precast Concrete Structures, Prestressed Concrete, Industrialised Building Systems, Self Compacting Concrete, Standardisation, Integrated Design, Recycled Concrete, Building Services.*

PRECAST CONCRETE IN THE MODERN CONSTRUCTION INDUSTRY

The latest generation of precast concrete structural frames has evolved over the past 30 years into buildings of high specification. Architectural structural precast concrete components are being used on an increasing number of prestigious commercial buildings, and steelwork, timber and masonry are being combined for total benefit. Designers are becoming more aware of the high quality finishes possible in prefabricated units, but changes are now being made to the way that the traditional precast structures are conceived and designed. The construction industry is calling for multi-functional design, where the optimum use of all the components forming the building must be maximised.

This paper shows that the precast concrete industry is ideally placed to accommodate the higher demands by using experienced design teams and skilled labour in a quality controlled environment to produce high specification components for IBS, together with robust and ductile connection systems. These are explained in great detail in the text books by Elliott (Elliot, K. S. 2002) the fib Manual on structural connections (Federation Internationale du Betong 2008) and the forthcoming fib Handbook convened by Van Acker (Federation Internationale du Betong 2013). Reading these texts it is clear that the requirement for off-site fabrication will continue to increase as the rapid growth in management contracting, with its desire for reduced on-site occupancy and high quality workmanship, will favour controlled pre-fabrication methods. There are no better examples than in the complexities of constructing student accommodation, such as the precast concrete apartments at the London 2012 Olympic village, or at expanding universities as shown in Figures 1 and 2.

Figure 1. Student accommodation at University of West of England, 2009. C.Buchan, UK

Figure 2. Student accommodation at Southend College, UK. c. Bell and Webster, UK, 2010

Precast concrete is widely regarded as an economic, durable, structurally sound and architecturally versatile form of construction. The precasting industry is continuously making efforts to keep on line with the demands of modern society: economy, efficiency, technical performance, safety, labour circumstances and environmental friendliness. On-site construction is fast, often beating structural steelwork, and of course concrete is inherently fire proof, typically at the rate of 1000 m^2 per week for flooring, and around 600 m^2 per week for the car park and shopping structure shown in Figure 3.

The evolution of building construction and civil engineering works during the next decades will undoubtedly be influenced by the developments in information processing, global communication, industrialisation and automation. They are already now to a certain extent being implemented in prefabrication. The only way to shift further from the traditional labour intensive method to a modern approach like prefabrication would involve the application of an industrial philosophy throughout the entire building process.

Prefabrication of concrete structures is an industrialised process with a large potential for the future. It is often considered by uninitiated designers as a variant execution technique of cast insitu construction. In this approach, prefabrication means only that parts of the construction are precast in specialized plants, to be assembled afterwards on site in such a way that the initial concept of cast insitu structures is obtained again. This viewpoint is false. Every construction system has its own characteristics which to a greater or lesser extent influence the structural lay-out, span width, stability system, etc. For the best results a design should, from the very outset, respect the specific and particular demands of the intended structure.

Figure 3. This shopping centre and car park uses a wide range of precast concrete elements. This is a so called skeletal frame, comprising beams, columns and slabs, using concrete shear-walls for stability.

Skeletal structures are most commonly used for low to medium rise buildings, about 90% are between 3 and 15 storeys, where concrete compressive cube strength is about 60 N/mm^2. However, recent developments in the high strength concrete, up to 100 N/mm^2, has enabled precast columns to compete with and beat equivalent structural steel Universal columns, when the combined advantages of strength, section size, self finish and fire resistance are all taken into account. Examples of this is shown in Figures 4 and 14, where tower buildings of 36 storeys have utilised 95N/mm^2 high strength concrete in columns as small as 600 mm diameter, shallow prestressed concrete beams, and lightweight hollow core floor slabs. A key element to the success of these buildings was the speed of construction; two storeys per 8 working days (Van Acker, A. 2006.)

Figure 4. Precast tower block in Belgium, 36 storeys plus 6 storey basement, using high strength concrete in columns, shallow beams and lightweight floors. c. Egron, Belgium.

OPPORTUNITIES FOR PREFABRICATION

Compared with traditional construction methods and other building materials, prefabrication as a construction method, and concrete as a material, have a number of positive features. It is an industrialised way of construction, with inherent advantages:

Factory Made Products

The only way to industrialise the construction business is to shift the work from the site to modern permanent factories. Factory production means rational and efficient manufacturing processes, skilled workers, repetition of actions, quality surveillance, etc. Competition and social environment are forcing the industry to continuously strive for improvement of efficiency and working conditions through development and innovation of products, systems and processes. Automation is gradually being implemented. Examples exist already in the domain of preparation of the reinforcement, assembly of moulds, concrete casting, surface finishing of architectural concrete and so on. Other operations will follow.

Figure 5. Continuous and automated production of prestressed concrete floor slabs by Bison Concrete Products, UK. The slab is made in a continuous length of 180 m, and later cut to length according to project requirements.

Optimum Use of Materials

Prefabrication has much greater potential for economy, structural performance and durability than cast insitu construction because of the higher potential and optimal use of materials. This is obtained through modern manufacturing equipment and carefully studied working procedures. Precasting works use computer controlled batching and mixing equipment. Additives and admixtures are used in the mix design to obtain the specific mechanical performances, needed for each product. Casting and compaction of the concrete is performed in indoors working conditions, with optimum equipment. The water content can be reduced to a minimum, and compaction and curing are done in controlled circumstances. The result is that the grade of concrete used can be exactly suited to the requirements of each type of component in order to expedite the use of more expensive and exhaustible materials. In addition, the mix efficiency is better than cast in situ concrete.

Figure 6. High strength concrete with a compressive strength of 250 N/mm^2 used by Alborg Cement in Denmark to construct this precast concrete spiral staircase. c. Alborg Cement.

High performance concrete, with cylinder strength f_{ck} 100 N/mm^2(cube 115 N/mm^2) is well known in prefabrication and most factories are using it daily. The major benefit for building structures concerns the improved structural efficiency enabling more slender products and optimum use of materials. Another positive property is the improved durability against frost and chemicals. The best advantages are achieved for vertical components, especially load bearing columns. Figure 7 shows that, for certain column and rebar sizes, the squash load capacity increases by factors of 1.8 to 2.1 when the concrete strength goes from 30 to 90 N/mm^2.

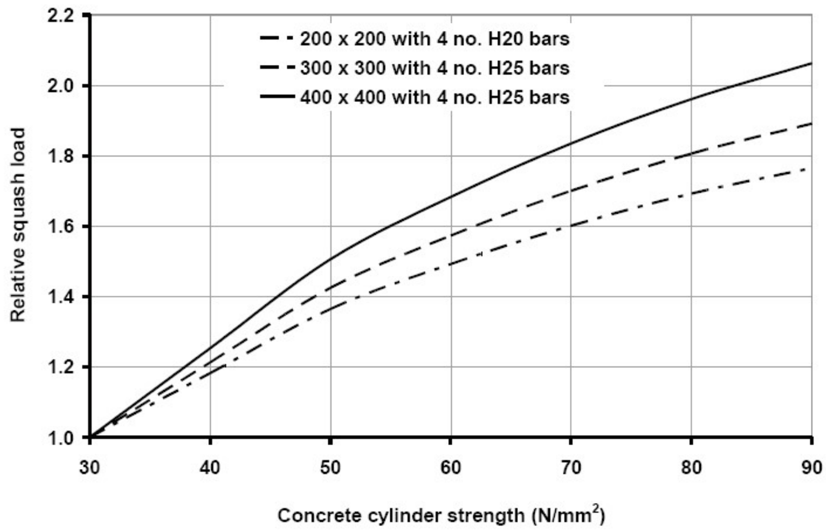

Figure 7. Relative load bearing capacity of columns in relation to concrete strength according to EC2 using high tensile bars grade 500.

Self Compacting Concrete (SCC)

A recently invented (1990) solution for precasting, used mainly since 2000, and more so in the past five years since rapid hardening SCC was developed. Whereas high strength concrete focuses mainly on strength and durability, SCC has also a serious beneficial impact on the production process. All the terrace units at Wembley Stadium, Figure 8, were manufactured using SCC with a labour force ¼ of the usual effort. SCC needs no vibration and thus opens a lot of advantages as low noise level during casting, less mould pressure, rapid casting, easy casting when using dense reinforcement or when having thin or complicated cross-sections, less air pores at the surface and easy to pump. The application of this new development in the precast concrete industry is rapidly growing and it is expected that in a few years from now, an important part of the daily production will be with this technique.

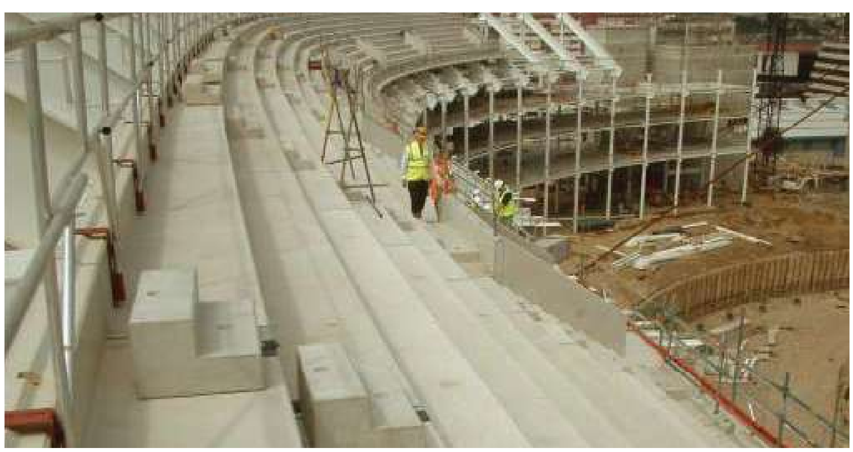

Figure 8. Precast terraces at Wembley Stadium using SCC, by Bison Concrete Products, 2007.

Prestressing

Pretensioning of steel tendons, either small diameter wires of 5 to 9 mm, or compound helical strands of 9.3 to 15.7 mm diameter with ultimate strength of 1570 to 1860 N/mm^2 compared to 500 N/mm^2 for rebars, is often applied in precasting, because of the possibility to use prestressing beds and tendons anchored by bond. The technique gives not only all the constructional advantages of prestressed concrete, but also economy at manufacture because of the low labour input, as shown in Figure 5, and the absence of expensive anchorage devices used in post-tensioning.

Shorter Construction Time

Precast concrete structures may be erected in less than two-thirds of conventional cast insitu construction time, particularly for tall buildings with a smaller plan area, say less than 300 m^2, where it is more difficult to increase the density of labour.

Because of the slowness of traditional insitu construction methods, long construction delays have been accepted. Today, the demand for a speedy return on investment is becoming more and more important: the decision to start the work is postponed until the last moment, but the initially agreed construction delay has to be met. In addition, projects are getting more complex, which is not in favour of construction delays.

Speed of construction is a major consideration in most building projects and it is here that the design of precast structures should be carefully considered. Designing for maximum repetition will make manufacture of the precast units easier and construction faster, but precast concrete can also be used in complex and irregular structures, although it may not then provide the same efficiency of construction as a rationalised design. The fixing rates shown in Table 1 are very approximate and vary depending on the shape and size of the structure, and are for typical site progress using a fixing gang of no more than 8 about 7 persons (3 skilled fixers and 4 labourers) and one crane driver, typical of the skeletal structure shown in Figures 3 and 4. No facade units are included.

Table 1. Typical site fixing rates (UK data)

		Construction rate m^2 per week*		
	Beam x floor span	**2-4 storey**	**5-8 storey**	**9-12 storey**
100% standard components on a rectangular grid.	100 m^2 75 m^2 50 m^2	1000-1500 850-1200 750-1000	900-1300 750-1000 600-800	650-900 450-700 350-550
75 % as above, 25 % non-standard on a non-rectangular grid.	100 m^2 50 m^2	900-1250 600-900	750-1000 500-700	No data
50 % as above, 50 % non-standard on a non-rectangular grid.	100 m^2 50 m^2	650-800 400-600	400-600 300-500	No data

* excludes cladding and cast insitu floor toppings.

Quality

The term quality has a broad meaning: the final aim being to supply products and services responding to the expectations of the customer. Quality control (QC) during manufacture is based on four poles: people; plant installations and equipment; raw materials and operating processes; and quality control of the execution. It is usually based on a system of self-control, with or without supervision by a third party. Factory QC consists of procedures, instructions, regular inspections, tests and the utilization of the results to control equipment, raw materials, other incoming materials, production process and products. The results of inspection are recorded and available to customers. Several precasting companies have obtained the ISO-9000 label.

Architectural Features Integrated into the Structure

The design of the building is not fixed by rigid concrete elements and almost every building can be adapted to the requirements of the builder or the architect. There is no contradiction between architectural elegance and variety on the one hand and increased efficiency on the other. The days are gone when industrialization meant large numbers of identical units; on the contrary, an efficient production process can be combined with skilled workmanship, which permits a modern architectural design without extra costs. For example, the polished concrete columns and spandrel beams shown in Figure 9 replaced separate grey columns and beams with over-cladding, saving 30% on the cross sectional area and 40% costs. Figure 10 is a fine example of using polished granite precast concrete columns, spandrel beams and perimeter walls, all developed by the architect, engineer and precaster working together to complete this shell shaped structure.

Figure 9. Polished precast concrete give a clean and white mock ”marble” effects at a pharmaceutical’s offices, Nottingham, UK. C. Trent Concrete Ltd., UK.

Figure 10. Precast concrete structural facade elements at Shell House in Melbourne, Australia.

Structural Efficiency

Precast concrete offers considerable scope for improving structural efficiency. Longer spans and shallower construction depths can be obtained by using prestressed concrete for beams and floors. For industrial and commercial halls, roof spans can be made up to 40 m and even more. For car parks, precast concrete enables occupier's greater parking densities because of the large span possibilities and more slender column sections. Figure 11 shows 400 mm deep prestressed concrete hollow core slabs giving two parking lots and the driveway in an uninterrupted span of 16 m. In office buildings, the trend is to construct large open spaces, to be filled in with partitions, with typical spans of 9 to 12 m. It offers not only flexibility in the building but extends its lifetime, because of the easier adaptability. In this way, the building retains its commercial value over a longer period.

Figure 11. Prestressed concrete hollow core slabs spanning 16 m are 400 mm deep, and weigh just 5.2 kN/m^2, 50% of a solid slab of the same depth.

Fire Resistance

Precast building structures in reinforced and prestressed concrete are inherently fire resistant to 1 to 2 hours, and potentially up to 4 hours with special additions to the soffit. The fire resistance is based on new guidance in the 2011 edition of the European Product Standard BS EN 1168 (British Standards Institute, 2010). Prestressed concrete hollow core slabs have a special geometry, due to the open cores and the variation of prestress in the webs that requires analysis and full scale fire testing. The slabs have been analysed and tested by Van Acker, 2010. Figure 12 shows images from fire tests carried out on 3 bays of hollow core slabs (Bailey, C. G., 2008 and Brown, N. E, 2007)

Figure 12. Left, three 6.0 m wide bays of 7.0 m span hollow core slabs are on top of the blockwork walls during the 3 hour test which reached 1050°C. Right, afterwards the integrity of the floor was assured. C. Precast Flooring Federation, UK in 2007 (Brown, N. E, 2007)

SUITABILITY OF PRECAST CONSTRUCTION

Most buildings are suitable for construction in precast concrete. Buildings with an orthogonal plan are of course ideal for precasting, because they exhibit a degree of regularity and repetition in their structural grid, spans, member size etc.

However, when designing a building, one should strive for standardization and repetition in the context of economical construction, not only in precast concrete alone, but also in any other construction system. Irregular ground layouts are on many occasions equally suitable for precasting, if not totally, then certainly partially. It is a completely false understanding that precast concrete has no flexibility. Modern precast concrete buildings can be designed safely and economically, with a variety of plans (Figure 13) and with considerable variation in the treatment of the elevations, to heights up to 20 to 40 floors as shown in Figure 14.

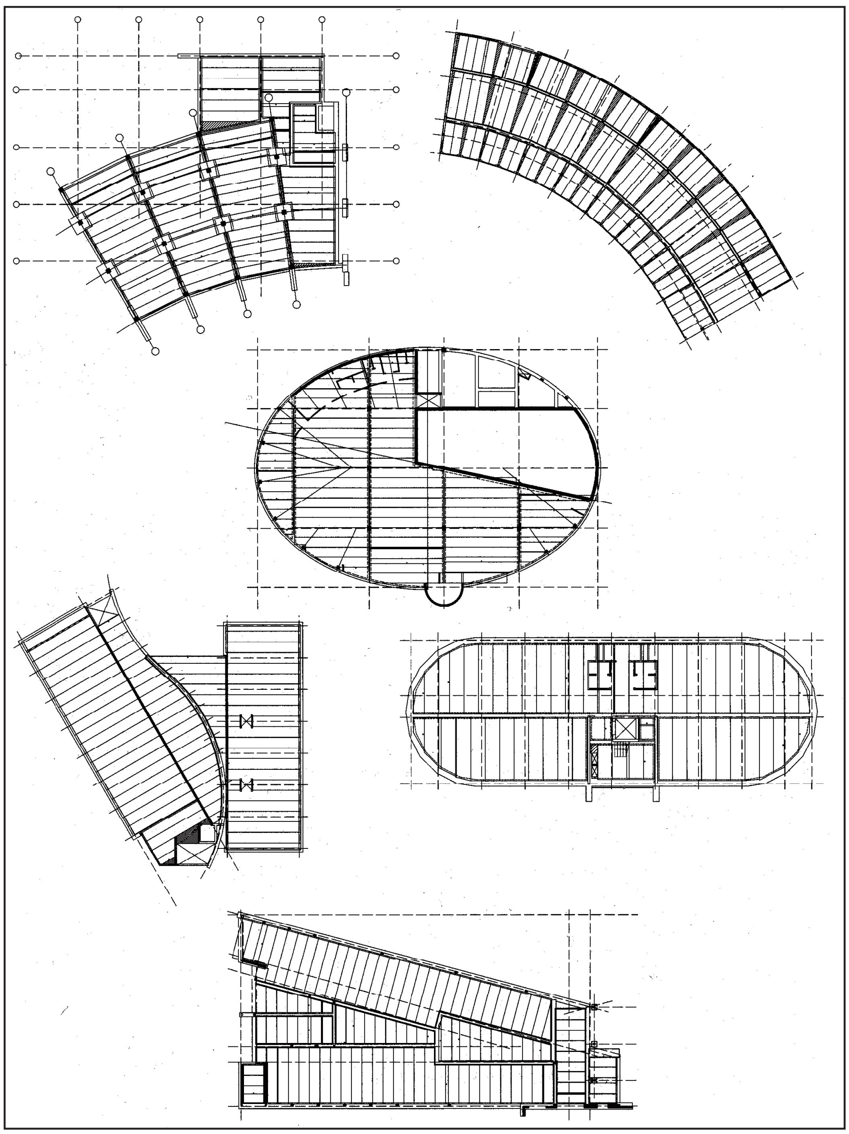

Figure 13. Irregular ground layouts are also suitable for precast concrete construction.

Figure 14. Oval and ellipse shaped precast concrete skeletal frames. C. Consoli, Belgium, 2008.

BASIC DESIGN PRINCIPLES

Designers should consider the possibilities, restrictions, and advantages of precast concrete; including the detailing, manufacture, transport and erection and serviceability stages before completing a design in precast concrete. Good organisation of the project team and design routines is very important. It is recommended that precast concrete organisations should make available design and production information to the client, architect, consulting engineer, services engineers and all other disciplines to give unified guidance to the entire design team. This will ensure that all parties are aware of the particular methods adopted in all phases of the project, leading to maximum efficiency and benefit. This is particularly true with the manufacturing and erection stages, as many consulting engineers may not be familiar with all of the methods used.

It is also very important to realise that the best design for a precast concrete structure is arrived at if the structure is conceived as a precast structure from the very outset and is not merely adapted from the traditional cast insitu method. The major beneficial advantages of a precast concrete solution will be met when at the conceptual design stage the following four points are considered.

Respect the Specific Design Philosophy

One of the most important objectives is to explain the specific design philosophy of precast structures, since it is the key to efficient and economical construction. The basic guidelines to be followed are:

- Use own stabilizing systems
- Use large spans
- Provide for structural integrity

Use standard solutions

Standardisation is an important economic factor in prefabrication. It enables repetition and experience, and hence lower costs, better quality and reliability, and faster execution. Standardisation is applicable in the following areas:

- Modular design
- Standard products
- Internal standards for detailing and working procedures

A good design in precast concrete should use details that are as simple as possible. Details that are too elaborate or vulnerable should be avoided.

Take account of dimensional tolerances

Precast concrete products inevitably present differences between the specified dimensions and the actual ones. These deviations must be recognized and allowed for in the design from the very outset, for example:

- Possibility to absorb tolerances in the connections (both between precast units mutually, and between precast elements and cast insitu parts, Figure 15 for example).
- Need for bearing pads.
- Consequences from upward camber (due to eccentric prestress) and differences in it.
- Allowance for movement, due to shrinkage, thermal expansion, etc.

Figure 15. The contrasting quality of precast concrete staircases and landings, of ten cast together (left), and cast insitu staircases (right)

Take advantage of the industrialised process

Precast concrete production should be based on industrialisation. This is partly influenced by the design, and may include:

- Prestressing long-line production, up to 150 m long x 1.2 m wide in just 3 hours.
- Standardisation of components and details enables standardisation of the process, Figure 16 for example.
- Adequate positioning of details, e.g. waiting bars etc., decreases labour time.
- Simplicity of documents helps to avoid mistakes.
- Last minute modifications trouble the production planning, induce mistakes.

Figure 16. Industrialisation and repetition for student accommodation, Simmons Hall, MIT, USA. c. ELITE Journal.

STANDARDISATION

Standardisation of products and processes is widely spread in prefabrication. Precast manufacturers have standardised their components by adopting a range of preferred cross-sections for each type of component. Standardisation is generally limited to details, cross-sectional dimensions and geometry, but seldom to the length of the units. Standard products are cast in existing moulds. The designer can select the length, dimensions and load bearing capacity within certain limits. This information can be found in catalogues from the precast element producers. Wall elements have usually standard thicknesses but the height and width is free within certain limits. Openings for windows and doors are normally free. Facades are always designed individually for each project. Cladding panels for utility buildings are sometimes available in standard dimensions.

Precasters are also producing non-standard elements. In addition to the already mentioned facade elements in architectural concrete, the precast industry produces also other purpose-designed elements, for example stairs and landings, balconies, special shaped elements, etc.

Standardisation constitutes an important economic factor in prefabrication, because of the lower costs for moulds, industrialisation of the production process with high productivity, large experience in execution, etc. Standardisation has also a beneficial impact on the series of identical elements, resulting in a serious reduction of the labour input per produced unit. Also for non-standard products, series are playing an important role on the production cost.

Precasters have developed design routines and organisation manuals that are helping the design staff to elaborate the projects. Standardisation of systems, products, connections etc., does not only mean industrialization of the component production, but repeated handling means also avoiding errors and bad experiences.

Figure 17. Standardised hollow core slabs in widths of 1200 mm generally (also 400, 600, 2400) and depths from 150 to 500 mm in 50 mm increments.

Figure 18. Standardised double-tee (or TT) slabs in widths of 2400 mm generally and depths from 300 to 1200 mm in 50 or 100 mm increments, depending on manufacturer.

Figure 19. Standardisation of beams is typically on a 50 mm module, but is less restrictive, as timber or steel moulds can easily be adjusted.

Figure 20 . Standardisation of columns is also based on a 50 mm increment, but for the same reasons can be varied.

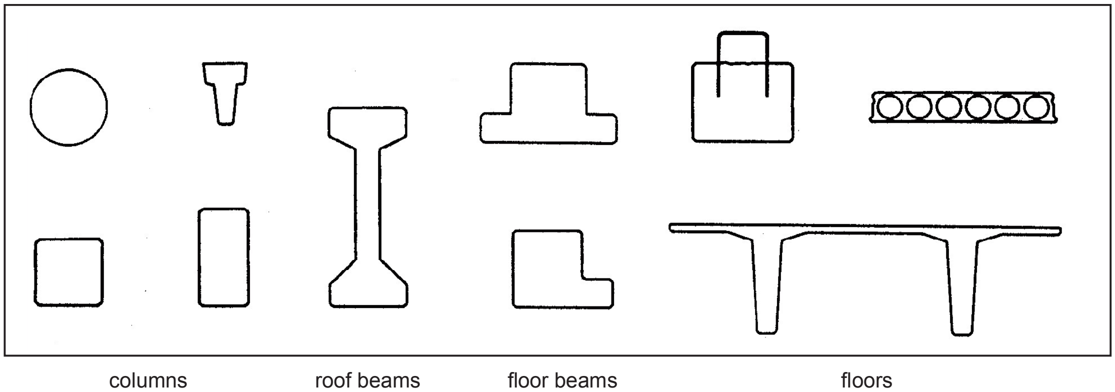

Figure 21. Other examples of standard cross-sections.

RECYCLED PRECAST CONCRETE

Each year most medium to large size precast manufacturers produce about 1000 m^3 (2400 tons) of waste material, particularly in hollow core production where there is always some wastage at the ends of the production lines, and defect slabs, for example in Figure 22 cannot be used on site. The policy is to crush the concrete, by first extracting the reinforcement, which is sold off to waste metal merchants, and to use the crushed material as a replacement for coarse aggregate because its size is between 10 and 20 mm. (Figure 23.) Recycled fine aggregate is to fine, i.e. silty, and makes water demand very difficult to control, particularly in hollow core mixes which have a low water/cement ratio. The shape of the crushed material, known as recycled concrete aggregate (RCA) is often very angular, and of course carries with it a certain amount of cement paste, and has a different porosity to natural aggregates, often around 5%. The maximum recommended replacement is 20% RCA, and this has been shown to have no effect on the strength or workability of concrete, achieving 60 N/mm^2 with replacements as high as 50%. In countries such as Holland the government will actually pay you to recycle, or pay for the crushing operation!

It is also possible to recycle slurry water, and to filter the cement particles from the slurry using flocculating agents. Some precast concrete factories adopt a zero waste policy, in that everything is used.

Figure 22. Defective hollow core units are rejected for recycling.

Figure 23. (left) Recycling hollow core slabs as RCA, (right) stage 2 processing into sizes.

BUILDING SERVICES

Building services may partly be integrated into the precast units. For example ducts, boxes or chases for electrical fittings may be cast in the wall elements. Another example concerns internal rainwater pipes cast into columns or facade units. Large prefabricated conduits for ventilation and other pipes can be installed inside double ceilings, or along projecting spandrel facade units during the erection of the precast units.

There are certain advantages and also some specific problems. A major advantage is that the precast structure can be designed according to the specific needs of the building equipment. Elements can be provided with a variety of holes, fixings can be cast in the units, and a lot of additional means are available on site after erection of the precast building.

The major difference with cast insitu concrete lies in the fact that everything which has to be cast into the units has to be planned at an earlier stage. Both the architect and services engineer must be ready to define their requirements in time for the precaster to prepare his drawings. Henceforth, the final study of the building services has to be made earlier than usually, but this could be seen equally well as an advantage.

Precasting offers also certain advantages with respect to building techniques. For example, thermal mass of concrete has been used satisfactorily to store thermal energy in hollow core floors, leading to substantial savings on cooling costs, Figure 24. The cores in floor elements are utilized to circulate the air for ventilation before it enters the room. The excess energy coming from machines, electrical light, sunshine and occupants is stored during daytime and recovered during the night. The system enables energy savings of 30%. The hollow cores may also be used to incorporate ducts and pipes in the floors, registered as ePipe floor in Figure 25, and is popular in some countries in Northern Europe.

Figure 24. Hollow core units with internal labyrinth to circulate the air for ventilation, registered as c. "TermoDeckR"

Figure 25. Hollow core units with ducts for pipes and conduits in the top flanges of the section makes "Pipe floor"

CONCLUSIONS

This paper has given an overview of the potential benefits in using precast concrete for a wide range of applications, and has stressed the need to fully exploit industrialisation and standardisation within the solutions. It has shown the key to success is to adopt an off-site construction methodology from the outset, and not to try to modify traditional solutions.

The structural efficiency of prestressed concrete, particularly for long span hollow core slabs and shallow depth beams, has been shown. Special materials, such as high strength and self compacting concrete, and the integration of building services, are shown to have special significance in precast construction. Precast concrete structures need not be limited to rectangular shoe-box designs, and offer clients and architects many options for modern construction.

REFERENCES

Bailey, C. G. and Lennon, T., (2008) Full Scale Fire Tests on Hollow Core Floors, *The Structural Engineer,* London, 18 March 2008, p33-39.

British Standards Institute, (2005) BS EN 1168+A3, 2011, Precast concrete products - Hollow core slabs, BSI, London, 2005.

Brown, N. E., (2007). Full scale fire tests show the benefit of using precast hollowcore flooring, http://www.precastfloors.info/news/press-precastfloors.html. [access in August 2012]

Elliott, K. S., (2002) Precast Concrete Structures, Butterworth-Heineman, Oxford, April 2002, 380pp.

Elliott, K. S., (2013) Multi-Storey Precast Concrete Framed Structures, Blackwell Scientific Press, Oxford, May 1996, 624 pp. 2nd edition to be published in 2013.

Federation Internationale du Beton, (2008) Bulletin 43, Structural Connections for Precast Concrete Buildings, Guide to Good Practice, fib, Lausanne, Switzerland, February 2008, 370 pp.

Federation Internationale du Beton, (2008) Bulletin 43, Structural Connections for Precast Concrete Buildings, Guide to Good Practice, fib, Lausanne, Switzerland, February 2008, 370 pp.

Federation Internationale du Beton,(2013) Planning and Design Handbook on Precast Building Structures, future bulletin in 2013. www.fib@epfl.ch

Van Acker, A.,(2006) Brussels North Skyline Now Dominated by Precast Tower Buildings, Journal of . *Concrete Plant International,* Cologne, Germany, Issue 5, 2006, p174-182.

Van Acker, A., (2010) Fire Safety of Prestressed Hollow Core Floors, *Journal of Concrete Plant International,* Cologne, Germany, Vol 1, 2010, p182-196.

CONSTRUCTION QUALITY OF SCHOOL BUILDINGS USING THE INDUSTRIALISED BUILDING SYSTEM (IBS)

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Abstract
One of the major problems in the Malaysian construction industry is the shortage of skilled labour. Due to this shortage, many contractors have resorted to employing semi-skilled and unskilled labourers thus resulting in poor workmanship in construction. To overcome this and its related problems, the Malaysian Government through the Construction Industry Development Board (CIDB) presently encouraged the IBS method of construction by the industry. With this initiative in place, it is expected that the quality of construction in buildings will be further improved. The aim of this study is to assess the quality of selected school buildings in Malaysia constructed using the Industrialised Building System (IBS) method of construction and comparing it with the quality of buildings constructed using conventional construction methods. This study involves the physical inspection of buildings, an analysis of the defect lists obtained from the relevant authorities and a questionnaire survey circulated to end users to obtain a feedback on their perception on the quality of the completed buildings. The results of this study demonstrate that the quality of IBS-constructed buildings had substantially better quality as compared to those constructed by the conventional methods. The result of the study together with numerous other studies on the IBS construction method would encourage the Malaysian construction players to increase the use of IBS in future construction projects.

Keywords: *Quality, Industrialised Building System, Conventional Construction Method, School Buildings*

INTRODUCTION

One of the major problem faced by the Malaysian construction industry is the shortage of labour; precisely skilled labour (Megat Rus Kamarani *et.al*., 2002, Thanoon *et al*, 2003a, Abdul Kadir *et.al*., 2006, Hamid *et.al*., 2008, Memon *et.al.,* 2011). Presently, most of the labourers used within the construction industry in Malaysia are foreigners and their influx into the country has caused many social-related problems which the Government has to grapple with (Abdul Aziz, 2001, Abdul Hamid *et. al.* 2011a). Due to this shortage, many contractors have resorted to employing semi-skilled and unskilled labourers in construction projects and this has resulted in poor workmanship and quality of the completed works (Abdul Kadir *et.al*., 2005, Abdul Hamid *et. al.* 2011b, Hassan and Ismail, 2008).

The Industrialised Building System (IBS) in construction was first introduced in Malaysia around 1964 with the construction of a pilot project consist of 7 blocks of 17 stories housing flats at Jalan Perkeliling, Kuala Lumpur. (Thanoon *et.al*., 2003a). Despite the fact that the system has been employed for over fifty years, surprisingly it has not been very well accepted by the Malaysian construction players (Hassim, *et.al.,* 2009).The Malaysian Government through the Construction Industry Development Board (CIDB) has been promoting the IBS construction method through "The Construction Industry Industrialised Board IBS Roadmap 2003-2010". This is a systematic and coordinated blueprint aimed at achieving a higher standard of quality coupled with the adoption of new construction methods such as the Industrialised Building System (IBS) to push the construction industry to a higher level of quality and standards at par with that found in other advanced countries (CIDB, 2007). In 2011, a new IBS roadmap covering the period 2011-2015 was introduced and implemented to replace a previous one (CIDB, 2011). A key element in the latest roadmap is the focus given in emphasising private sector adoption of the IBS method of construction. To achieve the desired results, the CIDB has narrowed down its policy objectives to four main areas; which cover issues on quality, efficiency, competency and sustainability. The deployment of a sustainable IBS method of construction will hopefully contribute to the competitiveness of the construction industry in Malaysia.

The IBS method of construction is defined as a construction system where components are manufactured at factories on/or off site, transported and then assembled into a structure with minimum work (CIDB, 2011). The IBS can further be sub-categorised as the Frame System, Panelled System, Cast in-situ Formwork System, Hybrid System and the Modular System. Studies done on construction works in other advanced countries noted that this method of construction has generally improved the quality of buildings and has substantially reduced the number of workers required to execute the work (Lessing, 2005, Lau, 2007, Oostra & Joonson, 2007, Goodier and Gibb, 2007, Pan *et.al*., 2008).

Arditi and Gunayande, (1997) defined quality as meeting the legal, aesthetic and functional requirements of a project. In the construction industry, quality can be defined as meeting the requirements of the designer, contractor and regulatory bodies as well as the client. Workmanship is not the only factor in determining the quality of the finished products in construction. The use of space functions in a way that add to the quality of life for those who use them are also important elements to be considered in the pursuit of better quality in construction. Other factors such as the quality of design and space planning (Gann et. al, 2003a), economy of construction, operation and maintenance (Leaman and Bordass, 2001), safety and security and accessibility to the handicapped are additional elements that need to be considered in ensuring higher quality buildings that must be considered. The durability of the materials specified and used in the building construction is also important to produce quality buildings that have longer longevity with less maintenance cost (Majid *et.al.,* 2010).

Whilst the construction industry has been dealing with the conventional method of building construction for a good many years, this method has inherent weaknesses such as too many on-site activities which are both time consuming and labor intensive (Mohd Nawi *et.al.,* 2009). The introduction of the IBS method of construction should bring about improvement and much needed betterment of the construction industry. However since its introduction in Malaysia in the 1960s, the impact of IBS on the development of the construction industry and quality of the finished work as a whole left much to be desired (Abd Rahman & Omar, 2006, Kamar*at.el.,*2007).Many studies have been carried out on the IBS construction method in Malaysia such as awareness, usefulness, ease of use and hindrances to its implementation (Majid *et. al.,* 2010,Thanoon *et.al.,* 2003a, Thanoon 2003b, Kamar *et.al*., 2009), however further studies are needed to evaluated the level of improvement that IBS as a construction method has contributed, namely in three important elements of construction i.e. time or duration, cost and quality (Hamid *et. al*., 2008).

The focus of this study is on the quality of building construction using the IBS method of construction. The aim is to assess the quality of selected school buildings constructed using the IBS method by comparing with those built using conventional construction method. School buildings are selected as representative of building types as these are average in size and complexity. The aim of this paper is to present an objective comparison through specific methods in order to quantify the qualitative impact of the IBS construction method by using buildings of similar complexity.

METHODOLOGY

From the literature reviews conducted, the quality of buildings can be measured in 3 distinct phases throughout the building life cycles (Arditi and Gunaydin, 1997); namely the pre- construction stage i.e. during design and planning (Gann *et.al.,* 2003b, Abdul Rahman, 1996, Tan and Lu, 1995), during construction and upon certificate of practical completion (CIS7, 2006) and post occupancy (Bordass, 2001) where customers' satisfaction are measured (Kärnä,2004). Comparative studies between IBS (prefabrication) and conventional method of construction had been carried out by a few researchers (Abdul Kadir *et.al.,*2006, Chen *et.al*, 2010) to measure construction performance such as productivity, structural cost, crew size, cycle time, constructability and quality. However the data were collected through questionnaire surveys, thus representing a "measure of quality in perception" (Arditi and Gunaydin, 1997).In this study, an attempt is made to measure "quality in fact" of a building through the eyes of experience professionals by carrying out systematic inspection of a building instead of relying on a questionnaire survey which measures the perception of the respondents. It also attempt to utilise secondary data (the defects list) by the relevant authorities. Questionnaire surveys were also carried out to measure the end users perception on quality of the buildings being studied.

Location of Study Site

The schools that were selected in this study were based on the following criteria:

i. Building completed about the same time thus the "age" of the selected buildings is rather similar.
ii. The buildings are located in the same region i.e. Lembah Klang.
iii. The buildings were about similar size in terms of construction build-up.

These criteria are chosen so that an objective comparison can be made between the schools built using the IBS method of construction and those constructed using conventional methods.

The schools were chosen based on the list of completed and on-going school projects given by the desk officer in-charge of schools projects in the Public Works Department (PWD) headquarters. The Public Works Department is a government technical department which is responsible for the implementation of government projects including schools in which they act as the project management consultants. Although the usage of the IBS method of construction for schools has been implemented since 2008, only a few schools have since been built using this method. The projects that use the IBS method of construction are mainly additional blocks to existing schools. Consequently the earliest completed IBS method of construction for schools available as samples in the study location have only been delivered to the clients in less than a year and have been occupied in less than 6 months.

After a thorough study on the availability of the relevant samples, only two schools constructed using the IBS method and one school constructed using the conventional method of construction fulfilled the above criteria. However the built up area of the school using the conventional construction method is 1.5 times bigger than the selected IBS-constructed schools.

Data collection

Data were collected by several methods and are listed as follows:

A. Physical and visual inspection and assessment on the quality of the completed building. Check list was based on the Construction Industry Standard 7 (CIS7) document by CIDB (CIDB, 2006)

B. Quality perception surveys i.e. post-occupancy surveys targeted at end-users of the buildings

C. Defect lists (prepared by the project appointed consultants) obtained from the District Public Works Department who supervised the projects.

The IBS construction system used in the schools studied is a precast concrete frame system with standardised components (doors & windows) where the beams, columns, slabs and staircases are cast in the factory and the contractor installed the members on-site after completion of the foundation works. The walls were built using a conventional method i.e. brickworks finished with cement mortar plastering and later painting work.

Physical and Visual Inspection

CIDB has introduced a system where the workmanship quality of a building can be assessed by using the CIS7 method of evaluation. For this study, the inspection checklist was adopted from the Quality Checklist for Architectural Works and defect rating column was added to the checklist. Since the study was carried out after the buildings had been completed, the Quality Checklist for Structural Works was not used as this requires the inspection for structural works to be carried out during the construction period. However structural elements that are visible such as beams, columns, slabs and staircases were inspected. Since the school buildings did not use any air conditioning systems, a quality checklist for Mechanical and Electrical works was not carried out. The inspections were carried out on the new buildings, a floor-by-floor starting from ground floor till the top most floors. The defects and quality of the finishes on the building elements such as floor, beam, internal wall, ceiling, doors and windows, roof, gutter and rainwater down pipe, external wall, perimeter drain and apron, corridor and staircase were noted and a defect rating was given to these elements.

The defect rating given for building elements are shown in Table 1.

Table 1. Defect Ratings

Defect Rating	Terms	Explanation
1	Satisfactory	Elements contain almost no defect
2	Minor	Elements have some defects but defects are minor and not many
3	Medium	Elements have some defects but defects are not major and not many
4	Major	Elements have many defects and the defects are major
5	Severe	Elements have many defects and the defect are severe and need to be repaired soon

The inspection was led by the researcher who has more than 20 years of experience in building construction and was assisted by two building technicians who had more than 10 years' experience each which included inspection of buildings before the issuance of the Certificate of Practical Completion (CPC) in building projects. Experienced inspectors are important because they are able to assign more accurate defect ratings to the buildings. To ensure consistent ratings are given to the level of defect found in the buildings, the same technicians were employed throughout the study. Equipment such as electronic measuring device, spirit level, L shaped ruler and steel rod are used to check the verticality, level, height, length width and the solidness of the concrete structures. Photographs of the defects were taken and marked in the checklist.

Quality Perception Survey

A quality perception survey was carried out by the teachers who used the buildings understudied. The sampling was done based on a non-probability basis where the population does not have an equal chance of being selected. 22 of the questionnaires relate to buildings constructed using the conventional method whilst 19 relates to buildings using the IBS method of construction.

The questionnaires were prepared based on the literature review conducted and to meet the objectives of the study. It was divided into three sections namely demographic of the respondents, perception on the quality of the buildings and ranking of factors that determine the quality of a building. The quality factors investigated were aesthetic, detailing and finishing, functionality of building, comfort, defect, durability and safety and security. From the literature review conducted, in order to achieve quality in buildings would require an interactive approach to the design process over and above just aesthetics, detailing and finishing (Gobster and Chnoweth, 1989, Susilawati *et. al*., 203, Vilnai-Yavetz *et. al*., 2005, Rustom and Amer, 2006). A pilot survey was carried out to verify the relevance of the intended questionnaires in capturing the factors or aspects contributing to the research objectives and to ensure that the questionnaires were adequately understood and not misleading. The questionnaire was subsequently refined accordingly. The survey questionnaires were printed in both English and Bahasa Melayu.

Pilot Survey

The draft questionnaire was distributed to a few students and lecturers; a combination of those with and without knowledge and experience in construction. The feedback collected was carefully considered and later used to amend, refine and improve the questionnaire. The most common comments were that the questions on aesthetic, function and safety aspects of the building need to be simplified for better understanding of the end-users who are mostly without the technical and construction background.

Defect Lists

At the completion of a project and before the issuance of the Certificate of Practical Completion, a final inspection was carried out by the PWD as the project manager, contractor, consultants and client. The outcome of this inspection included all the defects in the newly completed building as listed by the consultants for the contractor to repair before the project was handed over to the client. In this study the defects lists of the building understudied were obtained from the District PWD that was responsible for the supervision of the projects.

DATA ANALYSIS

From the physical and visual inspection, a defect rating for each element was summarized for the whole building. The highest rating that represents the worst in quality for each element was then taken and summarised. This is to reflect the worst condition for the elements in the whole building. The same process was carried out for buildings under studied constructed using both the IBS and conventional method of construction.

For the quality perception survey, a 5-point Likert scale method was used to indicate the level of agreement to the statement about quality in buildings. The ratings for the level of agreement by the respondents are as follows:

1 = Very low degree of agreement
2 = low degree of agreement
3 = Neutral
4 = High degree of agreement
5 = Very high degree of agreement

The data were analysed using the Relative Indices (RI) technique adopted by Holt *et al*. (1995)

$$RI = \frac{\sum (5n_5 + 4n_4 + 3n_3 + 2n_2 + 1n_1)}{5(n_5 + n_4 + n_3 + n_2 + n_1)}$$

where RI is the relative index

and n_5, n_4, n_3, n_2, n_1 are the number of responding indices

The computation of the RI using this formula yields values ranging from 0.2 to 1. The RI range and what it represents are shown in Table 2.

Table2. Categories for Range of Relative Index

Categories	RI Range
Very low level of agreement	0.20 – 0.35
Low level of agreement	0.36 – 0.51
Neutral in agreement	0.52 – 0.67
High level in agreement	0.68 – 0.83
Very high level in agreement	0.84 – 1.00

The respondents were also asked to list quality factors in the order of importance and the data were described using descriptive statistic.

In addition, the number of defects from the defect list was manually counted. It was expected that the number of defects to be larger when dealing with bigger size of building. Since the size of the buildings in this study was not the same, the number of defects was divided by the total built up floor areas of building under studied respectively. This was to allow for a more objective comparison to be made between the buildings regardless of its size.

Finally qualitative and quantitative comparisons were made between the physical and visual inspection, quality perception survey and defect list for the buildings constructed using both the IBS and the conventional method of construction.

RESULTS AND DISCUSSION

Result of physical and visual inspection and assessment

Table 3 is the comparison of summaries of the Quality Checklist for Architectural Works for the schools understudied. From Table 3 it was found that the defect ratings for the school constructed using the conventional method of construction are predominately 4 which is classified as severe, while the buildings constructed using the IBS method of construction showed a rating of mostly 1s or 2s which falls under the classification of satisfactory and minor. This statement is almost true for every building element in the buildings understudied which indicated that the IBS-built schools have a better quality than schools constructed conventionally. This is further verified when analysing the defect photos taken during the buildings inspection. Some of the photographs are shown in Figures 1 to 4.

Table 3. The Comparison of Summaries of the Quality Checklist

BUILDING ELEMENT	Inspection Standard	Defect Rating	Defect Rating	Defect Rating
		IBS School A	**IBS School B**	**Conventional School C**
FLOOR	Finishing	2	2	4
	Alignment&Evenness	2	2	4
	Crack andDamage	3	2	4
	Hollowness/ Delamination	3	1	4
	Jointing	2	2	4
	Tiled floor	1	1	3
INTERNAL WALL	Finishing	1	2	3
	Cracks and Damage	1	1	4
	Hollowness/ Delamination	1	1	4
	Alignment&Evenness	1	1	4
	Tilled Finishes	1	1	4
	Painting	1	1	4
CEILING	Finishing	1	1	4
	Crack and damages	2	1	3
WINDOW	Joint and gap	1	2	4
	Material and damages	1	1	4
	Functionality	1	2	3
DOOR	Joint and gap	3	1	5
	Material and damages	1	1	4
	Functionality	1	1	3
ROOF	Pitched roof	1	1	4
GUTTER & RAIN WATER DOWNPIPES	Visible damage	1	1	3
EXTERNAL WALL	Finishing	1	1	4
	Crack and damage	2	2	4
	Roughness	2	1	4
	Painting	2	1	4
PERIMETER DRAINS & APRONS	Drain	2	2	3
	Apron	2	1	4
STAIRCASE	Tread & Riser	1	1	4

Notes: *Defect Rating : 1 - Satisfactory 2 - Minor, 3 - Medium, 4 - Severe , 5 -Very Severe*

Figure 1. Poor plastering finishes of wall and column (Conventional Method)

Figure 2. Inconsistent height of staircase riser (Conventional Method)

Figure 3. RWDP punch through pre-cast column and slab (IBS Method)

Figure 4. Consistent height of staircase riser (IBS Method)

Results of the Quality Perception Survey

Most respondents in this questionnaire surveys were teachers teaching in the buildings under studied. Their ages ranging between 35 to 43 years with an average working experience of more than ten years and an average of eight year tenure at their respective schools. These periods were considered as reasonable and adequate for them to give accurate and effective answers to the questions posed as they also have the experience of teaching in the old blocks in their respective schools. This is an important consideration so that they can feel the difference in the building quality between the old and the new blocks in their respective schools. In addition, between of 30% to 50% of the respondents are degree holders indicative of a high level of education amongst the respondents.

Table 4 shows the respondents' relative index to the questions posed about factors that contribute to quality in buildings. The results show that the respondents from school that were constructed using the IBS method of construction do not agree or disagree (neutral level of agreement) to all the questions regarding factors that contribute to the quality of a building except for defects in buildings. The relative index for all the factors that contribute to quality are 0.67 for aesthetic and functionality, 0.64 for comfort, 0.60 for durability, 0.58 for detailing and finishing and 0.56 for safety and security. The respondents, however, have a low level of agreement (0.44) on the defect factor which literally indicated to them that the buildings built by the IBS method of construction have fewer defects. For buildings constructed using the conventional construction method, comfort (0.71) and functionality of the buildings (0.68) have a relative index that indicated a high level in agreement. The rest of the factors that contributed to the quality of a building such as aesthetic, detailing and finishing, durability, safety and security and defect, the respondents registered a natural level of agreement. It is interesting to note that whilst respondents from schools constructed using the IBS method of construction were in a natural state of agreement pertaining to the five main factors that contributed to quality namely aesthetic, detailing and finishing, durability, safety and security; the RI recorded was a little higher as compared to values obtained from respondents addressing quality in buildings constructed conventionally.

Table 4. Respondents' Satisfactory Average Relative Index

Quality Factors	Relative Index (IBS respondents)	Quality Factors	Relative Index (Conventional respondents)
Aesthetic	0.67	Comfort	0.71
Functionality of building	0.67	Functionality of building	0.68
Comfort	0.64	Aesthetic	0.66
Durability	0.60	Durability	0.55
Detailing and finishing	0.58	Defect	0.55
Safety and security	0.56	Safety and security	0.55
Defect	0.44	Detailing and finishing	0.53

Ranking of Factors that Contributed to Quality

Apart from asking the respondents of their perception on quality of the under studied buildings which they use, question B8 asked them to rank from 1to 8, all eight factors that contributed to quality; with 1 being the most important and 8 the least important. Table 5shows the results for respondents from schools constructed using the IBS method and Table 6 are for schools constructed using the conventional methods. From Table 5 it was found that 71% of respondents from IBS-constructed schools had ranked safety and security as the top most factor, comfort (27%) second, functionality (35%) third, detailing (27%) fourth and fifth, functionality and innovation (20%) sixth, innovation (40%) seventh and 67% of the respondent has ranked aesthetic as the least important at number eight.

Table 5. Quality Factors Order of Importance to the Respondents (IBS method school)

Order of importance	1st	2nd	3rd	4th	5th	6th	7th	8th
Aesthetic (%)	0	0	12	7	7	7	13	67
Functionality (%)	0	13	35	20	7	20	0	0
Durability (%)	18	20	18	20	7	7	7	0
Innovation (%)	0	7	0	7	20	20	40	7
Detailing (%)	0	0	6	27	27	20	20	0
Comfort (%)	6	27	24	13	20	7	0	0
Form (%)	6	13	6	7	13	20	20	13
Safety/security (%)	71	20	0	0	0	0	0	13

Table 6 illustrated that the respondents from school constructed by the conventional method also ranked safety and security (82%) as the most important and aesthetic as the least important (72%). They had ranked durability in buildings (60%) second, comfort (71%) third, functionality (69%) fourth, form (44%) fifth, innovation and form (36%) sixth and detailing (57%) seventh.

Table 6. Quality Factors Order of Importance to the Respondents (Conventional method school)

Order of importance	1st	2nd	3rd	4th	5th	6th	7th	8th
Aesthetic (%)	0	0	0	0	0	21	0	72
Functionality (%)	0	7	0	69	25	0	0	0
Durability (%)	12	60	29	0	0	0	0	0
Innovation (%)	6	0	0	0	6	36	43	11
Detailing (%)	0	0	0	25	19	7	57	0
Comfort (%)	0	13	71	6	6	0	0	0
Form (%)	0	7	0	0	44	36	0	17
Safety/security (%)	82	13	0	0	0	0	0	0

It is interesting to note that the majority of the respondents regardless whether they are users of schools constructed using the IBS or conventional method of construction, are of the opinion that safety and security is the most important factor while aesthetic is perceived as the least important factor. Hence it can be concluded that the important factors to be considered in the design of buildings depend on the types of building and its intended usage. For schools, safety and security of the staff and students are paramount for the end-users as indicated from this study.

Defect lists

Table 7 shows the number of defects per 100 square meters of the respective schools. It was found that school buildings constructed using the conventional method of construction (School C) had the highest number of defects/100m^2 (6.2) as compared to buildings constructed using the IBS method (3.1 and 0.3). In fact the defect intensity of school buildings built using the IBS method are found to be less than half that for the conventionally built schools. In the case of School B (IBS method of construction), the defect intensity is lower than that for school buildings constructed using the conventional method by a factor of 20. Between the IBS-built schools, there was a big difference in defects between School A and School B. The unstructured interview with the supervisor of the projects revelled that that contactor for School B was a better contractor compared to that for School A and this was reflected in the less number of defects registered. Result from Table 7 clearly revealed the superiority of the IBS constructed schools over the conventionally built schools in terms of their defect intensity and quality. The data also verified and concurred with the findings obtained from the site inspection whereby the school buildings using the IBS construction method again proved that they were of much better quality compared to the conventionally built school buildings.

Table 7. No. of Defects per 100 Meter Square of Built up Area

Item	IBS method School A	IBS method School B	Conventional method School C
No of Defects	56	6	199
Built up area (m^2)	1791.1	2133.8	3205.8
No of Defects/100m^2	3.1	0.3	6.2

Physical and Visual Comparisons

From the physical and visual inspection and assessment it was found that the school buildings constructed using the IBS method showed a rating of mostly 1s or 2s which falls under the classification of satisfactory and minor while those constructed using the conventional method of construction are predominately 4 which is classified as severe. From the quality perception survey for most factors that contributed to quality, the IBS built buildings respondent's answers were in the neutral state of agreement (neither agree nor disagree) but when asked about the defects, they have a low level of agreement (0.44) which meant that the buildings built by the IBS construction method had less defects. From the defect lists, it is found that the defect intensity of the school buildings using the IBS construction method was less than half that of the conventionally built schools. From these comparisons it can be concluded that the school buildings using the IBS construction method displayed higher and better quality than those constructed conventionally.

CONCLUSIONS

To assess the quality of buildings constructed using the IBS method of construction, a comparative study was carried between school buildings constructed using this method and that constructed using the conventional methods of construction. Methods of assessment were done by physical and visual inspection and assessment, quality perception surveys by the occupants and comparison of the defects lists obtained from the authorities managing the projects.

Findings from visual inspection and assessment showed that school buildings constructed using the IBS method has a higher and better quality as displayed by the ratings adopted. The school buildings constructed using the IBS method showed a rating of mostly 1s or 2s which falls under the classification of satisfactory and minor while those constructed using the conventional method of construction are predominately 4 which is classified as severe.

From the quality perception surveys, respondents from school buildings constructed using the IBS method had a low level of agreement (0.44) when asked about defects indicative that school buildings built by the IBS method have less defects compared with schools constructed conventionally. Both groups of respondents from schools constructed using the IBS and conventional method are of the opinion that safety and security are most important whilst aesthetic was perceived as the least important factor.

From the defects lists, it was found that the defects intensity (number of defects/100m^2) of school buildings built by the IBS method of construction was less than half that of the conventionally built schools.

As a summary, it can be concluded that school buildings constructed using the IBS construction method showed far more superiority in quality when compared to those constructed using the conventional method of construction. This was also in line with the opinion of the teachers as end-users and technical personnel who were involved with the construction of the buildings. Besides the positive results in terms of higher quality obtained from the IBS method of construction, this method offers a faster rate of construction for building contractors. This is in agreement with the findings of other studies on construction in developed countries.

Limitation of Study

In this study due to the factors mentioned in location of study site, only 3 schools were studied and out of those three only one was conventional. Thus generalisation of the results just based on one case is less accurate. The quality of buildings varied due to the variation in the workmanship. The studies were performed on buildings constructed by different contractors who were employing different specialist sub-contractors and hence produced inconsistent standard of workmanship.

Recommendation for Further Research

In this study only a small element of quality was considered. For future research it is highly recommended that a bigger scope to cover all aspects of quality involved in the process of producing quality IBS building need to be strongly considered. The process shall include among others the planning and design, manufacturing of IBS components, transportation, installation, testing and commissioning and other related factors.

Selection of samples is very important. As more and more buildings are using IBS, selection of suitable samples and number of samples could be improved. Sample is the source of data and information which must be of highest accuracy in order to produce good and accurate results for the analysis.

REFERENCES

Arditi, D. and Gunaydin H. M., (1997), Total Quality Management In The Construction Process *International Journal of Project Management* Vol. 15, No. 4, pp. 235-243.

Abdul-Aziz, A.R., (2001), ForeignWorkers and LabourSegmentation inMalaysia's Construction Industry,*Construction Management and Economics* 19, pp 789–798.

Abdul Hamid, A.R., Singh, B., Wan Yusof. WZ ., Md Yusof, A. and Mustafa,N., (2011a),Problems Faced By Contractors in Managing Foreign Workers On Construction Sites, *2nd International Conference on Construction and Project Management IPEDR vol.15 © IACSIT Press, Singapore*.

Abdul Hamid, A. R., Singh B., Wan Yusof.,W.Z., Md Yusof, A. and Mustafa,N., (2011b),The Employment of Foreign Workers at Construction Sites,*2nd International Conference on Construction and Project Management* IPEDR vol.15 © IACSIT Press, Singapore.

Abdul Kadir M.R., Lee W.P., Jaafar M.S., Sapuan S.M. and Ali A.A.A., (2005) Factors Affecting Construction Labour Productivity For Malaysian Residential Projects*Structural Survey* Vol. 23 No. 1, pp. 42-54.

Abdul Kadir, M.R., Lee W.P., Jaafar, M.S., Sapuan, S.M. and Ali, A.A.A., (2006),Construction Performance Comparison between Conventional and IndustrialisedBuilding Systems in Malaysia*Structural Survey* Vol. 24 No. 5, pp. 412-424.

Abd. Rahman, A.B., Omar,W., (2006), Issues And Challenges In The Implementation of Industrialised Building Systems In Malaysia,*Proceedings of the 6th Asia-Pacific Structural Engineering and Construction Conference* (APSEC 2006), 5 – 6 September 2006, Kuala Lumpur, Malaysia.

Abdul Rahman,H., (1996),Some Observations on The Management of Quality Among Construction Professionals in the UK,*Construction Management and Economics*14, pp. 485- 495.

Chen ,Y., Okudan,G.E.,Riley,D.R., (2010),SustainablePerformance Criteria for Construction Method Selectionin Concrete Buildings, *Automation in Construction* 19 pp. 235 – 224.

CIDB, (2007), IBS Roadmap 2003-2010, in: IBS Digest@malbex, Kuala Lumpur. .

CIDB, (2010), Construction Industry Master Plan (CIMP) 2006-2015, Kuala Lumpur.

Coffey, Vaughan,(2008), Measuring Quality: How Does This Improve Construction Performance?CIB *International Conference on Building Education and Research: Building Resilience*, 11th – 15th February 2008, Heritance, Kandalama, Sri Lanka.

CIDB: IBS Centre, (2011), Retrieved on 22nd March 2011, http://www.ibscentre.com.my/ibsweb/

Gann, D., Salter, A. and Whyte, J., (2003a), Design Quality Indicator as a Tool for Thinking,*The Built Environment, Building Research & Information*Vol 31 issue 5 pp 318-333.

Gann, D. and Whyte, J., (2003b), Design Quality, Its Measurement And Management, *The Built Environment, Building Research & Information*Vol 31 issue 5 pp 314-317.

Goodier, C. and Gibb, A., (2007), Future opportunities for offsite in the UK, *Construction Management and Economics*, 25 (6), pp. 585 — 595.

Gobster, P. H. and Chenoweth, R. E., (1989), "The Dimensions of Aesthetic Preference: a Quantitative Analysis", *Journal of Environmental Management*, 29, pp. 47-72.

Holt G.D, Dlmolaiye, P.D and Harris F.C., (1995), A Review of Contractor Selection Practice in the UK, *Journal Building and Environment* Vol. 30 pp. 553-561.

Hamid, Z.A., Kamar,K.A.M., Mohd Zain,M.Z., Ghani,M.K., Abdul Rahim A.H.(2008), Industrialised Building Systems (IBS) in Malaysia: The current state and R&D Initiatives, *Malaysian Construction Research Journal,* Vol. 2 (No. 1).

Hassan H, Ismail, E., (2008), CIDB**,** Navigating the IBS Blue Ocean: Formation of the IBS CentreICCBT2008- B - (02) – pp21-28.

Hassim,S., Jaafar,M.S.,Sazali,S.A.A.H., (2009),Contractor Perception Towards Industrilised Building System Risk in Construction Projects in Malaysia,*American Journal of Applied Sciences* 6(5) pp 937-942

Kamar, K. A. M., Alshawi, M. and Hamid, Z., (2009),Barriers To Industrialized Building System (IBS)The Case Of Malaysia, *Proceedings In BuHu 9th International Postgraduate Research Conference* (IPGRC) , Salford, United Kingdom, 29-30 January 2009.

Kamar, K. A. M., Hamid, Z.,Ghani M. K and Hazim.A,, (2007), Industrialised Building System: Current Shortcomings And The Vital Role Of R&D, *Master Builder* Second Quarter 2007, pp 62-65.

Kärnä,S.,(2004),Analysing Customer Satisfaction and Quality in Construction – The Case of Public and Private Customers,*Nordic Journal of Surveying and Real Estate Research* - Special Series Vol. 2.

Lau, J.M., (2000), The HDB Experience,*Proceedings of Prefab Technology for Quality Public Housing, Singapore*.

Leaman,A., and Bordass,B., (2001), Assessing Building Performance in Use 4:Tthe Probe Occupant Surveys and Their Implications,*Building Research Information*, V29, 2,pp 129-143.

Lessing,J., Stehn. L, and Ekholm,A.,(2005), Industrialised Housing: Definition and Categorization of The Concept, *Proceedings IGLC-13,* Sydney, Australia.

Megat RusKamarani,M.K.A., (2002), Reforming Malaysian ConstructionTechnology Towards Higher Dynamism, *Asian Forum 2002 For The Field Of Architecture And Building Construction.*

Memon, A.H., Abdul Rahman,I., Abdul Azis,A.A.,(2011), Preliminary Study on Causative Factors Leading to Construction Cost Over run, *International Journal of Sustainable Construction Engineering & Technology*,Vol 2, Issue 1.

Majid, T.A., Azman, M.N A., Zakaria, S.A.S., Zaini, S.S., Yahya, A.S., Ahamad, M.S.S., and Hanafi. M.H., (2010), The Industrialised Building System (IBS) Survey Report 2008,*Second International Conference on Computer Research and Developmen*t.

Abdullah, M.R., Kamar, K.A.M., Mohd Nawi M.N., Haron, A.T. and Arif, M., (2009), Industrial-ised Building System: A Definition and Concept, *Proceedings in ARCOM Conference 2009*, Nottingham, UK, 7-9 September, 2009.

Mohd Nawi, M.N., Kamar,K.A.M., Abdullah,M.R., Haron,A.T., Lee,A. and Arif,M.,(2009), Enhancement Of Constructability Concept: An Experience In Offsite Malay-sia Construction Industry, *Proceeding Changing Roles, New Roles: New Challenge Conference,*NoordwickAan Zee, Nederland.

Oostra, M.,and Joonson, C., (2007), Best practices: Lesson Learned on Building Concept (edited by) Kazi, A. S., Hannus, M., Boudjabeur, S., Malone, A. (2007), Open Building Manufacturing – Core Concept and Industrial Requirement', *Manubuild Consortium and VTT Finland Publication*, Finland.

Pan, W., Gibb, A. G. F. and Dainty, A. R. J., (2005), Offsite Modern Methods of Construction, *House Building Perspectives and Practices of Leading UK.*

Pan, W., Gibb, , F., A. G. and Dainty, A. R. J., (2008), Leading UK House builders' Utilisation of Offsite Construction Methods, *Building Research & Information*, 36 (1),pp 56 —67.

Rustom R.N and Amer, M.I., (2006), Modeling The Factors Affecting Quality In Building Construction Projects in Gaza Strip, *Journal of Construction Research,* V7, Issue 1-2, pp. 33-47.

Susilawati, C., Rahardjo, J. and Yudiyanty, Y., (2003), Measuring Building Quality of Shopping Centres in Surabaya by Analytical Hierarchy Process (AHP)*, Proceedings of The 9th Annual Conference Pacific Rim Real Estate Society*, 19 - 22 January 2003, Customs House, Brisbane, Queensland.

Tan R.R.and Lu Y. G.*,(1995),*The Quality Of Construction Engineering Design Projects:Criteria And Impacting Factors, *International Journal of Quality& Reliability Management,* Vol. 12 No. 5, pp. 18-37.

Thanoon W.A., Lee W. P, Abdul Kadir M.R., Jaafar, M.S. and Salit,M.S., (2003a), The Experiences Of Malaysia And Other Countries in Industrialised Building System*, International Conference Industrialised Building Systems,*Kuala Lumpur, Malaysia.

Thanoon W.A., Lee W. P, Abdul Kadir M.R., Jaafar, M.S. and Salit,M.S., (2003b) , The Essential Characteristics of Industrialised Building System, *International Conference Industrialised Building Systems,* Kuala Lumpur, Malaysia.

Vilnai-Yavetz, I., Rafaeli, A. & Schneider-Yaacov, C., (2005), Instrumentality, aesthetics and symbolism of Office Design**,** *Environment and Behavior***,** 37(4), pp. 533-551.

QLASSIC – CAN IT BE AN EFFECTIVE CONTINUAL QUALITY IMPROVEMENT TOOL FOR INDUSTRIALISED BUILDING SYSTEM (IBS) PROJECTS?

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Abstract

Quality has and will always be craved by the stakeholders in the construction industry. Construction projects that are able to be completed with distinctive quality will definitely enable to delight their customers. In this regard, quality is one of the areas that had been emphasized in the Construction Industry Master Plan (CIMP), 2006-2015. Notwithstanding this, there are several quality related programs that had been formulated by Construction Industry Development Board (CIDB) among these is the QLASSIC. The later is essentially a quality performance assessment standard for building construction works. As at end of the year 2011, almost 406 construction projects have been assessed by QLASSIC with an average QLASSIC Score of about 69.7 %. Since its inception in the year 2006, QLASSIC is mainly used as benchmarking tool. However after more than five years of its existence it is timely to review and improvise QLASSIC to the next level to become continual improvement tool for quality. The enormous data generated during the QLASSIC assessment has the potential to be analyzed to ascertain areas for improvement which eventually can lead towards continually improves the quality performance of the construction works. Hence it enables to assist contractors certified to ISO 9001:2008 to comply with the requirements on continual improvement. However not many studies have been undertaken in this area. Having said that this research is endeavour to review the current implementation of QLASSIC, identify any shortfalls for it to become continual improvement tool, explore the potential areas for improvement and subsequently proposes recommendation areas for improvement. Taking into consideration that IBS is steadily gaining its importance in the future thus this research is focusing on IBS projects.

Keywords: *Continual Improvement, Contractor, IBS, ISO 9001:2008, QLASSIC, Quality, Quality Performance*

INTRODUCTION

QLASSIC is an acronym for 'Quality Assessment System in Construction'. It was mooted by Construction Industry Development Board (CIDB) somewhere in late 90's which led to the introduction of QLASSIC Guideline. Eventually in the year 2006, the said document was upgraded to Construction Industry Standard (CIS) known as CIS 7:2006 'Quality Assessment System for Building Construction Works'. The main assessment structure of this standard is adapted from Construction Quality Assessment System (CONQUAS) practiced by Building and Construction Authority (BCA) in Singapore. There are several similarities in the categorizing the buildings as well as the distribution of the weightage on the building components between QLASSIC and CONQUAS. One of the deliverables of QLASSIC is the assessment report that can be potentially used to continually improve the quality performance in construction Quality Management System (QMS). Quality performance can be measured either qualitatively or quantitatively and QLASSIC adopts both of these approaches.

The internationally accepted quality management regime is ISO 9001 QMS. The current ISO QMS is ISO 9001:2008. This standard was introduced somewhere in 15th November 2010 to replace ISO version 2004. The latest ISO 9001 has no major changes on the standard requirements but elaborate further clarity on some elements. One has to remember that ISO 9001 is a generic and prescriptive standard. However it does not provide the tool to implement it. Thus the organization needs to develop or select any available management tools in the market that fit their purpose. One of the key areas being emphasis in ISO 9001 Quality Management System (QMS) is performance measurement towards continual improvement (Mukhtar *et al*, 2010a). The later is stated under several clauses for instance clause 4.1, clause 5.1, clause 6.1, clause 8.1 and clause 8.5.1 under ISO 9001:2008 requirements. In order to execute continual improvement the organization requires to perform data analysis as stated under clause 8.4. This clause relates to performance measurement. According to Tsai, 1998 performance measurements can be financial or non financial. In the context of construction industry, QLASSIC can be considered as one of the performance assessment tools to continually improve the construction quality performance especially for projects adopting Industrialised Building System (IBS). The later was introduced by CIDB somewhere in 1999 through its IBS Strategic Plan. The strive towards IBS is expected to address several crucial issues that plagued the construction realm i.e. low productivity, labour intensive, shoddy workmanship, poor quality of finished works, projects delay etc. The desired outcomes for implementing IBS in Malaysia can be broadly summarized as follows: to achieve quality, faster completion time and fewer site workers (CIDB, 2007). The chain of events on IBS by CIDB is shown in **Figure 1.**

Having said the above which leads to several research questions as follows:

- Can QLASSIC be a continual improvement tool for IBS QMS?
- If the answer is yes, then this research will develop the framework on how to implement it.
- If the answer is no, then this research will explore the possibility of improvising QLASSIC to become the continual improvement tool.

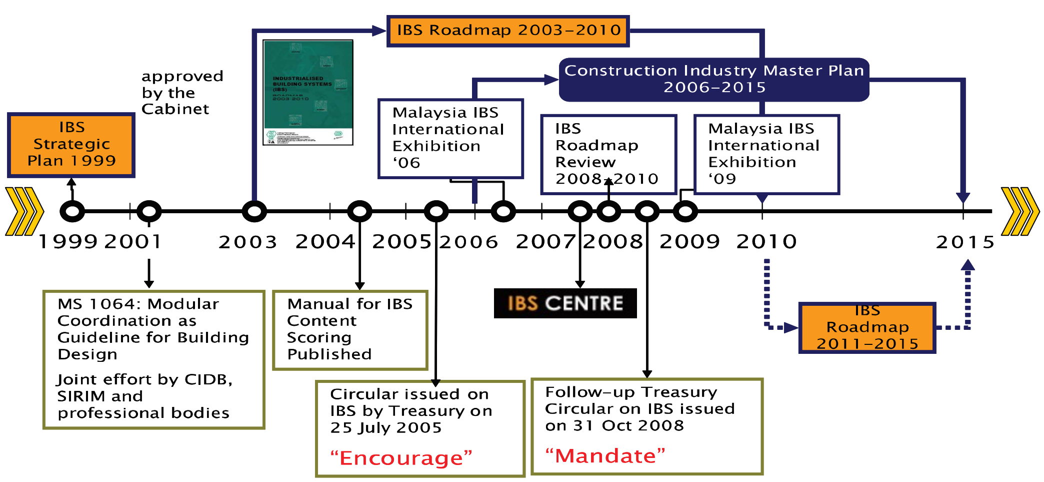


Figure 1. IBS Milestones in Malaysia from 1999 to 2015 (Adopted from Elias, 2011)

LITERATURE REVIEW

In 1993 Standard and Industrial Research Institute of Malaysia (SIRIM) has introduced the MS ISO 9000, a quality standard system recognized throughout the world, to the Malaysian construction industry (Wan and Norizan, 1996; Mokhtar 1996). Implementing of ISO QMS in IBS construction has direct impact in delivering quality deliverables in construction projects. This is because QMS emphasis greatly on proper planning, well organize in optimizing resources, effectively monitor and control the performance as well as endeavour for continual improvement which ultimately would delight the customer (Mukhtar, 2010a). Quality management provides the culture and climate essential for innovation and construction innovation advancement (Djebarni and Eltigani, 1996). By establishing proper QMS the contractor is expected to manage systematically the scope, time, cost and resources in meeting the project objectives. Consequently it enable to address some of the major contemporary issues prevailed in construction industry i.e. work defect, cost overrun and delay of construction project. Commonly the parameters used by the ISO 9001 certified contractors to indicate their quality performance are number of client's complaints, scoring from customer's feedback forms, wastage of materials, number of defects works, failure in inspection, failure in testing results etc (Chen, 2007). Apart from these metrics, data generated from the QLASSIC also can be used to measure the quality performance in construction projects.

IBS is defined as a construction technique in which components are manufactured in a controlled environment (on or offsite), transported, positioned and assembled into a structure with minimal additional site work (Hamid *et al.*, 2008; CIDB, 2007; CIDB, 2005 and CIDB, 2003). It consists of precast component systems, fabricated steel structures, innovative mould systems, modular block systems and prefabricated timber structures as construction components (CIDB, 2003). Parts of the building that are repetitive but difficult – and too time consuming and labour intensive to be casted onsite – are designed and detailed as standardised components at the factory and are then brought to the site to be assembled (CIDB,2003). The onsite casting activities in IBS utilise innovative and clean mould technologies The construction industry has started to embrace IBS as a method of attaining better construction quality and productivity, reducing risks related to occupational safety and health, alleviating issues for skilled workers and dependency on manual foreign labour, and achieving the ultimate goal of reducing the overall cost of construction. Apart from this, it offers minimal wastage, fewer site materials. The experiences in some developed countries such as Japan, Germany and the United Kingdom indicate that there is a great potential for IBS to progress, as shown by their market share (Peng *et al.* 2003).

Overview Relationship of Quality Assessment System in Construction (QLASSIC) and Quality Management System in Construction (QMS)

QLASSIC (CIDB, 2006) was designed and developed to enable the user to achieve any of the following objectives:

- To benchmark the level of quality of the construction industry in Malaysia
- To have a standard quality assessment system for quality of workmanship of building projects
- To assess quality of workmanship of a building project based on the approved standards
- To evaluate the performance of contractors based on quality of workmanship
- To compile data for statistical analysis

Basically QLASSIC is an independent method to assess and evaluate the quality of workmanship of building projects based on CIS 7: 2000 standard. The later is intended to complement the normal contractual drawings and specifications in the project. It is not intended to be used independently as working specifications. It is still the responsibility of the qualified person to ensure that the quality of the construction works conforms to the approved standards, practices, specifications and drawings.

Generally, the Quality Assessment System for Building Construction Work covers four main components as follows:

- Structural Works
- Architectural Works
- Mechanical and Electrical Works (M&E)
- External Works

Each of these components is assigned a weightage which differ from one category to another, as shown in Table 2.2. Among these building components, noticed that the architectural work is being allocated comparatively with a high weight age. Since the architectural work is being allocated comparatively high weightage therefore QLASSIC score broadly signifies the quality of the finished construction works. Generally these weightage are allocated according to the distribution between the cost proportions of the four components in the various categories of building and also preferential is given to aesthetic consideration.

Table 1. Allocation of weightage for components of the building construction work according to building category

Component	Category A Landed Housing	Category B Stratified Housing	Category C Public Building	Category D Special Public Building
Structural work (%)	25	30	30	30
Architectural work (%)	60	50	45	35
M&E work (%)	5	10	15	25
External work (%)	10	10	10	10
Total score (%)	100	100	100	100

(Source: CIS 7:2006)

Assessments on the workmanship are carried out based on this standard and marks are awarded if the workmanship complies with quality requirements stipulated in the standard. These marks under each building component are then summed up to give a total quality score in term of percentage known as QLASSIC Score for the building project. However, the assessment excludes works such as piling, a foundation and sub-structure works which are heavily equipment-based and normally called under separate contracts or subcontracts.

As mentioned earlier that one of the pertinent elements in QMS is quality performance. Since QLASSIC is considered as a measurement tool therefore it can be integrated into QMS. Even though the application of QLASSIC at this moment is on voluntary basis however contractors are encouraged to adopt it in their QMS. Firstly QLASSIC score can be used as quality objective to reflect the overall quality performance of a given construction project. Secondly the scoring point attained can be used to benchmark project performance of similar project scope internally and externally (i.e. among competitors). Thirdly the trend analysis on QLASSIC scoring marks can be used to reflect the effectiveness of the developed QMS. Fourthly by performing descriptive analysis on the elements under each component of building category can assist the contractor to prioritise the areas that need to be improved. Hence the introduction of QLASSIC is expected to address several of the predominant quality issues that prevailed in the construction realm (Mukhtar, 2010b).

Advantages of Implementing Quality Management System (QMS) in Construction

Generally the implementation of QMS in construction projects is to integrate the resources effectively towards improving the quality performance of construction works. This concurs with Abdul-Rahman, 1997 that quality management is a critical component to the successful management of construction projects. The common features of construction projects usually have a prescribed scope, schedule and budget to produce quality 'product' (Aoieong, 2004). The four common characteristics as outlined by Ritz (1994) for a given construction project are as follows:

- Each project is unique and not repetitious.
- A project works against schedules and budgets to produce a specific result.
- The construction team cuts across many organizational and functional lines that involve virtually every department in the company.
- Projects come in various shapes, sizes and complexities.

With the emergence globalisation economy, the local contractors need to compete with foreign contractors for market share. In this scenario contractors with effective QMS may have the advantage to survive. As a result a well established QMS enable the contractors to improve the management capacity and capability to produce a desirable quality product or service, is becoming the most important decision in business nowadays (Mat Naim, 2004). The tools and methods used to manage QMS have emerged from those based on statistical techniques, quality circles, quality standards to those broadly categorized under the label of total control/management (Lee *et. al.,* 1999).

Based on literature review many researchers have reported the advantages in implementing QMS in construction companies. (Djebarni and Eltigani, 1996; Low *et al*, 1999; Hareton *et al*, 1999; Abdulaziz and Tawfiq, 1999; Low and Henson 1997; Tat *et al*, 1999). Based on these reports, Mat Naim (2004) had summarised the list of advantages as follows:

- communication would be improved
- reduce rework
- time and money would be saved
- increase work performance and
- increase market share

Based on a survey in Hong Kong (Lee, 1998), the benefits derived by the ISO certified firms are achieving better team spirit, having fewer staff conflicts, reducing wastage, increasing efficiency, improving sales through new customers and getting less customer complaints.

Taking into account the result of the survey conducted locally by Chen, 2007 discovered that among the significant areas of improvement at project level by Malaysian contractors after having certified to ISO QMS are listed below:

- Improve storage and traceability of project quality records
- More organized and systematic submission of VOs
- More organized of inspection
- Improve overall site management
- Improve testing and commissioning activities
- Facilitate the preparation of handing over project
- Improve control of construction drawings on site

In view of the above explanation denoted QMS incorporated practices that can generally influence the performance of the organization. Lakhal *et. al (*2006) discovered that there is a positive relationship between the quality management practices and organizational performance.

Issues and Challengers in Implementation of IBS

A survey conducted by CIDB in Malaysia stated that in 2003 the level of usage of IBS in the local construction industry stood at 15% (CIDB, 2003). Kamar, 2011 had compiled challenges and barriers to successful IBS adoption in Malaysia are:

- The industry is already familiar with the conventional system and, for them, the technology suits them well and therefore they are not willing to switch to a mechanised system and IBS (Kamar *et al*. 2009 and Hamid *et al*.2008).

- Lack of experience, lack of technical knowledge and lack of skilled labour are very important barriers to successful IBS adoption. There have been cases where buildings were awarded and constructed using the IBS system but it contributed to project delays and bad quality (CIDB, 2010; Kamar *et al.* 2009 and Rahman and Omar, 2006).

- It is admitted presently that switching to IBS would not guarantee significant cost savings, especially with the small volume of buildings constructed. Currently, there is no guidance in terms of finance and cost control method in IBS projects (Rahman and Omar, 2006).

- Further, there is a lack of proper project management techniques, specifically for IBS, and there is no specific cost control mechanism adopted by contractors in IBS (Hussein, 2007). Therefore, the risk of trying an unfamiliar technology is too high compared to the current profit margin in construction (Hussein, 2007).

- At present, common practice shows that manufacture of IBS components is involved only after the tender stage of the value chain. This lack of integration among relevant players in the design stage has resulted in a need for redesign and additional costs to be incurred if

IBS is adopted (Hussein, 2007 and Hamid *et al.* 2008). There is a desperate need of a new approach of procurement using strategic partnering in the construction delivery system.

- Lack of support and understanding from construction professionals due to a lack of professionals trained in the IBS. This in turn is perhaps due to uncoordinated and incomprehensible training awareness and syllabus (Thanoon *et al.* 2003 and Rahman and Omar, 2006).

The barriers to total industrialisation in construction are more or less the same in Malaysia and across the globe. Changes in the IBS method will have an influence on the design, manufacture and site work as a result of an increased use of prefabricated structural elements. Therefore changes in the overall process are required. There is a consensus of opinion that IBS is best handled as a holistic process and requires a total synchronization of construction, manufacturing and design (Hamid *et al.* 2008). Factors such as project management, rationalization, standardisation, repetition, collaboration, Information Technology (IT), lean management, integration, supply chain partnering, planning, skills and training would be essential (Pan *et al.* 2008; Pan *et al*. 2006 and Goodier and Gibb, 2007).

Benefits of IBS Implementation

IBS does have apparent advantages that drive the industry players to consider and adopt them in their project. IBS offers numerous benefits to the adopters which ultimately lead to a cost advantage. Figure 2 , compiled from CIB recent research (CIB, 2010), clearly reveals streamlining potential for better work preparation, logistics optimization and continuous improvements which have a major impact on the cost structure of a project. For example, the cost saving that could be achieved by optimizing construction logistics is more than 20% of the total labour costs. It also has potential to optimize construction supervision by up to 19% by moving the works away from the construction site to the manufacturing floor.

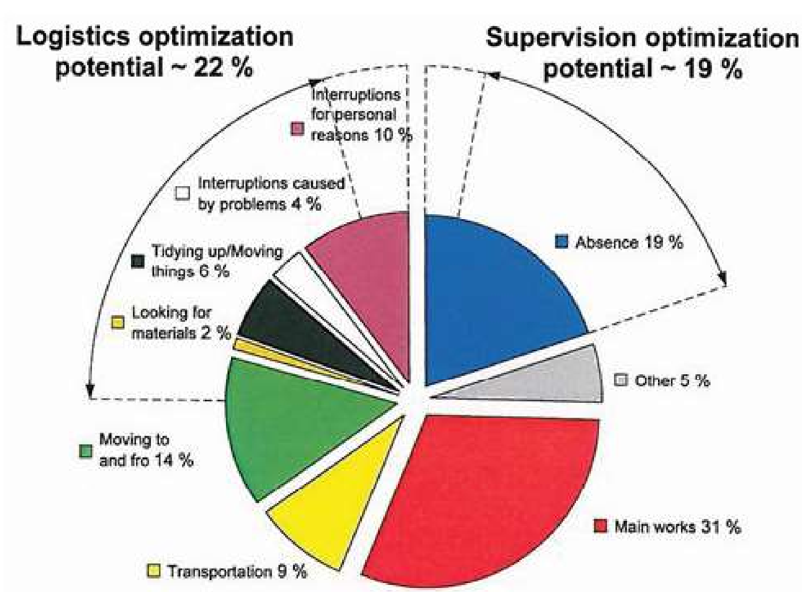


Figure 2. Potential cost reduction of industrialised construction (CIB, 2010)

Other advantages of adopting the IBS method as compiled by Kamar (2011) are:

a) Reduced build time - one of the obvious drivers to use IBS is a reduction of construction build time. IBS projects have proven to be quicker to complete compared to conventional construction projects due to the usage of standardised components and a simplified construction process (Pan *et al.* 2008; Blissmas, 2007; Pan *et al.* 2007 and Trikha and Ali, 2004). It has proven to be faster to build since on-site and manufacturing activities are usually undertaken in parallel (Trikha and Ali, 2004). It cuts down the duration of work and simplifies the processes by reducing onsite activities and the number of trades (Blismas and Wakefield, 2008; Blismas, 2007 and Mann, 2006).

b) Labor reduction - IBS offers significant savings in labour and material costs, as the number of labour forces required in IBS is far lower than those required in traditional methods (Na and Liska, 2008; Marsono *et al.* 2006 and Badir *et al.* 2002). In many cases, the usage of IBS has proven that it will reduce substantially the amount of unskilled and skilled laborers directly involved on site. This has been proven in Israel where a study was carried out to compare IBS with conventional construction methods in1984. The results showed that the use of IBS has brought savings in site labor up to 70% and savings in total construction costs of 5-8% compared to conventional methods (Warszawski, 1999). Similarly, in Singapore, the use of a fully prefabricated system provides labour savings of up to 46.5%as compared to the conventional method (Chung, 2006). The usage of IBS will open up many opportunities to the younger generations who seem reluctant to be involved in the construction industry. It is necessary, however, to emphasise that there are relatively far fewer workers that still need the training and skills appropriate to IBS (Trikha and Ali, 2004). It is expected that such trained skilled workers in IBS would be much more quality-conscious than the unskilled labourers doing manual jobs in conventional construction (Trikha and Ali, 2004).

c) Solving skills shortages - IBS alleviates the issue of skills shortages in construction since all the construction elements are fabricated at factory. IBS eliminates extensive use of carpentry work, bricklaying, bar bending and manual jobs at site (Na and Liska, 2008; Hamid *et al.* 2007; Hashimi,2006; BRE, 2002; Pan *et al.* 2005 and Haas and Fangerlund, 2002).

d) Fewer disturbances to the community - fewer tradesmen visiting construction sites in IBS projects has reduced local disturbances (Blissmas *et al.* 2007 and BRE, 2002). This benefit is critical for hospital, school and hotel refurbishment projects, particularly in the city centre area (Blissmas *et al.* 2007).

e) Improvements in construction quality - IBS offer improvements in quality, productivity and efficiency from the use of factory-made products, thus reducing the possibilities of poor workmanship and lack of quality control. The quality of the final IBS products is normally far superior to conventional work as the former is produced under rigorously controlled conditions (Gibb and Isack, 2003; BURA, 2005; BRE, 2002; Trikha and Ali, 2004 and Haas and Fangerlund, 2002). Complex shapes and finishes can be inspected and any substandard component rejected before it gets erected into the structure. As observed, IBS also provides high-quality surface finishes where the joints section is the only part to be grouted, eliminating the requirement for plastering (CIDB, 2010).

f) Clean site conditions and reduced health and safety risk - IBS construction sites have proven to look very tidy and organized compared to the wet and dirty conventional method sites. Wastage of temporary works such as timber formworks and props, which are normal in conventional construction, are not there when one applies IBS. Thus it reduces the risk related to health and safety by promoting safer working conditions (Chung, 2006; BURA, 2005 and Pasquire and Connolly, 2002).

g) Increase construction build rate - in the house-building sector, IBS improves the build rate of housing schemes dramatically by increasing the number of houses completed over a period of time. This will help developers to meet demands in housing and contribute to the government's aim to provide a sufficient supply of affordable housing (Pan *et al.* 2006; BURA, 2005 and Badir *et al.* 2002).

h) Waste reduction - IBS also proved that wastage can be reduced greatly due to prefabrication of most of the building components. The system offers the potential to minimize the environmental impact of construction activities in many ways. Prefabrication in a factory environment enables waste reduction through process orientation which entails controlled production and standardized processes. IBS also promotes economic and environment sustainability as component moulds could be used repeatedly for different projects, allowing economy of scale and reduction in cost (CIDB, 2010; Kamar *et al.* 2009 and Thanoon, 2003).

i) Potential cost financial advantage - IBS in some ways could be a cheaper method of construction compared to conventional method. The saving could come from a lower number of workers. IBS can also be cheaper ifone considers the whole life costing of the building (Kamar *et al.* 2009).There are direct cost savings in materials and construction overheads, while indirect cost saving occurs due to faster delivery of building (Trikha and Ali, 2004). This particular advantage is beneficial for the construction of small shops and offices, as demonstrated in the construction of McDonald's outlets in the UK (Ogden, 2007). Furthermore, construction of prefabricated elements in IBS results in a considerable reduction in the use of scaffolding, shuttering and other temporary supports as compared to onsite construction (Trikha and Ali, 2004).

PROBLEM STATEMENT

In relation to the government green agenda, sustainability in construction has become a buzz word. Sustainability is not merely about safeguarding the environment instead it is also encompassed elements on social, economy, safety and quality. The craved for quality has and will always be the prime concerned of the project stakeholders in the construction industry (CIDB, 2009). Quality is an integral element in construction from its inception to completion (Alcock, 1994). Construction projects that are able to be completed with an exceptional quality will definitely able to delight their customers. Quality on construction projects, as well as project success, can be regarded as the fulfilment of expectations (i.e. the satisfaction) of those participants involved (Sanvido *et al*., Barrett, 2000). Moreover quality can be translated into durability in structural strength, efficiency in functionality in particular M & E equipments and less maintainability on the construction output. In lieu of this, quality is one of the areas that have been stressed in the formulated Construction Industry Master Plan (CIMP), 2006-2015. The referred blueprint has outlined seven Strategic Thrusts (ST), which enable to nurture, transform and elevate the construction industry to a higher level. Strategic recommendations pertaining to quality is spelled out under ST 3, which states that 'Strives for the highest standard of quality, safety and health, and environment practices'. Apparently that had warrant CIDB to develop several programs that deemed to propagate quality in the construction landscape. Among these programs, QLASSIC, CIDB ISO 9001 Do It Yourself (DIY) Scheme and IBS are the three programs that can provide significant impact on the quality in construction. It is interesting to study the potentiality of integrating several elements under these three programs. If the elements under these three programs can be integrated then that will catalyze the industry players in implementing these three programs. The related research issue is that can the elements under these three programs be integrated? This is the broad area of research that this proponent is going to explore.

The implementation of QLASSIC which used the document CIS 7:2006 was introduced by CIDB in year 2006, now has reached slightly more than 5 years. Being the standard itself, it is a good practice to review CIS 7:2006 for every 5 years. Standard which is a dynamic document should be reviewed periodically in order to align with changes of technology or the emergence of new technology. Ironically CIS7:2006 which had been existence for more than 5 years has never been reviewed. Hence it is due for revision to CIS 7:2006. According to Mukhtar, 2012 that it is very timely to review QLASSIC to sustain its relevancy, improves its credibility as well as its integrity. By improving the later QLASSIC can garner higher respect from the industry which could lead to increase in the number of applications for QLASSIC. Therefore one of these research proponents is to investigate the potential areas of improvement in QLASSIC. In this regards the output deliverables of this research seemingly can enhance the credibility of this standard and increase the level of acceptance of QLASSIC among the construction players. As at end 2011, about 406 construction projects (as shown in Figure 3) had been assessed using QLASSIC with an average QLASSIC Score of about 69.7 %.

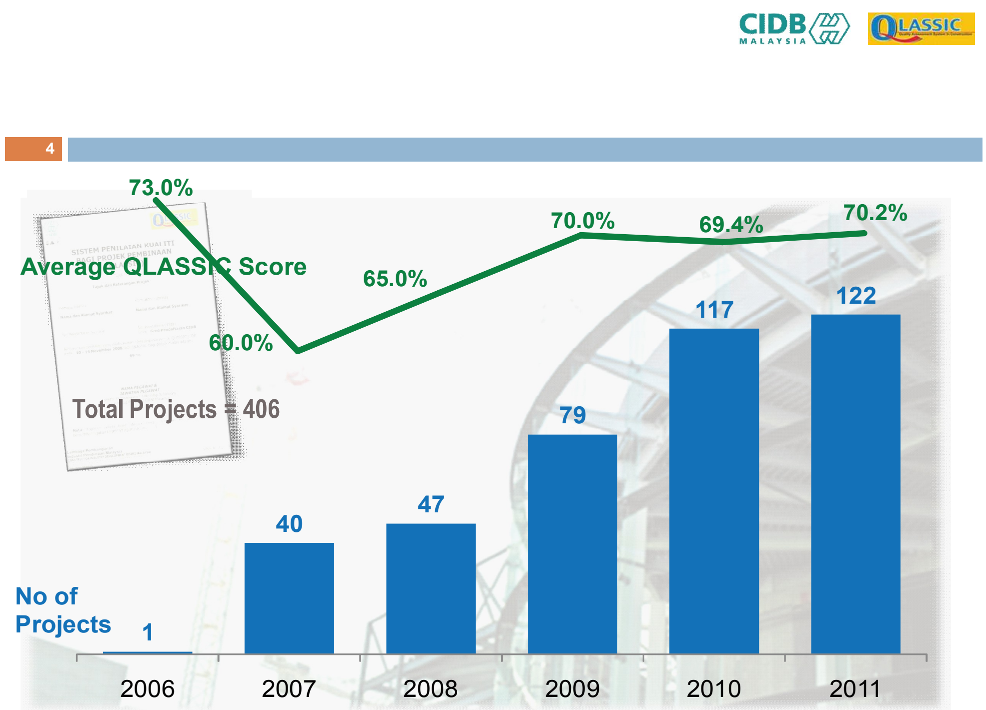


Figure 3. QLASSIC Score from the year 2006 till year 2011 (Adopted from Mukhtar, 2012)

One of the important deliverables in QLASSIC is QLASSIC Score. Currently QLASSIC Score is mainly used as a benchmarking tool. QLASSIC assessment generated substantial amount of project performance data. These data can be analyzed to ascertain the areas for improvement. Hence there is a potential for QLASSIC to be upgraded to become continual improvement tool. However not many studies have been undertaken to elevate QLASSIC Score to become effective continual improvement tool. Since this study is to review the CIS 7:2006, it is worth to extend the scope of this study in exploring to improvise QLASSIC to become continual improvement tool. Nevertheless there are several shortfalls for QLASSIC to become continual improvement tool. Firstly the presence approach of QLASSIC assessment is on sampling. This means that not all the buildings will be assessed during the assessment period. Therefore the result on the assessment depends on the quality of samples taken during assessment. Secondly not all building components are inspected because the inspections are on identified sample locations. Therefore this study is going to address the existence shortfalls found in QLASSIC and proposed corresponding recommendations in order to exert QLASSIC to the next level of becoming continual improvement tool.

Taking into consideration of time and financial constraints, this research is focusing on ISO 9001:2008 certified contractors that undertake IBS projects. The later was given the preference because the researcher has foresees the positive potential on using IBS in the future. This is due to some current measures that have been undertaken by CIDB. Firstly is the regulation on IBS has been incorporated in the newly amended CIDB Act, 2011 which was gazetted in September 2011 (CIDB, 2012). It is spelled out under Section 4(1) (m) which states that *to regulate the implementation of Industrialised Building System in the construction industry*. Secondly was the extension of the first IBS roadmap to the second roadmap known IBS Roadmap from year 2011 till to year 2015. This means that CIDB will continue to actively promote and facilitate the industry in using IBS. Hence that will drive for a higher usage of IBS in the construction industry. Where else on the issue of limiting to ISO 9001:2008 contractors because they have to demonstrate objectively their effort in continually improving their quality performance as required under clause 8.1, clause 8.4 and clause 8.5.1 of ISO 9001:2008 requirements. Otherwise they may be exposed to the issuance of Non-Compliance Report (NCR) by the external ISO auditors from the appointed certification body (CB) during auditing. Eventually this research is endeavour to improve QLASSIC to be an assessment system that can serve to assist ISO 9001:2008 contractor to consistently evaluate their quality performance towards continually improving their ability to propagate quality in IBS projects. Moreover this research is in line with the statement issued by our Prime Minister as reported in NST dated 6th February 2007 'It should become our practice that once we notice something is not right with a project, we act immediately to overcome the problem and prevent the project from being a flop. Follow-up and inspection are important but follow-up actions must always be there. He further added 'Actually, what is needed is effective distribution of work flow. *There must be improvement in the way we do things so that we can finish our jobs, fast and efficiently'*

RESEARCH OBJECTIVES

The aim of this research is to improvise QLASSIC by developing continual improvement model that can be adopted by ISO 9001 certified contractors to assist them to measure the quality of their project performance. The objectives of this research are as follows:

i. To review and identify the areas of improvement on the technical requirements in CIS 7:2006 and its implementation
ii. To examine the current QLASSIC assessment report in ascertaining areas of improvement to meet the provisions related to continual improvement under ISO 9001:2008
iii. To compare and recommend the relevant changes in the technical requirements in CIS 7:2006 with other of similar quality assessment standards locally and abroad
iv. To investigate the current shortfalls and determine the relevant clauses ISO 9001:2008 requirements that can be associated with QLASSIC pertaining to continual improvement
v. To observe the level of knowledge and practices by the construction management personnel in ISO 9001:2008 certified contractors in performing continual improvement.
vi. To develop the quality performance assessment (Q-PASS) model that potentially can serve as a continual improvement tool in IBS QMS.

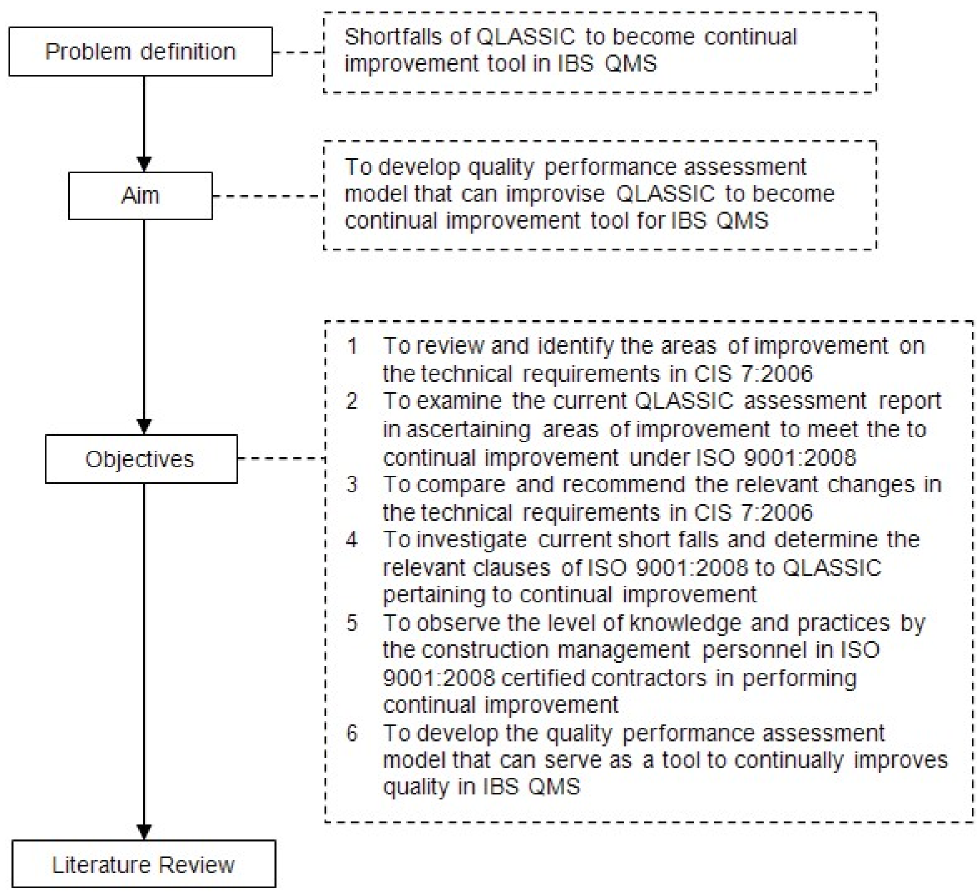
SCOPE OF STUDY

The scope of this study shall be confined to the following:

i. The main focus of this research is to improvise QLASSIC to become continual improvement tool by developing quality performance assessment model.
ii. This study shall confine to building construction works using IBS method of construction.
iii. The collection of data limited to IBS contractors that are certified to ISO 9001:2008
iv. The collections of data will be randomly made on active ISO 9001:2008 certified contractors that are registered with CIDB as IBS contractor.
v. The respondents may adopt a lackadaisical approach in completing the questionnaire forms.
vi. The discussion on common terminologies related to quality system will be limited to quality, quality performance and quality management system.

RESEARCH METHODOLOGY

In order to achieve the objectives of this study, a research process as shown in the flowchart below:



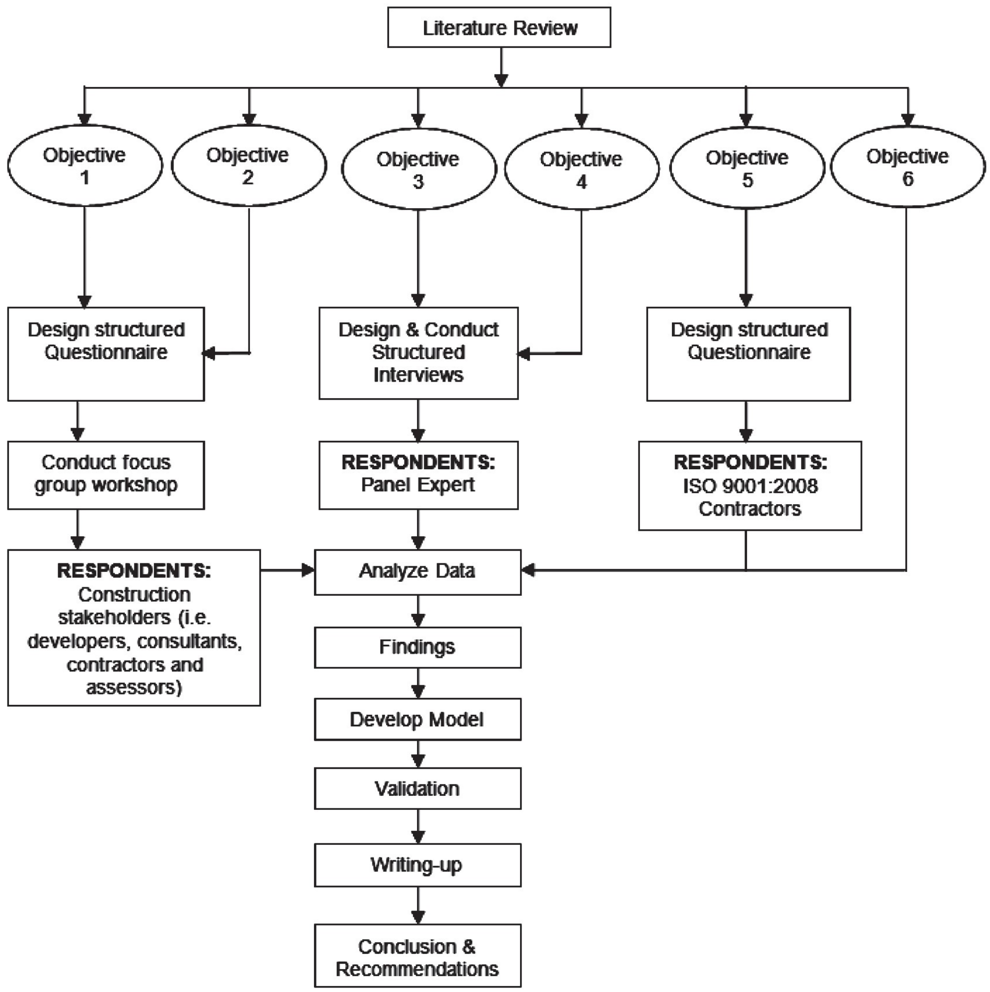


Figure 4. Research Process

The research will be started by identifying the broad research area which interest the researcher and that have the potential application to the construction industry. Once the problem is well defined then following the formulation of the theoretical framework for the research has to be executed. It entails in identifying the aim and the objectives of the research, research questionnaire, interview questions, research significance, research methodology etc. An extensive literature review will be performed at the initial stage. Reference will be made in data system and websites to gather articles, journals, periodicals, books, reports, standards etc. The collection of primary data was done by using a structured questionnaire. The questionnaire for this research consisted of a few different types of questions, namely open and closed questions. The large part of this questionnaire consisted of closed questions, where the respondents were asked a question and required to answer by choosing between a limited numbers of answers. All data collected will be analyzed using SPSS software. Subsequently the generated result will enable the author to develop the proposed quality performance assessment model that can be adopted by our local contractors as one of their measurement tool to measure their quality performance of IBS projects.

CONCLUSION

Since the inception of QLASSIC in the year 2006, it has never been reviewed. Hence after more than five years of its existence it is very timely to review QLASSIC to address technical and operational issues. This research adopted the stakeholders engagement in reviewing QLASSIC, therefore it enable to contribute to two areas of improvement. Obviously one of the significant contributions of this research is improving the technical specification of CIS 7:2006 meeting the contemporary needs of the industry. Another contribution is identifying the potential areas for improvement on implementation of QLASSIC that can be considered by CIDB. The proposed areas for operational improvement can enhance the overall efficiency of services on QLASSIC rendered by CIDB. Hence it will be able to increase the satisfactory level of the industry in using QLASSIC which could lead to higher application from the industry. That scenario will provide an avenue to broaden the data base for CIDB to analyze on the trends on quality performance in the construction industry.

Not to mention another significant contribution is elevating QLASSIC to the next level in becoming continual improvement tool that could facilitate ISO certified contractors to comply with clause 8.4 and clause 8.5.1 under ISO 9001:2008 requirements. Generally it can enhance the effectiveness of the established QMS. An effective QMS, quality related problems can be eliminated and prevented early stages prior to nonconforming occurrences (Battikha, 2002a,b) Indeed the proposed quality performance model can be a useful guide for ISO certified contractors to practice continual improvement using QLASSIC data. Therefore by continually improving the quality performance will enable to alleviate on issues of poor quality that has plagued the construction industry. Furthermore it can improve on the productivity and the image of the construction industry. Apart from that continually improving in quality also can assist in strengthening the project cost effectiveness. Eventually this can attribute to upgrade the level of competitiveness of our local contractors especially those that are certified to ISO 9001:2008.

REFERENCES

Abdul-Rahman, H. (1997), "Some observations on the issues of quality cost in construction", International Journal of Quality & Reliability Management, Vol. 14 No. 5, pp. 464-81

Alcock, T.D. (1994), "Application of ISO 9000 to the Construction Sector", Master Builders Association, 2nd Quarter, Malaysia

Aoieong R.T. (2004), "Capturing quality costs of construction process using the Construction Process Cost Model (CPCM)", PhD thesis, The Hong Kong Polytechnic University

Barrett, P. (2000), "Systems and relationships for construction quality", International Journal of Quality & Reliability Management, Vol. 17 No. 4/5, pp. 377-92

Battikha, M.G. (2002a), "QUALICON: computer-based system for construction quality management", Journal of Construction Engineering and Management, Vol. 128, No. 2, pp 164-173

Battikha, M.G. (2002b), "Problem patterns for infrastructure construction quality management", Proceedings of the 7th Conference on Application of Advanced Technology in Transportation, ASCE, Cambridge, MA, pp 545-552

Blismas, N. and Wakefield, R. (2008), " Offsite Manufacture in Australia - Barriers and Opportunities", In *Third International Conference of the Cooperative Research Centre*

(CRC) for Construction Innovation, Sydney, Australia, 12-14 March 2008

Blismas, N. (2007), "Off-site manufacture in Australia: Current state and future directions" Cooperative Research Centre for Construction Innovation, Brisbane, Australia, pp. 1-37

Chen G.H., (2007) "Quality performance of ISO 9001:2000 certified contractors", Msc Thesis, Universiti Teknologi Malaysia

CIB (2010), "Industrialised Construction: state of the art report", TG 57 Publication, International Council for Research and Innovation in Buildings and Construction

CIDB (2003), "Industrialised Building System (IBS) Roadmap 2003-2010", Construction Industry Development Board (CIDB), Kuala Lumpur

CIDB (2005), "IBS Survey 2005: Survey on Malaysian Architects". Kuala Lumpur, Construction Industry Development Board (CIDB)

CIDB (2006), Quality Assessment System For Building Construction Work, Construction Industry Standard, CIS 7: 2006

CIDB (2007), Construction Industry Master Plan 2006-2015

CIDB (2009), "Developing Quality Management System in Construction – A Guide Book for Contractor"

CIDB (2011), CIDB (Amendment) Act (Act A1407)

CIDB (2012), CIDB News, issue 01/June 2012

Djebarni R and Eltigani H (1996), "Achieving quality and productivity in the housing building sector", Property Management, Vol. 14, No. 1, pp 39-45

Elias Ismail, (2011), "IBS Roadmap 2011-2015 (Current and Future Trend)", Paper presented at International Seminar on IBS at CIDB Convention Center (CICC), Kuala Lumpur, 5th April 2011

Hamid, Z., Kamar, K. A .M. Zain, M.2., Ghani, M.K., and Rahim, A. H. A. (2008) "Industrialised Building System (IBS) in Malaysia: The Current State and R&D Initiatives", *Malaysian Construction Research Journal (MCRJ)*, Vol. 2 (1), pp 1-13

ISO (2008), "Quality Management System – Requirements", 4th edition

Kamar M.K, (2011)., "Critical success factors to industrialised building system (IBS) contractor", PhD thesis, University of Salford

Lakhal L., Pasin F. and Limam M. (2006), "Quality management practices and their impact on performance", International Journal of Quality & Reliability Management, Vol. 23, No. 6, pp. 625-646

Lee, T.Y. (1998) "The Development of ISO 9000 certification and the future of quality management – A survey of certified firms in Hong Kong", International Journal of Quality & Reliability Management, Vol. 15, No 2, pg. 48-60, pp 162-177

Lee T.Y., Leung H.K.N. and Chan K.C.C. (1999), "Case Studies – Improving quality management on the basis of ISO 9000", The TQM Magazine, Vol. 11, pp. 88-94

Mat Naim Abdullah@Mohd Asmoni, (2004) "An application model for effective implementation of quality management system in construction project", MEng Thesis, Universiti Teknologi Malaysia

Mukhtar C.A, Rosli M.Z., Zuhairi A.H. and Abdul Rahman A. (2010) "Quality cost in the construction industry – preliminary findings in Malaysia", Journal of Design and Built Environment , Vol. 6, June 2010, pp. 29-43

Mukhtar Che Ali (2010a), "Development of quantitative quality cost matrix for Malaysian construction quality management system", MEng Thesis, Universiti Teknologi Malaysia

Mukhtar Che Ali, (2010b), "Understanding the Underlying Principles of QLASSIC Assessment", Bulletin The Ingenieur, Vol 45, March-May 2010 edition, pp 51-54

Mukhtar Che Ali, (2012), "QLASSIC – Can It be an Effective Continual Improvement tool?" Seminar on QLASSIC – Way Forward for Quality Enhancement, 23 May 2012, Kuala Lumpur

Mokhtar Abdullah (1996). *Pengukuran Kualiti Ke Arah Peningkatan Daya Saing*. Bangi: Penerbit Universiti Kebangsaan Malaysia.

Peng, L. W, Kadir, M. R. A, Jaafar, M. S, and Salit M. S. (2003) The Experience of Malaysia and Other Countries in Industrialised Building System, Proceedings in International Conference on Industrialised Building Systems, Construction Industry Development Board (CIDB), 10-11 September 2003

Sanvido,T., Grobler, F., K., Guvenis, M. and Coyle, M (1992), "Critical success factors for construction projects", Journal of Construction Engineering and Management, Vol. 118, No. 1, ASCE, pp. 94-111

Trikha, D. N. and Ali A. A. A. (2004), "Industrialised Building System (Fist ed.)", Kuala Lumpur, Universiti Putra Malaysia Press

Tsai W. H. (1998), "Quality cost measurement under activity-based costing", International Journal of Quality & Reliability Management, Vol. 15, No. 7, pp. 719-752

Wan Yusoff Wan Mahmood and Norizan Mansor (1996). Quality Management In Construction Industry - Malaysia Experience. *Jurnal Ukur Bahan*. Skudai: Penerbit Universiti Teknologi Malaysia.

TOWARDS A SUSTAINABLE AND GREEN CONSTRUCTION IN MALAYSIA

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Abstract

The adoption of sustainable and green construction has become an important subject in Malaysia and has been duly highlighted under the Malaysian Construction Industry Master Plan (2006-2015). This paper highlights two initiatives in Malaysia to encourage the adoption of sustainable and green construction. The challenges of the adoption are lack of skill and capacity, overlapping of roles among the government agencies, slow industry follows through on government programs, lack of research and innovation, and cost versus benefits in term of implementation of green technology. The paper in particular will discuss the issue on sustainability through IBS adoption, green technology strategy and Green PASS program. Both are true potential catalyst forward sustainable and green construction in Malaysia. The way forward is to accelerate the adoptions are, to adopt life cycle costing and Industrialised Building System (IBS) method of construction, to establish green procurement, to encourage Research and Development (R&D) in related field, to educate and change public perception and mind set and to provide legislative and financial framework for sustainable development and green construction.

Keywords: *Sustainability, Green Construction, Industrialised Building System* (IBS)

INTRODUCTION

The purpose of the paper is to discuss the issue on sustainability through IBS adoption, green technology strategy and Green PASS program. The methodology used in this study was done through general concept and on-going initiatives in Malaysia.

Sustainability has become the buzzword over the last 25 years. In 1987 the Bruntland Commission articulated the concept of sustainable development, as it is known today. The Commission provided the most simple and widely used definition for sustainable development as “Development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs” (WCED, 1987). In this concept, social well-being environmental conservation as well as intra and intergenerational equity are simultaneously possible, while a nation achieves its full economic potential and enhances its resource base. The concept was given currency at the United Nations Conference on Environment and Development (UNCED) in 1992, and reinforced at the World Summit on Sustainable Development (WSSD) in 2002. UNCED saw the first global agreement on programmes for action in all areas relating to sustainable development, as documented in Agenda 21. The Commission on Sustainable Development (CSD) was established to monitor the progress of implementing Agenda 21 which also includes sustainable construction as one of the key areas under it (Latiff, et. al., 2004).

Sustainable construction is defined as "The creation and responsible maintenance of a health built environment, based on ecological principles and by means of an efficient use of resources". It is a fact that about 30-40 percent of the total natural resources used in industrialised countries are exploited by the building industry (Bourdeau, 1999). Almost 50 percent of this energy flow is used for weather conditioning (heating and cooling) in buildings. In construction, one of the areas that sustainable development researchers have concentrated on is energy efficiency of the building by reducing the energy consumption of buildings (Bourdeau, 1999). The other aspect of sustainability within construction is the idea of making buildings producers of energy using solar, wind and other non-conventional sources of energy, that can be produced on the building itself (Unruh, 2008).

Sandra *et. al,* (2002) describes the pertinent elements in sustainability agenda that include social, economy and environmental. The sub-elements of sustainability spheres are social-environmental, environmental-economic, and economic-social (Sandra *et. al,* 2002). In developing country like Malaysia, the sustainable construction trend tends to focus on relationship between construction, human development and marginalising environmental aspects. However, in light of the severe environmental degradation experienced by most of the developing countries, the construction industry cannot continue to ignore the environment (Begum, 2005).

Apart from the three spheres of sustainability mentioned, the main thrust of the sustainability in construction is encapsulated in three areas of classic construction management, which target namely time, cost and quality. Each of these do not stand alone, but dynamically compliment with the other elements, which is pertinent to be part of the holistic structure for sustainable construction that considers safety, security, environmental and health in construction as seen in Figure 1. With the technology advancement and competitive environment striving for excellence, creating a positive balance of interaction between all aspects is paramount.

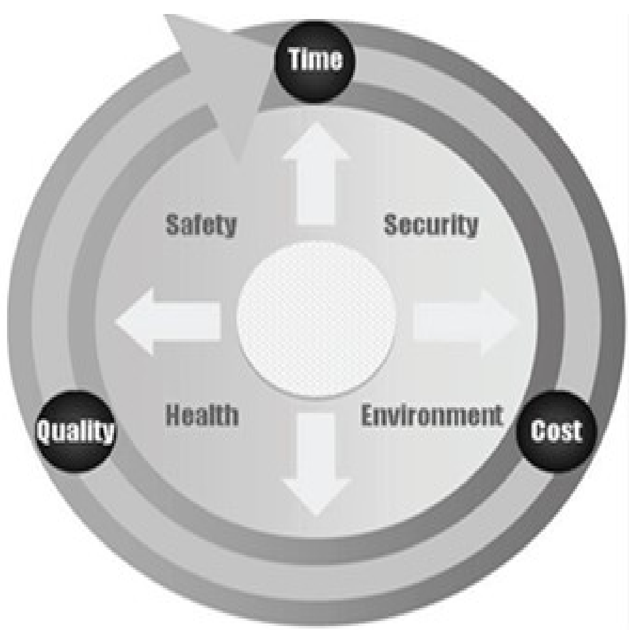


Figure 1. Holistic Structure in Sustainable Construction

The construction industry is facing massive challenges of sustainable construction. In this respect, scholars in the field have articulated the challenges for sustainable construction adoption, some issues raised cover:

1. The "circle of blame" among the project participants. Service providers namely the contractors and consultants; said clients do not ask for sustainability (Baldock, 2000). The design team persists in the old ways and is reluctant to make the first move to new territory. Clients, on the other hand, are afraid that the building will cost more and take a longer time (Bordass, 2000). They also expect the service providers to take the lead in improving their services (Business Vantage, 2002).

2. Sustainability is treated as a discrete problem with an isolated solution, which creates difficulties in blending it into the construction process (Griffith, 1996; Barrett *et al.,* 1998). Introduction of sustainability issues at later than the design stage causes changes in plan or design, which can incur more costs than savings (Connaughton and Green, 1996; Norton and McElligott, 1995).

3. Ofori (1998) stated that construction faced difficulties in providing guidance for good environmental practice in construction. Proper guidance needs to be formed to resolve this matter.

4. Unruh (2002) argued that numerous barriers to sustainability arise because today's technological systems and governing institutions were designed and built for permanence and reliability, which inhibits many change efforts.

5. Change resistance is viewed as involving change in individual values, whether at a personal, corporate, or collective level. Although the values are generally at the right place, the problem is how to enact them.

SUSTAINABILITY IN INDUSTRIALISED BUILDING SYSTEM

The rising awareness of sustainability around the globe has put the construction industry under immense pressure to improve project efficiency and deliverables. It is necessary for all parties involved such as local authorities, contractors, governments, consultants and architects to respond quickly to these changes and constraints. Industrialised Building System (IBS) concept has the potential to promote sustainability development and green construction. This may be achieved from a controlled production environment, minimisation of construction waste, extensive usage of energy efficient building material, a safer and more stable work environment, and possibly better investment for long term project economy. The industry need to seize this opportunity and use IBS as their competitive advantages in promoting sustainable construction. There are several aspects of IBS that have the potential of contributing to different aspects of sustainability and green construction. Some of the major aspects are explained below:

1. **Sustainability from Controlled Production Environment:** Whilst life cycle performance depends heavily on good quality design it is clear that, in the more easily controlled factory environment, elements are much more likely to be produced in accordance with the specification and design intent. IBS offers a controlled manufacturing environment, with the ability to reach difficult nooks and corners, which are often inaccessible in regular construction. With the availability of production tools, and permanent jigs and fixtures, it is easier to control the workmanship of construction, ensuring a tighter construction which results in energy savings due to leakages (thermal leakage)

2. **Controlled Emission and Energy:** IBS can promote sustainability because factories can control energy and emissions more easily than construction sites.

3. **Industrialised Building System and Waste:** Construction sites have made significant strides forward in recent years in reducing waste and recycling, driven, in part, by the increased taxes on landfill. But factories are still much better able to reduce waste and recycle un-used materials than sites. IBS traditionally has been known to minimise waste, with the ability to reuse material from one module or product into another; the sustainability agenda is supported through its use. However, several aspects of planning both, in terms of materials management and production management have to be monitored in order to achieve the waste minimisation benefits promised by IBS.

4. **Industrialised Building System and Building Materials:** Several pre-fabricated technologies such as Structural Insulated Panels (SIPS) etc. offer great potential in terms of fabrication of more energy efficient buildings. However, if appropriate process control and planning are not implemented these potential benefits could be lost due to expensive on-site assembly processes. Therefore, it is important that the advent of new technologies should be accompanied by proper process design for on-site assembly.

5. **Industrialised Building System and Logistics:** Some estimates recently have put the amount of environmental impact from material transportation activities to be one-third of total environmental impact on the entire construction process. IBS offers additional benefits, specifically the ability to order large quantities, thus reducing the number of trips taken. Despite these potential benefits, it is important that a detailed material transportation and logistics plan is established.

6. **Industrialised Building System and Economic Sustainability:** Most government's emphasis on reduction of reliance on foreign labour, and the ability of IBS to deliver this goal is well documented. However, for this to succeed there is a need to develop a detailed training and dissemination strategy for promoting IBS and preparing the workforce for that.

7. **Industrialised Building System and Recycling of Building Material:** IBS in term of precast buildings can also be disassembled and rebuilt at other locations, providing another means of extending service life. At the end of a building's useful life, 100% of concrete demolition waste can be recycled. After removal of the reinforcement, concrete can be crushed to produce aggregates that are primarily used in pavement construction, as granular sub-base, lean-concrete sub-base, and soil-cement aggregates. Recycled concrete has also been used on a limited scale as replacement aggregates in new concrete production.

8. **Industrialised Building System and Socio Economic Responsibility:** From a social perspective, manufacturing and assembly facilities can be located in areas where there is currently high unemployment, thus providing viable work for suitable operatives. Many of the manufacturers use multi-skilled workers and often draw these from non-construction backgrounds such as other manufacturing sectors.

9. **Industrialised Building System and Safety Issue:** IBS require less on-site work than traditional techniques, resulting in less local disruption through dust and noise and fewer health and safety risks for workers. In particular, offsite can eliminate the need to work at height which is the main cause of construction fatalities and major accidents.

By examining these advantages, IBS can easily be considered as the most appropriate way to serve sustainable building projects.

GREEN CONSTRUCTION

The construction industry stakeholder needs to take a holistic approach along the construction value chain activities to achieve sustainable construction. The way forward for Malaysian Construction industry is to address the issue of sustainability and green construction as follows:

1. Introducing indicators as one of the sustainability improvements. Various indicators related to sustainability have emerged. Most of the indicators are used for evaluation or assessment purposes.

2. Assessment tools are another way to identify present performance, which could be used to instigate improvement.

3. Issues on 3R (reduce, reuse and recycle) can be seen as a way forward for the construction industry to achieve sustainable development on the various environmental, social, economic and even cultural factors.

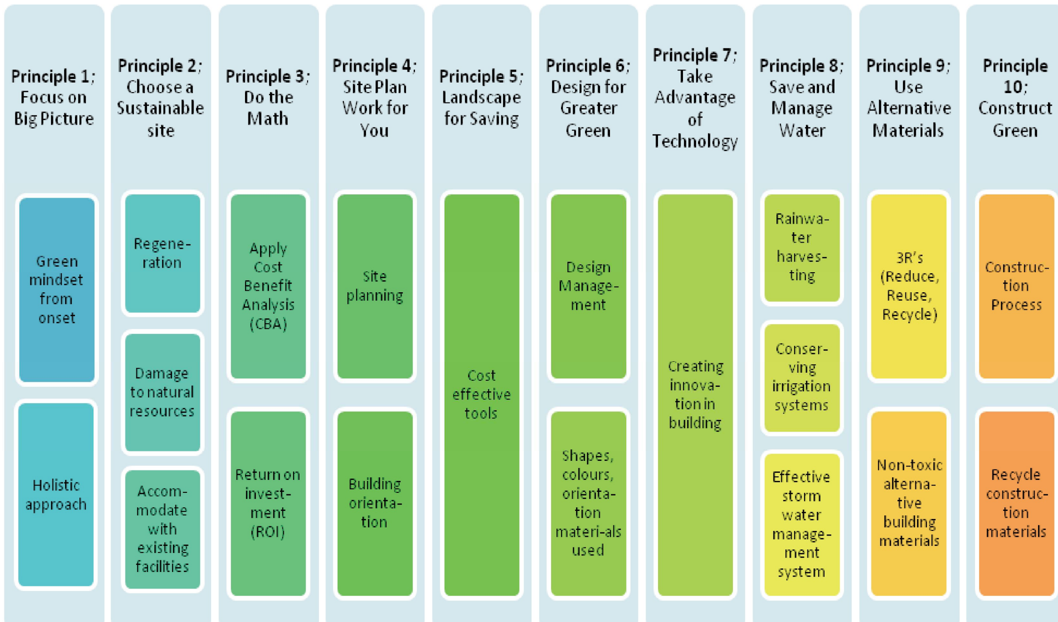
4. Government support is needed to promote the sustainability agenda. To achieve the agenda, changes in policy and activities at all levels are needed.

5. Research and innovation is a good way of improving and expanding knowledge and technology (Zainul Abidin, 2010).

6. The introduction and adoption of Whole Life Cycle Costing (WLCC) and green procurement in the construction industry.

7. Establishment of eco-labelling scheme for construction materials.

8. Benchmarking and technology transfer of best practices from developed countries in implementing sustainable and green construction agenda.



(Source: Developed from Lockwood, 2007)

Figure 2. Embedding Aspects of IBS to 10 Principles of the Green Sustainability for the Malaysian Construction

The construction industry plays a vital role in helping the efforts of the government to attain sustainable development and green construction when there is a requirement of balance between economy growth, social expansion and environmental protection.

Migration to a sustainable 'mentality' requires a lot of change in attitude, innovation, creativity, research and support from many stakeholders. The strategic direction, implementation strategies and research and development have to be driven in harmony. It is envisioned that all initiatives mentioned need to be taken forward simultaneously. Every stakeholder involved must stand together and react as a team not as individual champion. The construction industry must change its traditional approach to construction with little concern for environmental impact, to a new mode that makes environmental concerns a centre piece of its efforts.

A strategic way of implementing sustainable and green technology could show the path to adoption of Whole Life Cycle Costing (WLCC) and towards green procurement in the construction industry. The era of sustainability is currently taking its stand, and the construction industry must demonstrate that it can lead and take this forward. Green technology is an important element under the sustainability domain. Based on a research by Lockwood (2007), there are ten principles to be adopted if one wants to implement green construction as shown in Figure 2. This shows the ten principles of the Green Way as guiding principles for industries in implementing green building as a holistic approach.

Embedding aspects of economy viability, design principles and environment for example within IBS framework to adopt the 10 Principles of the Green Way (Lockwood, 2007) will bring synergy towards green construction and implementation of sustainability in Malaysia.

GREEN CONSTRUCTION INITIATIVES IN MALAYSIA

CIDB's Green Technical Committee / Eco-Label Committee

In 2010, CIDB formed the Technical Committee on Best Practice in Green Technology in the construction industry, comprising representatives from government agencies, professional bodies, academicians and societies related to the construction industry. The committee is to assist the CIDB to identify the preparation and development of the construction industry's standards, guidelines, manual, technical reports and training modules related to green technology

Furthermore, CIDB is currently running an eco-label program. This programme is to encourage manufacturers and producers of construction materials to make environmentally friendly construction materials. Green labelling is able to boost the green building assessment system or index, and green procurement to be implemented by the government soon.

Green Performance Assessment System in Construction

CIDB is in the midst of developing Construction Industry Standard (CIS) primarily to assess the impact of building construction work to the environment. The title of the standard is Green Performance Assessment System in Construction (Green PASS). The CIDB recognizes the need for performance-based standard in addressing green construction to provide a framework linking sustainability with performance in order to mitigate climate change (CIDB, 2012). This standard underscores on low carbon building performance without compromising on the desired comfort level of the building.

Green PASS is designed to meet these needs through standard conformance that promote sustainable construction in an integrated manner with other Construction Industry Standard (CIS). It is an independent construction standard that assesses and rates the impact of building construction upon the environment. Green PASS is founded on the principle that a model standard must address building performance beyond those captured by rating systems or other evaluation guides, and therefore, it shall be usable, adoptable and stringent in making it an effective system for the construction industry.

The standard once applied will establish minimum requirement for buildings and systems using prerequisites and performance-related provisions, and compliments existing standards to form a comprehensive standard for green construction (CIDB, 2012). The objectives of the Green PASS are:

a. To provide a foundation for CIDB to establish a reliable and robust database on construction carbon footprint

b. To accommodate the need for performance based standard in addressing green construction

c. To provide a framework linking sustainability with performance

d. To drive towards sustainable construction

Green PASS estimates the carbon emissions from building construction works throughout a building's life cycle. The building life cycle defined within this standard covers pre, during and post construction stages, with carbon emissions divided into embodied carbon and operational carbon. These provisions are applicable to new and existing buildings. Embodied carbon is referred to as CO2 emitted throughout the pre and during construction stages. Operational carbon is CO2 emitted throughout the post construction stage to the end of life of any building. The Certification level will be named as Diamond Rating.

CONCLUSIONS AND RECOMMENDATIONS

Based on the discussion above, recommendations to accelerate the adoption of sustainable and green construction in Malaysia are:

1. To further incorporate and applies innovation in construction in the form of Industrialised Building System (IBS). The fundamental idea of IBS is to move on-site work to a controlled environment of manufacturing floor. IBS promote sustainability from controlled production environment minimisation of waste generation effective usage of energy, efficient building materials, effective logistic and long term economic stability which can contribute to better investment in environment technologies.

2. The introduction and adoption of while whole life cycle costing and green procurement in construction industry is important way forward. The concept refers to the total cost of ownership over the life of an asset. It also commonly referred to as cradle to grave or womb to tomb costs. The primary benefit of whole-life costing is that costs which occur after an asset has been constructed or acquired, such as maintenance, operation, disposal, become an important consideration in decision-making. By introducing the whole life cycle costing and green procurement, the industry has resources to plan for sustainable and use green materials when the investment is justified.

3. 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.

4. Human capital development is one of the important elements that need to be taken on-board. A system for formulation of grading and certification mechanisms for competent personnel in green technology is the way forward. The learning curve and education syllabus on sustainable and green construction should be included right from primary education until university level.

5. Research and innovation is the best way to improve and expand knowledge and technology. The government should increase grant allocation on the research related to sustainable and green construction and encourage research cluster on green issues. The research agenda needs to include benchmarking and technology transfer of best practices from developed countries in implementing sustainable and green construction agenda.

6. 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. However, there is a need for clarity in the roles of the agencies to avoid confusion and overlapping in roles and programs.

7. Mitigation to sustainable mentality requires a lot of change in attitude, innovation, creativity, research and support from many stakeholders. Construction industry must inevitably change its historic of operating with little regard for environmental impact to a new mode that makes environmental concern a centre piece of its effort. The era of sustainability is taking its stand and the construction industry must demonstrate that it can abide by this new stand. It is important for the government of Malaysia to exploit their foresight regarding this transition to maximise its potential benefit through policies supporting the development of the private demand for and supply of activities which meet this agenda. Change requires investments, and the vast majority of those investments must happen through collaboration between private sector, the government and research institute by providing adequate enabling effect.

REFERENCES

Baldock, H. (2000). Enter the green knight. Building, 265(13):24-26.

Barrett, P., Sexton, M., and Curado, M. (1998).Sustainability through integration. *In Proceedings, CIB World Building Congress 1998, Symposium D,* 1767-1776.

Begum, R. A. (2005).*Economic Analysis on the Potential of Construction Waste Minimisation and Recycling in Malaysia.*Unpublished PhD Thesis. Universiti Kebangsaan Malaysia (UKM). Bangi, Selangor.

Bordass, B. (2000). Cost and Value: Fact and fiction. *Building Research and Information,* 28(5/6): 338-352)

Bourdeau, L., (1999), *Sustainable Development and the Future of Construction: A Comparison of Visions from Various Countries,* Building Research and Information, 27(6), 354-366.

Business Vantage.(2002). Equal Partners - Customer and Supplier Alignment in Construction.London: Business Vantage Ltd.

CIDB, (2012) Draft of Construction Industry Standard (CIS): Green Performance Assessment System in Construction (Green Pass)

Connaughton, J.N. and Green S.D. (1996).Value Management in Construction: A Client's Guide. London: CIRIA.

Griffith, A. (1996). Review of environmental assessment in UK building construction: Current awareness, concerns and issues. Engineering, Construction and Architectural Management, 3(3): 205-217. Ibrahim, R. (1999). Environmental Management in Malaysia. *The Ingeniur , Board of Engineers Malaysia,* Issue 1, January. Kuala Lumpur.

Latiff, A., Pereira, J.J., Hezri Adnan, A., Aldrie, A.A. (2004), Assessing Changes in Environmental Conditions. Institut Alam Sekitar dan Pembangunan (LESTARI) Universiti Kebangsaan Malaysia, Bangi.

Lockwood, C. (2007). Building the Green Way, Harvard Business Review on Green Business Stategy, Harvard Business School Press, USA.

Norton, B.R. and McElligott, W.C. (1995).Value Management in Construction: A Practical Guide. London: Macmillan Press.
Ofori, G. (1998). Sustainable construction: principles and a framework for attainment - Comment. Construction Management and Economics, 16: 141-145.
Sandra, I., Rodriguez, Matthew S., Roman, Samantha, C., (2002). Sustainability Assessement and Reporting for the University of Michigan's Ann Arbor, USA.
Unruh, G.C., (2002). Escaping carbon lock-in. Energy Policy, March, 3(4): 317-325.
Unruh, G.C., (2008), The Biosphere Rules, Harvard Business Review, February, 111-116.
WCED (1987).Our Common Future.World Conference on Environment and Development. Oxford University Press, Oxford.
Zainul Abidin,N. (2010), Environmental Concerns in Malaysian Construction Industry. Penerbit Universiti Sains Malaysia, Pulau Pinang.

SEISMIC ASSESSMENT OF A FULL-SCALE SINGLE BAY DOUBLE-STOREY HOUSE USING FRAGILITY CURVE

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Abstract
Seismic assessment of a single bay of double storey house is performed using fragility curve. Fragility curve is employed to determine the percentage Confident Interval (CI) for a double storey house constructed using precast shear-key wall panels and cast-in-situ concrete. A full-scale of the house is constructed on pad footing and seated on strong floor in Heavy Structural Laboratory, CREAM, Kuala Lumpur was tested under reversible lateral cyclic loading. Visual observations were recorded and their classification of damage states are in accordance to drift limits. Damage states limit of these two walls are followed by the definitions and descriptions as given in HAZUS 99-SR2. Colour-coded system is fully utilized in order to identify performance level, damage level, drift damage and ductility factors. Fragility curve for this house is developed based on the probabilistic hazard level, cumulative probability function and classification damage-states. This house has 40% of CI for green colour-coding and 95% of CI for yellow colour-coding under Design Basic Earthquake (DBE) with PGA=0.12g. There is slightly difference for Maximum Considered Earthquake (MCE) where this type of house has 10% of CI for green colour-coding and 65% of CI for yellow colour-coding. The green colour-coding indicates that the house is fully functional while the orange colour-coding show the house still functional even though there are minor cracks on the house. It is recommended that this house should be designed in accordance to Eurocode 8 (EC8) in order to survive under moderate or severe earthquakes.

Keyword: *Colour-Coded System, Damage States Limit, Fragility Curves, Design Basis Earthquake, Maximum Considered Earthquake*

INTRODUCTION

Frequent earthquakes in neighbouring countries such as Sumatra, Java Island and Philippines had trigger some of semi-active and sleeping fault lines in West and East Malaysia. Some of the semi-active fault lines in West Malaysia are Lebir Fault, Terengganu Fault, Bukit Tinggi Fault and Kuala Lumpur Fault, while in East Malaysia are Keningau Fault, Labou-Labou Fault, Tabir Fault and others. Past earthquakes records which occurred in Banda Acheh Sumatera, Pulau Nias and Padang with magnitude ranging from 4.4 to 9.4 on Richter scale caused a significant impact on the structures and semi-active fault lines in West and East Malaysia. Recent earthquake in Silboga, Sumatera with 5.6 Richter scale with epicenter of 481km from Kuala Lumpur causes some tremor to the people who live in high-rise buildings around Penang, Klang Valley, Melaka and Negeri Sembilan.

Local earthquakes in West Malaysia such as Bukit Tinggi, Dam Kenyir, Jerantut and Manjong did not cause any severe structural damages to the reinforced concrete buildings within their vicinities. These earthquakes have very low magnitude and intensity ranging between 2.6 to 4.8 on Richter scale. Since 1980's, Peninsular Malaysia is not as prone to tremors due to earthquake, but over a period of three years beginning in 1984, the area around the Kenyir Dam in Terengganu recorded about 20 tremors, the strongest of which registered at magnitude 4.8 on Richter scale. Bukit Tinggi in Pahang was hit by three earthquakes on Nov 30, 2007, followed by more than 10 separate events until the last in May 2008, but the strongest was at magnitude 3.5 on the Richter scale. There were two more isolated earthquakes occurred in Manjung, Perak and Jerantut, Pahang, on April 29 and March 27 in year 2009, measuring 3.2 and 2.6 Richter scale, respectively.

Figure 1 shows the hazard map together with Peak Ground Acceleration (PGA) for West and East Malaysia with return period of 500 years (exceedance 10% in 50 years under DBE). The highest range of PGA for West Malaysia is between 0.08g to 0.1g located along the West Coast of Selangor, Perak and Melaka and for East Malaysia is between 0.1g to 0.12g. Figure 2 shows the hazard map of Malaysia for the peak ground acceleration with return period of 2500 years (exceedance 2% in 50 years under MCE). The maximum value of PGA is situated in East Malaysia ranging between 0.18g to 0.12g.

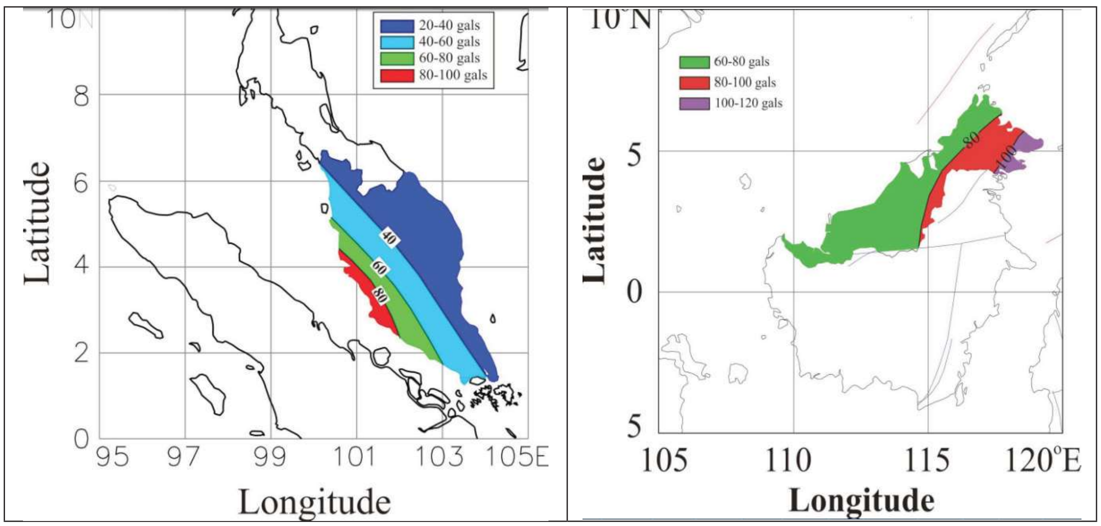


Figure 1. Peak Ground Acceleration (PGA) map for Malaysia in 500 years (Azlan, 2010).

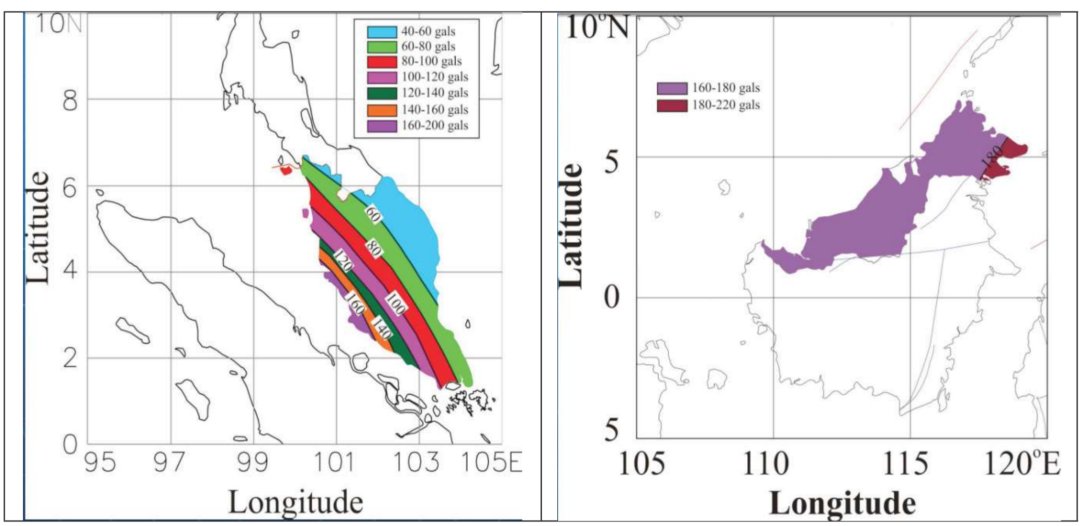


Figure 2. Peak Ground Acceleration (PGA) map for Malaysia in 2,500 years (Azlan, 2010).

Currently, the hazard map with different ranging peak ground acceleration is not adopted in the current code of practice. However, most of the reinforced concrete buildings in Malaysia are designed according to BS 8110 where there is no provision for earthquake loading. The level of safety for these buildings is still questionable if bigger earthquakes strike either in Sumatra or local earthquakes. Therefore, the intention of this research is to determine the probability of survival double-storey residential house under DBE and MCE using fragility curve. This type of residential house is erected using precast shear-key walls and cast-in-situ concrete for the slabs, beams and columns. Fragility curve is utilized by incorporating the drift damage limit which obtains from experimental work.

FINDING FROM PREVIOUS RESERACH

Peak Ground Acceleration (PGA) and structural damage are the two common parameters which normally used to predict the structural damages distribution of the buildings over certain seismic regions. Previous researchers, Blejwas and Bresler (1978) proposed damage states of structures can be measured by taking the ratio of demand on the seismic response over the capacity of the system. Meanwhile, Banon et al. (1981) defined damage state parameters in terms of rotation ductility, curvature ductility, Flexural Damage Ratio (FDR) and Normalized Cumulative Rotation (NCR). Later on, Banon and Veneziano (1982) pointed out the necessity to define the terms flexural damage ratio (FDR) and Normalized Cumulative Ratio (NCR). They defined the Flexural Damage Function (FDR) as the ratio of initial flexural stiffness to the reduced secant stiffness and Normalized Cumulative Rotation (NCR) is the ratio of cumulative plastic rotations in n_{cycle} cycles to the yielding rotation of the nonlinear spring. However, Park and Ang (1985) expressed the seismic damage of reinforced concrete structures as a linear combination of maximum deformation and absorbed hysteretic energy. To prove this relationship, an extensive damage analysis of Single Degree of Freedom (SDF) system and a typical Multi-Degree of Freedom (MDF) reinforced concrete building were performed. Theoretical results showed a simple relationship between the destructiveness of seismic ground motion in terms of characteristic intensity and structural damage in terms of Damage Index (DI).

More research work had been conducted by DisPasquale and Cakmak (1990) on global damage indices for the complex structures using an optimal time variant linear model fitted to strong motion records. They discovered a good correlation between the numerical values of damage indices with actual visual observation of the structures. More explorations on building damage functions made by Kircher et al. (1997) for earthquake loss estimation using others parameters such as ground shaking characteristics, site/soil amplification and shaking durations. Further verification was made by O'Rourke and So (2000) on the seismic performance of 400 water tanks in nine separate earthquake events. They realized that the relative amounts of stored water contents in the tank and the tank's height to water tank diameter ratio had a significant influence on the tank's seismic performance.

After defining the parameters on structural damages, structural indices and loss estimation, another method is required to assess the probability of damages states in relation to ground motion. This method is known as fragility curve. Fragility curve can be used to predict the probability of reaching or exceeding specific damage states for a given level of peak earthquake response. The probability of being in a particular state of damage and the input used to predict building-related losses are calculated by taking the difference of damage states in the fragility curve analysis. The expected seismic performance of the structures system can be achieved by combination the fragility curves, probability of ground shaking and an integrated possible outcome such as Monte-Carlo simulation (Singhal and Kiremidjan, 1996). One application of fragility curves was tested on gravity-type quay walls . He proposed design charts based on effective stress-based FEM and some parametric study on gravity-type quay walls. Then, fragility curves were generated by considering the difference between the observed displacements in case histories and estimated displacement by the chart. Fragility curve can also be used in assessing the seismic performance of three different types of concrete wall panels which are monolithic cast-in-situ wall panel, slender precast wall and precast hollow core wall. Hamid (2010) conducted experimental work using three different types of wall panels and tested under quasi-static lateral cyclic loading. Out of these three panels, precast hollow core wall showed the most excellent performance under two different intensity of earthquake (DBE and MCE). Until now, there are very limited studies on assessing the safety of full-scale double-storey house using fragility curve. Therefore, this paper focuses on the seismic assessment and safety of precast double-storey house under DBE and MCE. The visual observation on damages during experimental work and calculated drift will be used to analysis the seismic behaviour of double-storey house under quasi-static cyclic loading.

CHARACTERISATION OF DOUBLE-STORY HOUSE'S DAMAGES

A full-scale of double-storey residential house was constructed at heavy structural laboratory and tested under reversible quasi-static lateral cyclic loading. Figure 3 shows the isometric view of double-storey house which has been constructed on strong floor in heavy structural laboratory. The overall height of the building is 5000mm; length and width of foundation beam are 4.5m and 3.9m, respectively. WALL 1 and WALL 2 are constructed using shear-key precast wall system and the connections between these walls were made from cast-in-situ concrete and at the same time behaving as monolithic column which connected to the foundation beam. A total number of ten (marked as red colour) linear potentiometers attached to reaction frame are used to measure the in-plane displacement/deformation when the applied reversible cyclic loading was imposed at in-plane direction of WALL 1 and WALL 2.

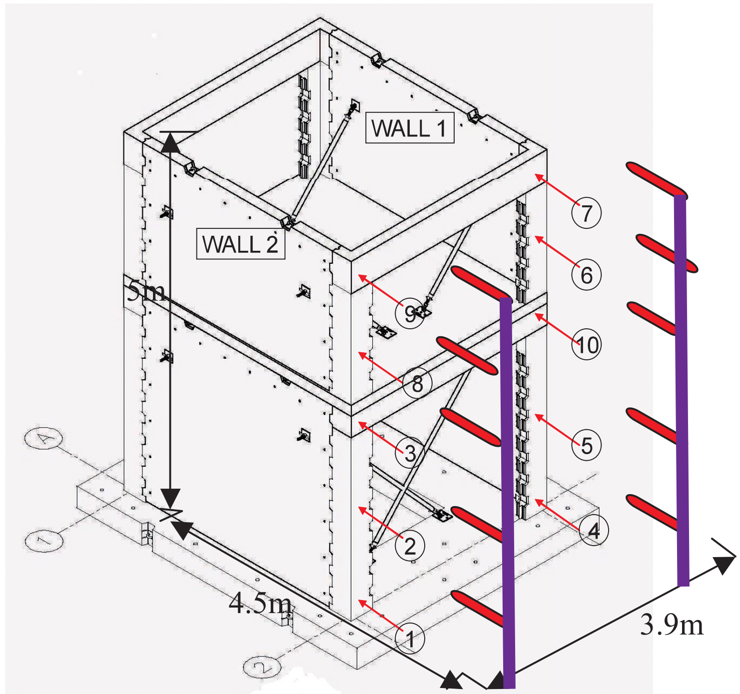
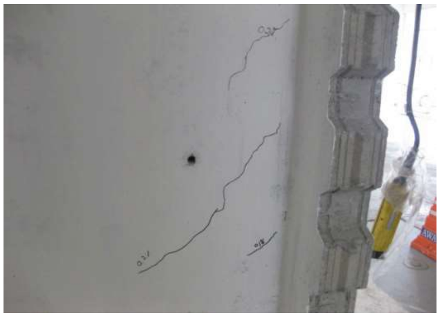


Figure 3. Isometric view of a double-storey house

Table 1. Damages based on the visual observation during experimental work

Visual damages observed during experimental work	Drift	Damage State	Description of Damage	Ductility
	0.05%	1	No damage or crack was observed at any parts of the building. The building remain fully functional and can be occupied after the earthquake	$\mu = \frac{2.25}{13.5} = 0.17$
	0.1%	1	The building experienced only slight damage with few hairline cracks at the inner part at the connection on wall-column. The wall remains elastic and fully functional.	$\mu = \frac{4.5}{13.5} = 0.33$

	0.2%	2	The wall has slight structural damage such as wider cracks occurred on cast-in -situ column. The building experiences minor damage and it is remaining functional after earthquake.	$\mu = \frac{9}{13.5} = 0.67$
	0.3%	2	The wall has minor damage with longitudinal cracks occurred between wall and column. Bigger cracks were observed at the inner wall panels. Minor cracks also notified on slab but the remain functional	$\mu = \frac{13.5}{13.5} = 1.00$
	0.4%	3	More cracks were observed at cast-in-situ columns and beams, crack on first floor slab, spalling of nominal concrete cover. Building losing its elastic stiffness and experienced significant damage.	$\mu = \frac{18}{13.5} = 1.33$
	0.5%	3	Wider opening of cracks at wet connections and more spalling of concrete. Strength degradation occurs with some lateral force remains and the building need to repaired before occupied.	$\mu = \frac{22.5}{13.5} = 1.67$

	0.6%	4	The building has lost a significant amount of its origin stiffness. A lot of cracks and spalling of concrete observed in the column, wall, beam and slab. The building is not safe.	$\mu = \frac{27}{13.5} = 2.00$
	0.7%	4	Building lost the stiffness and strength. Severe structural damage occurred at joint intersection of beam-column and column-wall interfaces. The building experienced near collapse phase.	$\mu = \frac{32.5}{13.5} = 2.41$

Table 1 shows the visual damages during experimental work with respect with drift, damage state,description and ductility. WALL 1 and WALL 2 were pushed and pulled at 0.05%, 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6% and 0.7% drift.

SEISMIC ASSESSMENT OF THE HOUSE USING FRAGILITY CURVE

There are several models which can be used to quantify the damages, characterization of damage state and estimation of losses after the earthquakes. One of the models used in this research is called “HAZUS 99-SR2” which had been developed by Federal Emergency Management Agency (FEMA) and National Institute of Building Science (NIBS). The primary objective of HAZUS 99-SR2 (2004) is to provide a methodology and software application to develop earthquake losses on a regional scale. The loss estimation is useful for local, state and regional officials to plan and stimulate efforts in reducing risks from earthquakes and to prepare for emergency response or recovery. The loss estimation is based on the damage states of the buildings/structures after earthquakes. The status for damage states for the overall buildings after an earthquake is tabulated in Table 2 (HAZUS 99-SR2, 2004). The combination of damages states as stated in Table 2 and Table 1 are used to generate Table 3. Table 3 shows the relationship between damages of wall panel observed in the laboratory and the State of Damage as defined by HAZUS 99-SR2 together with colour-coding system. Table 3 is produced by tagging the colour-coding against the performance level, description of the damages, structural damage based on the percentage of drift and the upper limit of the ductility factor. Table 3 and Table 4 are merged together to produce a fragility curve for double-storey house using the following equations as mentioned in section 5 of this paper.

Table 2. Definition of Damage States (HAZUS 99-SR2, 2004)

Damage State	HAZUS Descriptor	Post earthquake Utility of Structures	Evidence	Outage time	Expected Ductility Factor
1	None	No damage	None (pre-yield)	-	0.33
2	Slight	Slight damage	Cracking	< 3 days	1.0
3	Moderate	Repairable damage	Large cracks cover spalled	< 3 weeks	1.67
4	Heavy	Irreparable damage	Failure of components	< 3 months	2.0
5	Complete	Irreparable damage	Partial/total Collapse	> 3 months	2.7

Table 3. Definition of colour-coding and performance level for precast shear wall.

Tag Colour	Performance Level	Description of damage level	Drift Damage	Ductility Factor
Green	Operational	Minor cracks, no damage, building occupiable	0.1%	0.33
Yellow	Functional	Wider cracks, initial spalling at corner of walls with moderate level of damage. The warehouses can be entered to remove belongings.	0.3%	1.00
Orange	Life Safety	Extensive spalling along bottom walls, longitudinal bars buckling with heavy damage on the walls. Warehouse can be entered for short periods for removing important items.	0.5%	1.67
Red	Near Collapse	Fracturing of longitudinal bars, no stability of structures, near collapse. The building cannot be entered.	0.7%	2.41

THEORETICAL DEVELOPMENT OF FRAGILITY CURVE

A fragility curve describes the probability of reaching or exceeding a damage state at a specified ground motion level. Thus, a fragility curve for a particular damage state is obtained by computing the conditional probabilities of reaching or exceeding that damage state at various levels of ground motion. The probabilistic hazard levels frequently used in FEMA (1997) and their corresponding mean return periods are tabulated in Table 4. By referring to Table 4, there are two limit states in designing a precast double-storey building under performance levels namely, life safety limit state and collapse prevention limit state. Under life safety limit state, the probability of occurring earthquake within 50 years is 10% and the return period is 500 years. For example, life safety limit state for these buildings which designed under Basic Design Earthquake (DBE) for Wellington, New Zealand is taken as $F_vS_1 = 0.4g$ and for Malaysia is $F_vS_1 = 0.12g$ (see Figure 1) where g is defined as peak ground acceleration for any particular area. The collapse prevention limit state is defined as 2% probability occurrence earthquake exceeding 50 years with mean return period of 2500 years. The limit peak ground acceleration for collapse prevention or also known as "Maximum Considered Earthquake" (MCE) is taken as the value of $F_vS_1 = 0.8g$ for Wellington, New Zealand and $F_vS_1 = 0.22g$ for Malaysia. However, the value for DBE and MCE is depending on the location of these buildings to the earthquake epicenter. The DBE and MCE which denoted as dotted line in fragility curve which can be utilized to predict the percentage of Confidence Interval for the performance levels such as operational, immediate occupancy, life safety and collapse prevention.

Table 4. Probabilistic Hazard Levels

Performance Level	Earthquake Having Probability of Exceedance	Mean Return Period (years)
Operational	50%/50year	75
Immediate Occupancy	20%/50year	225
Life Safety	10%/50year	500
Collapse Prevention	2%/50year	2500

In order to plot fragility curve for double-storey precast house, the theoretical equations together with design earthquake levels of DBE and MCE need to derive first. The first step of developing fragility curve is to set the spectral acceleration amplitude of an earthquake for a period of T = 1 sec and then, the drift damage limit must be converted into spectral acceleration units (A). Base shear demand (C_d) for period of the structures for high damping is given in equation (1) as stated by FEMA (1997):

$$C_d = \frac{SA}{TB_L} \tag{1}$$

in which S is soil type factor, A is the peak ground acceleration (normalized with respect to g), T is the period of vibration and B_L is the factor of damping which is taken as more than 5%. The second step is to calculate the structural period of vibration according to yield strength and displacement for Single Degree of Freedom (SDOF) as given in equation (2).

$$T = 2\pi\sqrt{\frac{m}{K}} = 2\pi\sqrt{\frac{W\Delta}{Fg}} = 2\pi\sqrt{\frac{\Delta}{C_c g}} \tag{2}$$

where the base shear capacity of the structure is defined as $C_c = \frac{F}{W}$, where F is the yield strength (base shear) of the structure, W is seismic weight of the structures, Δ is the yield displacement of the structure, and K is the stiffness of the structures. By substituting equation (2) into equation (1) and equating base shear capacity equal to base shear demand, the equation becomes:

$$C_c^2 = C_d^2 = \frac{C_c g}{4\pi^2\Delta}\left(\frac{SA}{B_L}\right)^2 \tag{3}$$

Then, by substituting $\Delta = \theta H$, then

$$(SA)_i = 2\pi B_L\sqrt{\frac{C_c\theta H}{g}} \tag{4}$$

The third step is to convert the damage drift limit to spectral acceleration. Equation (4) is used to convert from damage drift limit to the spectral acceleration in developing the fragility curves. The fourth step is to transform the spectral acceleration into Cumulative Probability Function (CPF). According to Mander (2003), the items which should be considered in developing fragility curves by taking into account the theoretical cumulative probabilistic functions are as follows:

i. Expected site-specific response characteristics;
ii. Inelastic strength and deformation capacity of the structure;
iii. Damage limit states;
iv. Randomness of ground motion response spectral demand;
v. Uncertainties in modelling structural capacity.

The intersection of the capacity curve and appropriate damped elastic demand curve provides a "performance point" based on the estimate of the structural strength and displacement demand. The probability distributions over these two curves indicated the uncertainty and randomness of the structures performance with a wide range of possible performance outcomes. The randomness and uncertainty can be represented as probability distribution function. This distribution function can be expressed as a lognormal cumulative probability density function known as "fragility curve". The cumulative probability function is give by equation (5) as

$$F(Sa) = \Phi\left[\frac{1}{\beta_{C/D}}\ln\left(\frac{S_a}{A_i}\right)\right] \tag{5}$$

where Φ = standard log-normal cumulative distribution function; S_a = the spectral amplitude (for a period of $T = 1\sec$); A_i = the median spectral acceleration necessary to cause the ith damage state to occur and $\beta_{C/D}$ = normalized composite log-normal standard deviation which incorporates aspects of uncertainty and randomness for both capacity and demand.

The fifth step is to use central limit theorem by incorporating the normalized composite log-normal standard deviation. The central limit theorem requires the composite performance outcome to be distributed log-normally. By using the derivation of this theorem, the coefficient of variation for lognormal distribution is given by Kennedy *at el.*

$$\beta_{C/D} = \sqrt{\beta_C^{\,2} + \beta_D^{\,2} + \beta_U^{\,2}} \tag{6}$$

The value of $\beta_C = 0.2$ represented as randomness of the structural capacity based on the analysis carried out by Dutta and Mander (1998). $\beta_U =$ uncertainty associated with strength reduction factor and the global modeling process, the assumed values is ranging between 0.2 and 0.4. The overall value of $\beta_{C/D}$ is calibrated by Pekcan *et. al* (1999) and validated by Dutta and Mander (1998) against fragility analysis based on the site data obtained in the 1994 Northridge Earthquake and the 1989 Loma Prieta Earthquakes which recommended the value to be $\beta_{C/D}$ =0.6. After obtaining all the parameters of the cumulative probability function, the final step is to plot fragility curve for double-storey house using precast wall panel using lognormal distribution function as explained in the following section.

RESULTS AND DISCUSSION

The fragility curves are used to represent the probabilities that the structural damages, under various levels of seismic excitation, exceed specified damage states. Figure 4 shows the fragility curves for double-storey together with seismic vulnerability assessment performance when classified under coloured-coded and damage states numbering format. These fragility curves plotted based on equation (5) and equation (6) as derived above. The x-axis represents the Peak Ground Acceleration (PGA) which denoted as $F_v S_1$ and both y-axes represent Cumulative Probability Function (CPF) and Confident Interval which measured in percentages. The percentage Confident Interval (CI) is taken as the value of one subtracted from the value of Cumulative Probability Function and multiplied by 100%.

For low seismic region as Malaysia, the Design Basic Earthquake (DBE) which refer to the probability of 10% occurrences within 50 years or mean return period of 500 years is PGA= 0.12g while Maximum Considered Earthquake (MCE) with probability of 2% occurrences within 50 years or mean return period of 2500 years with PGA = 0.22g. Under DBE with PGA= 0.12g, the percentage confidence interval level would be 40% under green colour-tag, and 95% percentage confidence interval under yellow tag. Green colour-coding refers as fully functional and yellow colour-coding refers as functional for these buildings. It can be concluded that this building is still below the life-safety requirement, survive under PGA=0.12g and safe to be occupied after the earthquake. Under MCE with PGA=0.22g, the percentage confidence interval for green colour-coding is 10% , 65% confidence interval for yellow colour-coding, 85% confidence interval for orange colour-coding and 95% confidence interval for red colour-coding. It can be summarized that this building experience a significant structural damages and worst condition is that it will experience partial collapse of the buildings at PGA=0.22g. Therefore, this building will not survive under Maximum Considered Earthquake. The worst scenario will occur if the PGA of DBE and MCE increase to PGA=0.4g and PGA=0.8g, respectively.

Finally, it is suggested that this building needs to be designed using current seismic code of practice such as Eurocode 8 in order to survive under Maximum Considered Earthquake by increasing the percentage of reinforcement bars concrete, improved the strength capacity of buildings, better connection at beam-column interfaces and wall-column interfaces and lastly, increase the ductility of the system by increase the percentage drift of the structure.

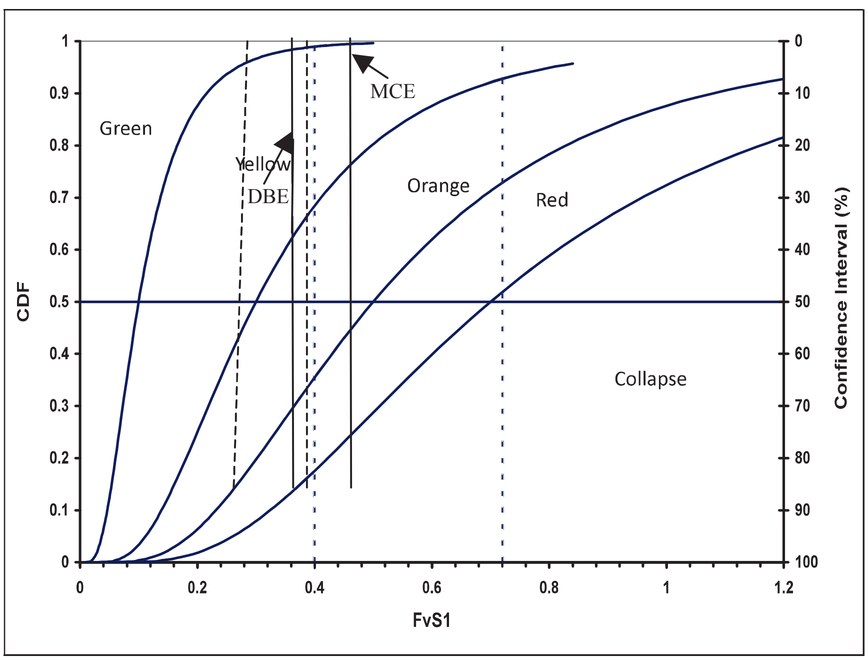


Figure 4. Fragility curve for precast double-storey house constructed using shear-key wall panel.

CONCLUSIONS AND RECOMMENDATIONS

Based on the experimental results and discussion on precast double storey house, the following conclusions and recommendation are drawn:

1) Visual observation on the damages of precast shear-key wall are captured until 0.7% drift and the overall seismic performance of this type of building under reversible cyclic loading is poor and experience severe structural damage.

2) Precast double-storey house has 40% confidence interval of green colour-coding (fully functional) and 95% confidence interval of yellow colour-coding (functional) under Design Basic Earthquake (DBE) with PGA=0.12g.

3) Double-storey house has 10% confidence interval of green colour-coding (fully functional), 65% confidence interval of yellow colour-coding (functional), 85% confidence interval of orange colour-coding (life safety) and 95% confidence interval of red colour-coding (near collapse) under Maximum Considered Earthquake (MCE) with PGA=0.22g.

4) It is recommended that shear-key precast wall panel need to design in accordance to current seismic code of practice such as Eurocode 8 to cater for lateral seismic loading which comes from earthquake. Some modifications and improvements on the joints between wall-foundation interface, wall-column interface and wall-beam interface need be focused.

REFERENCES

Adnan, Azlan, (2010). "New Seismic Hazard Map using New Generation Attenuation for Seismic Design of Infrastructures in Putrajaya, Malaysia", Seminar Teknikal Kebangsaan Gempa Bumi & Tsunami di Malaysia (NaTSET 2010), Kuala Lumpur, Malaysia.

Blejwas, B and Bresler, B.,(1978)." Damageability in Existing Buildings." *EERC Rep. No.UCB 71-13*, University of California, Berkeley, 1971 UCLA, March 1978, pp.505-512.

Banon, H., Biggs, J. M., and Irvine, H. M.(1981). "Seismic Damage in Reinforced Concrete Frames." *Journal of Structural Division,ASCE*, 107(9), pp 1713-1729.

Banon, H., Veneziano, D,(1982)."Seismic Safety of Reinforced Concrete Members and Structures." *Earthquake Engineering Structural Dynamics*, Vol. 10, 1982,pp 179-193.

Park, Y. J., and Ang, A.-S.(1985). "Seismic Damage Analysis of Reinforced Concrete Buildings." *Journal of Structural Engineering, ASCE*, Vol. III, No. 4, pp740-757.

DiPasquale, E., and Cakmak, A. S. (1990). "Seismic Damage Assessment using Linear Models." *Soil Dynamic and Earthquake Engineering*, 9(4), pp 194-215.

Kircher, C.A., Nassar, A.A., Kustu, O.,Holmes, W.T,.(1997), "Development of Building Damage Functions for Earthquake Loss Estimation." Earthquake Spectra, EERI, November 1997, Vol. 13, N.4, pp663-683.

O'Rourke, M. J., and So, P. (2000). "Seismic Fragility Curves For On-Grade Steel Tanks." *Earthquake Spectra*, Volume 16, No.4(November 2000), pp801-815.

Singhal, A., and Kiremidjan, A. S.(1996). "Method for Probabilistic Evaluation of Seismic Structural Damage." *Journal of Structural Engineering, ASCE*, Vol 122, No.12(December, 1996), pp 1459-1467.

Ichii, K. (2004), “Fragility Curves for Gravity-Type Quay Walls based on Effective Stress Analyses.” *13th World Conference on Earthquake Engineering*, Vancouver, B.C., Canada, August 1-6, 2004, paper No.3040.

HAZUS 99-SR2. (2004).“ Earthquake Loss Estimation Methodology.” HAZUS Technical Report, Federal Emergency Agency and National Institute of Buildings Science, Washington D.C., http://www.fema.gov/hazus/[accessed 4/4/10).

Hamid (2010). “ Assess Seismic Performance of Three Types of Concrete Structural Wall Panels Using Fragility Curves”, Malaysian Construction Research Journal, Volume 6, No. 1, ISSN No: 1985-3807, pp 13-28

FEMA 273:(1997), “ NERHP Guidelines for the Seismic Rehabilition of Buildings” and FEMA 274:(1997) “Commentary”. Federal Emergency Management Agency, Washington, U.S.A.

Mander, J. B.(2003) “Beyond Ductility: The Quest Goes On.” *Symposium to Celebrate the Lifetime Contributions of Professors Emeriti Tom Paulay and Bob Park*, Christchurch, New Zealand, pp75-86.

Kennedy, R.P.,Cornell, C.A., Campbell, R.D., Kaplan, S. and Perla, H.F.(1980). “Probabilistic Seismic Safety Study of an Existing Nuclear Power Plant.’ *Nuclear Engineering and Design*, No.59, pp5-338.

Dutta, A., and Mander, J.B. (1998), “Capacity design and fatigue analysis of confined concrete columns.” Technical Report. MCEER-98-0007, Multidisciplinary Center for Earthquake Engineering, State University of New York, Buffalo, NY, U.S.A

Pekcan G., Mander, J.B, Chen, S., (1999), “Fundamental Considerations for the Design of Non-Linear Viscous Dampers.” *Earthquake Engineering and Structural Dynamics*, N28. pp1405-1425.

DAMAGE ASSESSMENT OF REINFORCED CONCRETE BEAMS AT DIFFERENT FLEXURAL DAMAGE LEVELS USING ACOUSTIC EMISSION TECHNIQUE

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Abstract
Reinforced Concrete (RC) structures could deteriorate or damage during their service life due to the effect of heavy loads, fatigue and aging. These effects could induce excessive cracking to the structure, and consequently, structural damage could be progressively developed. There are several techniques which could be used for the assessment of cracking and degree of damage. Among these techniques, the Acoustic Emission (AE) has been realized as an effective and valuable Non-Destructive Testing (NDT) method for the evaluation of RC structural damage. This paper presents an investigation on the usage of AE technique for testing the effect of beam depth on the damage mechanism of the RC beams resulted from flexural failure mode. MICRO - SAMOS (μ-SAMOS) Digital AE system was used to conduct the test. Cumulative absolute energy was used to analyze the integrity of the beams. The results showed good agreement between visual observation and AE results in determining the damage mechanism of the RC structure. As the level of damage increased, the cumulative absolute energy increased with increasing beam depth. This study demonstrated that AE technique can be a useful tool in monitoring the structural health performance of RC beams.

Keywords: *(Acoustic Emission; NDT; Structural Health Monitoring; Cumulative Absolute Energy.)*

INTRODUCTION

Reinforced Concrete structures (RC) in service life could be deteriorated as a result of heavy loads, fatigue and aging of the structures. Cracking is commonly observed in concrete structures. It is important to understand that all types of cracking is due to different causes and may have different effects on short and long-term performance due to the confounding effects of design, imposed loads, and climatic conditions relevant to the structure (Yoon *et al*., 2000). There are many types of concrete cracking which can be divided into two major categories namely micro-cracking and macro-cracking. On one hand, crack development in the composite materials depends on the mechanical interaction between the inclusions (fine sand or coarse aggregate) and the cement-based matrix, whereas strain softening and the fracture energy depend on the material composite structure which it is controlled by the mechanical interaction of the aggregates with the cement-based matrix (Wittmann, 2002). Such defects require monitoring to satisfy durability and serviceability requirements (Kabir *et al*., 2009). Structural cracks, such as flexural crack and shear crack, are active only if the overload condition continues or if settlement occurs (Yoon *et al*., 2000, Kabir *et al*., 2009). In the regions of constant bending moment, only tensile and flexural cracks occur without sliding along the crack. Additionally, flexural crack opening is usually produced by elongation of tension reinforcing bars only when there is no slip at their end (Hassan *et al*., 1991). Previous investigators reported that the spacing between flexural cracks is influenced by the type of longitudinal reinforcements (Hassan and Ueda, 1987, Zararis, 2003). Extending of structural life and avoiding structural failure can be achieved by early detection of cracks. Besides, the control of cracking in concrete structures is very much desirable to satisfy durability and serviceability requirements (Wan and Leung, 2007, Hassan *et al*., 1991).

Presently, there are several methods of testing that can be used detect and monitor the deterioration of concrete in structure. The test methods can be divided into two maincategories, namely: destructive test and Non-Destructive Test (NDT). These methods are based on different principles and have different effectiveness on different types of deterioration (Mahmood, 2008). One of the most promising NDT techniques is Acoustic Emission (AE) (Matsuyama *et al*., 2010). There are mainly two different aspects between AE method and the other NDT methods. Firstly, the energy signal originates from the sample itself for the case of AE. Secondly, the AE can detect the dynamic process, due to its capability in detecting movement or strain, whereas most of the other methods have the ability in detecting existing geometrical discontinuities or fractures (Degala, 2008). In the determination of location of cracks, the principle used is the Time-of-Arrival (TOA) approaches (Huguet *et al.,* 2002). Microscopic and macroscopic events are two main mechanisms that generate AE, and this technique is highly sensitive for detecting active microscopic and macroscopic events in material or composite (Luo *et al*., 2004). In addition, AE monitoring strategies can be divided into two types, namely global and local. Local monitoring tackles a specific area of damage, such as monitoring in real time damage growth in laboratory specimen(Shah and Chandra Kishen, 2010, Ohno and Ohtsu, 2010, Vidya Sagar and Raghu Prasad, 2010), while a global monitoring helps in evaluating the health and integrity of the whole structure (Nair and Cai, 2010, Lovejoy, 2007)

AE can be defined as a localised stress wave that propagates within the materials from active deformation (Degala *et al.,* 2009). AE events also can be produced by crack onset, fiber breaks, disbands, moving dislocations, plastic deformation, etc. (Pollock, 2003). The objective of an AE test is to detect the presence of emission sources and to provide as much information as possible about the source (Degala *et al.,* 2009). There are five commonly used signal measurement parameters which are amplitude, counts, measured area under the rectified signal envelope (MARSE), duration, and rise time. The AE signal features are shown in Figure 1.

Cracking pattern and the propagation of cracks are mainly dependent on the loading type and loading conditions. According to a recent study (Bunnori *et al*., 2011), the initial cracking position depend on the internal cracks and flaws during loading, and the mechanical behaviour of reinforced concrete beam can be divided into five different stages, namely; micro–cracking, first visible crack, distributed flexural cracking, shear cracking, and damage localization.

The AE signal features such as rise time, average frequency, amplitude, counts, and duration are influenced by several conditions namely attenuation such as discontinuities, scattering and dispersion while propagation is mainly due to heterogeneity of concrete which results from its microstructure (fine aggregates, coarse aggregates, cement, air voids, pores as well as all kinds of cracking, etc.). The differential velocity of the distinct wave modes originated from the source crack can be one of the inflammations (Aggelis, 2011)/. AE had been applied to investigate the effect of the maximum aggregate size (d_{max}) on the fracture properties (Chen and Liu, 2007). In addition, AE parameters are also found to be influenced by type of loading (Lim and Koo, 1989, Yun *et al.,* 2010, Ohtsu *et al.,* 2002, Henkel and Wood, 1991), material characteristics (Soulioti *et al.,* 2009, Aggelis et al., 2011, Chen and Liu, 2008), and etc. However, research on the effect of size of structure on the AE output data is still scarce.

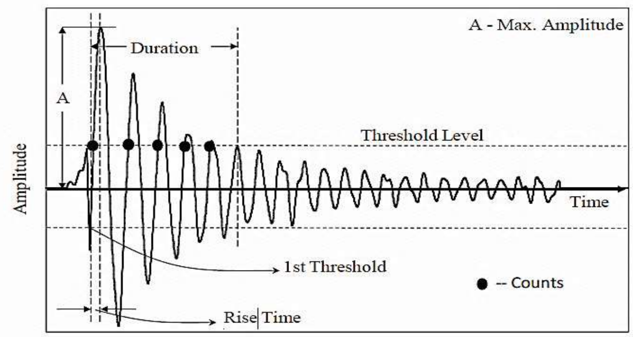


Figure 1. Acoustic Emission Signal Features (Degala, 2008)

In the current study, the AE results from flexural bending tests at different types of RC beams are presented and discussed. Twelve specimens of RC beams with different depths were prepared and tested under the four points bending while concomitantly monitoring their AE activity.

The objective of the present study is to investigate the capability of the AE technique for monitoring of RC beams subjected to flexural failure mode by considering various beam depths. This study is conducted by exploring the cumulative absolute energy for different damage levels of the RC beams. The values of the absolute energy (aJ) at each level of damage are proposed.This value can be used for indicating the onset of concrete cracking, and is significantly importance when monitoring concrete structures.

SAMPLE PREPARATION

According to significant mechanical behaviour obtained from test results, the damage levels in the sample are classified into: (1) Micro–cracking, (2) first visible crack, (3) distributed flexural cracking, and (4) damage localization. The AE signal characteristics for each level of damage are computed.

Three typesof RC beam with same span length 1500mm with different depth of beams were prepared and the detailed sizing are given in Table 1. In this study, the beams were reinforced with 2-No.3 and 2-No.1 diameter deformed steel bars at the tension and compression faces, respectively according to American Standard (ACI318-08). They were denoted by Type I (TI), Type II (TII) and, Type III (TIII) with stirrups center-to-center spacing of No.1 diameter at 80mm, 100mm and, 130mm, respectively. The cross section detailing for all types are presented in Figure 2.

Table 1. Descriptions of test specimens according to ACI-08 code

Types	Section b x h (mm)	Longitudinal reinforcement (%)	Shear reinforcement (%)	Maximum Factored load (kN)
TI	200 x 200	2-No.3	No.1@80mm	21.1
TII	200 x 250	2-No.3	No.1@100mm	27.7
TIII	200 x 300	2-No.3	No.1@130mm	34.3

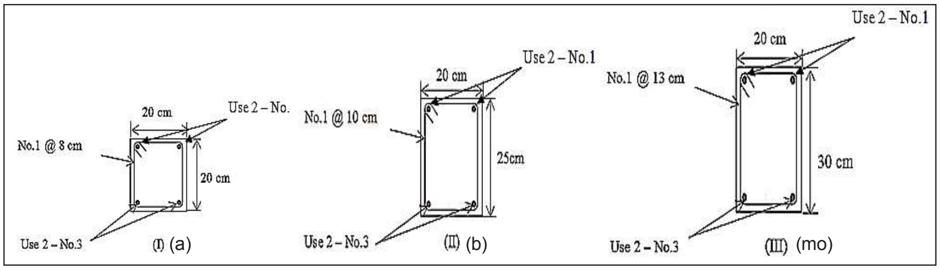


Figure 2. Cross section detailing forbeam s: (a) Type I, (b) Type II, and (c) Type III

Properties of Materials

The specified characteristic compressive concrete strength was 45MPa while the compressive concrete strength on the day of testing was 47MPa. The mechanical properties of concrete and steel are given in Table 2. All RC beams were cured in water for 28 days prior to testing.

Table 2. Properties of concrete and steel reinforcement

Materials	Concrete	Steel
Compressive strength (MPa)	47	-
Yield stress (MPa)	-	420

Loading and Acoustic Emission System

All the beams were tested under the four point loading (stepwise monotonic loading) to examine the flexural cracks behaviour and the level of damage in all specimens using the AE technique, as shown in Figure 3. The tests were conducted using a 500kN capacity loading frame system consisting of a hydraulic jack, load cell (TCIP-20B) and a Kyowa data logger (UCAM-20PC)). Four AE sensors (R6I) with frequency ranges of 35–100 kHz were mounted on the specimen surface using magnetic clamp. Silicon grease was used as coupling agent between the sensor and the concrete surface. The locations of the four sensors are shown in Figure 4. AE source locations were identified by the AE detection system (MICRO -SAMOS (μSAMOS) Digital AE System) based on the differences in AE signals arrival time at an array of four AE sensors on the specimen and a preset wave velocity measured with pencil lead breaks in accordance with Hsu-Nielsen source method (ASTME976, 2010). In this study,the data hits parameters were set for all parameters to avoid any missing data information. To improve the results of the FastFourier Transform (FFT) and eliminate edge effects, the waveform length and sampling rate was set to (1000kSPS) and the pre trigger setting was 250.000 μs which allows for the entire waveform to be captured with no signal at the start and end of the waveform. To eliminate electrical and mechanical noises, the threshold level was set at 45dB(Miller and McIntire, 1987). The monitoring system was hold for one minute for ensuring there is no noise of emission was detected during that period. After a minute, the load was applied in stepwise loading as presented in Figure 4. The first step of loading was from 0.5 to 10kN and it was kept constant for 3 minutes prior to the next loading step until the failure stage.

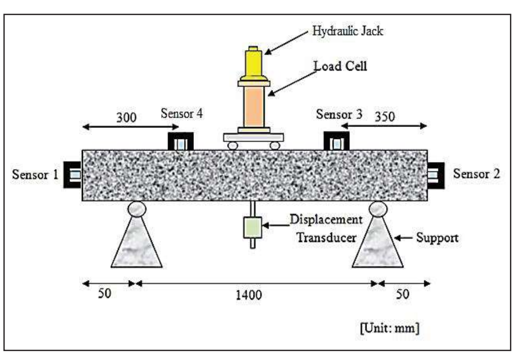


Figure 3. Set up of the four point bending test

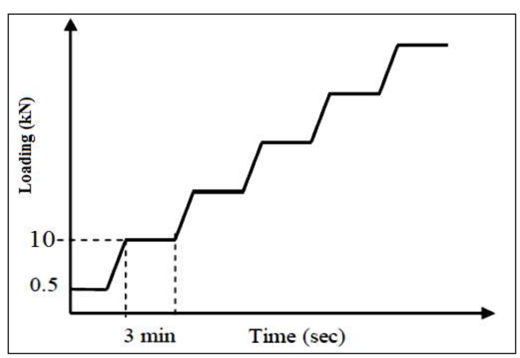


Figure 4. Graphical representation of the stepwise loading

TEST RESULTS AND DISCUSSION

The test results and the subsequent discussion focused on all stages of damage, while the important region was the region between regions I and II, where micro-cracking and the onset of surface cracking usually occurred.

Crack Development

The crack pattern and propagation are mainly dependent on the loading type and loading conditions. The initial cracking position is depending on the internal cracks and flaws during the loading. Hence, the propagation of internal cracks will lead to the first visual crack (Bunnori et al., 2011, Yun et al., 2010). From the test and observation, it was found that all beams failed in flexural mode. Figure 5 shows the load-deflection curve for the three types of RC beams, and the different damage levels, namely (I) Micro-cracking, (II) First visible cracks (point A), (III) Distributed flexural cracks (point B), and (IV) Damage localization (point C) are clearly identified on the load-deflection curves.

Type I beams, which have the smallest depth was regarded as controlled beams. Figure 6(a-e), shows the typical crack propagation process observed for one of the control beams (TI) at the specified damage levels, while Figure 7(a) and (b) shows the crack patterns obtained through visual observation for the TII and TIII beams, respectively at the identified damage levels.

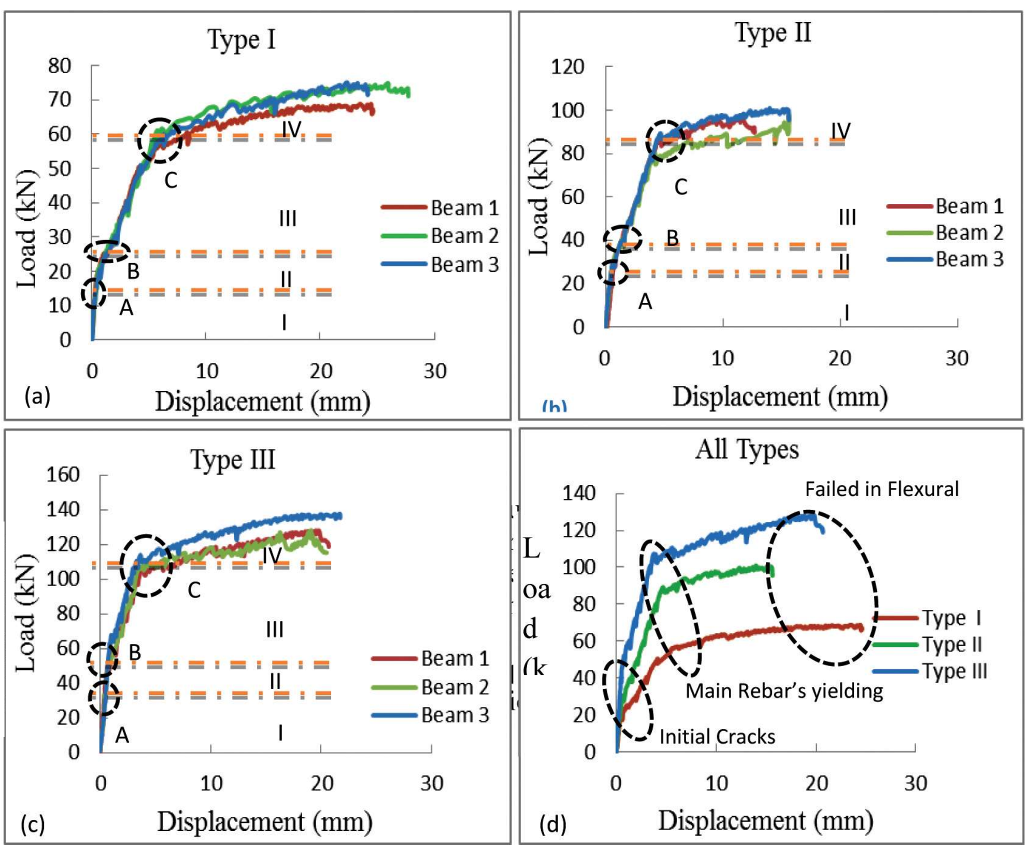


Figure 5. Load-displacement: (a) Type I, (b) Type II, (c) Type III and/ (d) All Types

From the test and observation, it was found that all beams failed in flexural mode as shown in Figure 6. Determination of the failure stages of the reinforced concrete beams was done based on visual observation of the onset of crack; as shown in Figure 6(b-e), while Figure 6(a) shows there was no visible cracking, although there was internal micro-cracking developed inside the RC beams. In this study the test results and the subsequent discussion focused on all stages of damage, while the important region was the region between level of damage I and level of damage II, where the micro-cracking and the onset of surface cracking usually occurred, respectively as shown in Fig. 5. In the controlled beam the first cracks were observed visually on the surface at approximately 930 mm in Figure 6(b) at 15kN. While the first cracks for TII and TIII beams were observed at approximately 510 mm, 700 mm, 820 mm, and 1000 mm as in Figure 7(a) and 480 mm and 715 mm as in Figure 7(b) at 23kN and 36kN, respectively. The respective load corresponding to the first crack for beams TII and TIII is shown in Figure 5(b) and Figure 5(c), respectively. The crack propagation in TII and TIII were largely spread; though, the same crack propagation was noticed in TI beam as shown in Figure 6. For the TI, as the load increased, a flexural crack propagated between the two point loads of the beam after an initial flexural crack was generated at the bottom surface of the mid span in the tension zone. These flexural cracks were observed at approximately 460 mm, 585 mm, 760 mm, 910 mm and 1070 mm as in Figure 6(c) at 28kN. While for TII and TIII, these were observed at an applied load of 37kN and 48kN, respectively. The load and the corresponding displacement are shown in Figure 5(b) and 5(c)for TII and TIII beam, respectively.

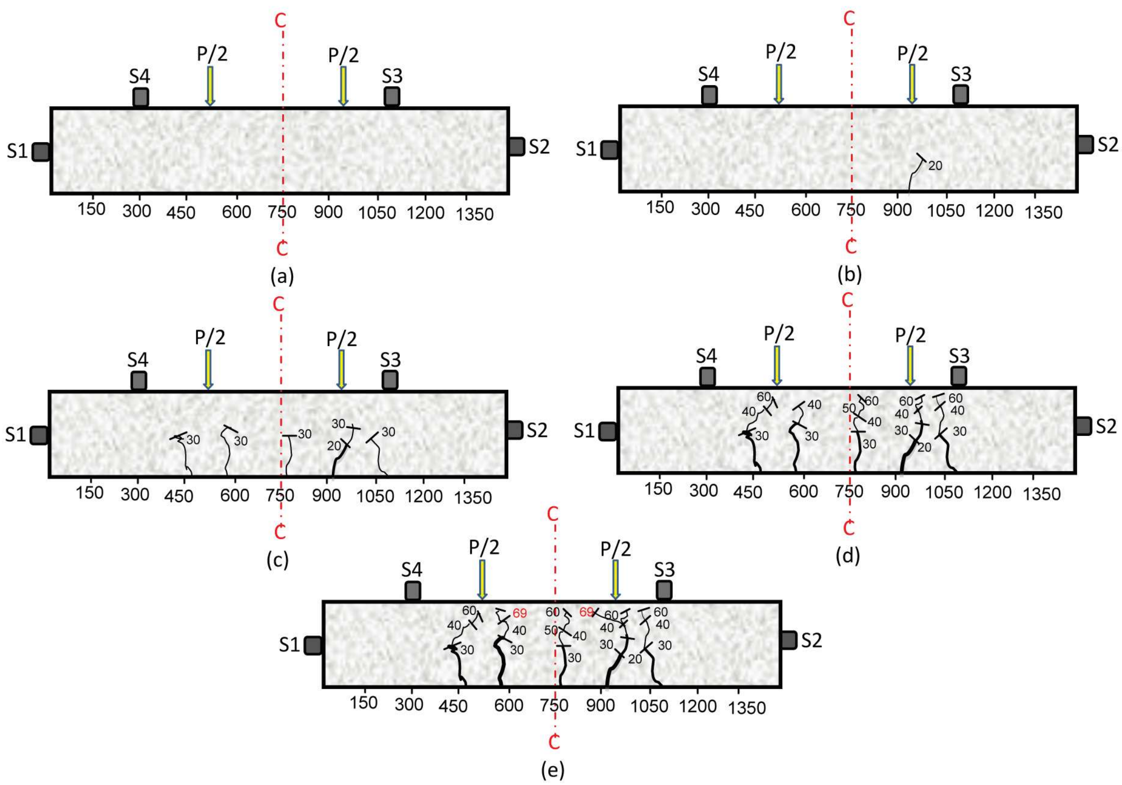


Figure 6. Crack patterns obtained by visual observation of all Category I: (a) Stage I- as a micro-cracking , (b) Stage II- as a first visible cracks, (c) Stage III- as a distributed flexural cracks, (d) Stage IV- as a damage localisation , (e) Failure mode. (Load in kN, and distance in mm)

As the load was further increased, the initial cracks propagated upward to the compression zone and all cracks started to localize into major cracks where the width of each crack was significantly widened, which corresponds to damage localisation stage. Figure 5(d) shows that the cracks start to localise at an applied load of 60kN, 85kN and 107kN for TI, TII and TIII beam, respectively. When the load reached the maximum capacity of 69kN, 97kN, and 120kN as shown in Figure 5(d) for TI, TII, and TIII beam, respectively, the beams failed in conventional ductile flexure with the yielding of the tension steel, followed by the crushing of the concrete in the compression zone. Finally, it can be concluded that the overall cracks distribution for all beams were similar to that

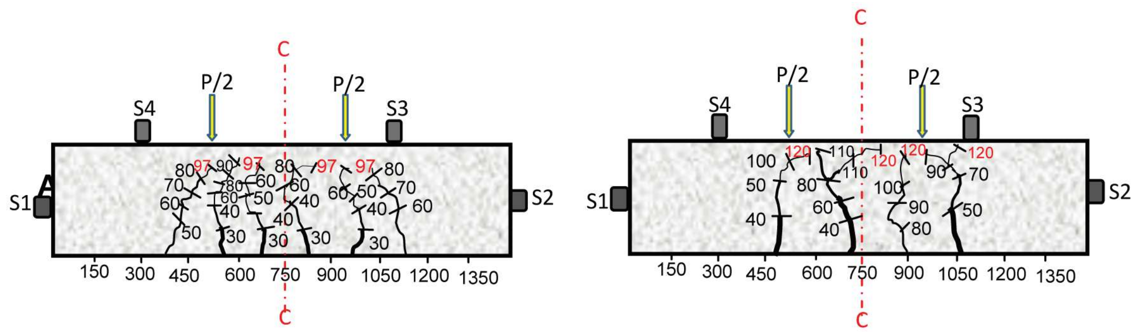


Figure 7. Crack patterns obtained by visual observation at the final stage of damage : (a) TII, (b) TIII. (Load in kN, and distance in mm)

AE Source Locations

In monitoring the crack initiation, propagation, and the location of damage localisation in the beams, a two-dimensional AE source location technique was performed as shown in Figure 8. This graph represents the AE linear location in term of Absolute Energy against X-position of the beams during the stepwise loading processes. The cracks propagation of the beams was represented by an Absolute Energy level vertically. As the cracks continuously propagated, the vertical Absolute Energy has moved side-way in the X-position along the beam.

In determining the location of cracks, the principle used was the Time-of-Arrival (TOA) approaches (Huguet et al., 2002). Figure 8(i-iii) showed the evaluation of the AE source locations at five different stages of TI, TII, and TIII, respectively. Figure 8(a (i-iii)) showed that at the first level of damage a few AE sources were generated close to the center of the lower surface of all the beams, where the maximum bending moment occurred. This corresponds to the development of micro-cracking (non-visible) in the beams. Comparison of the highest peak value of the absolute energy (aJ) for all types of beams were alsomade. It had indicated that the absolute energy in the three types tend to increase as the depth of the beams (i.e., 200–300 mm) increases, as shown in Figure 8(i-iii).As shown in Figure 8(a(i-iii)) and Figure 9, TIII beams exhibited the highest value of absolute energy of approximately 1.78 x106 (aJ) at a location near to 500 mm within the first level of damage. It was also observed that, before the cracks were visible, emission from AE had enabled the micro-cracks to be located accurately before the actual impairment occurred.

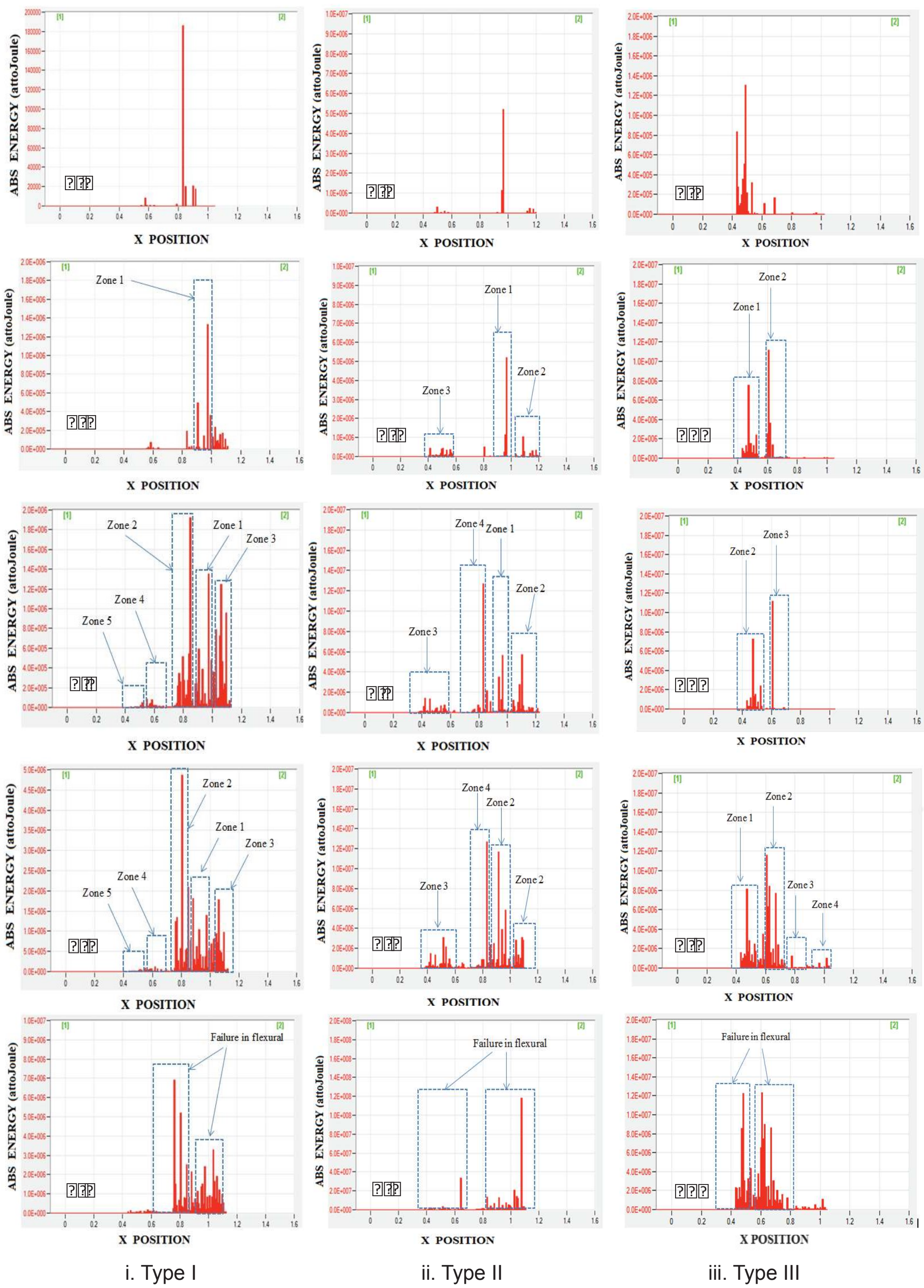


Figure 8. AE source location for TI, TII, and TIII: (a) Damage Level I; (b) Damage Level II; (c) Damage Level III; (d) Damage Level IV and (e) Final Failure (from damage level I to failure).

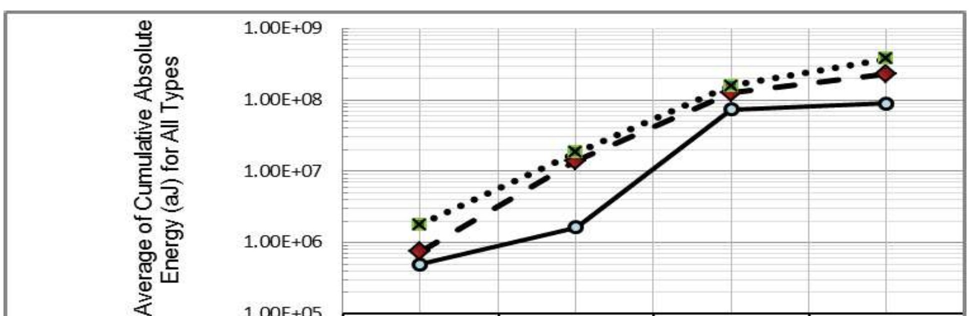
At the first visible cracks, AE sources were constantly generated at the tension face of the RC beam where the crack was located as per the previous level (Bunnori *et al*., 2011). This constant generation may have produced the flexural tension crack at the tension face of the RC beam. These cracks were propagated as the load increases which had been shown previously in Figure 6 and Figure 7. The highest value of the absolute energy at the first visible cracks stage was approximately 1.85x107 (aJ) as shown in Figure 8(b (i-iii)) and Figure 9. The location that has been detected by AE was at 620 mm (zone 2) in Figure 8(iii-b). The actual observation is shown in Figure 7(b).

When the load was increased the initial cracks was propagated upward and the stage of damage is known as distribution of flexural crack on the reinforced concrete beam surface. This observation is illustrated acoustically in Figure 8(c (i-iii)). Referring to Figure 9, the various sizes of the beam specimens clearly affected the absolute energy, this was proven as the highest peak value for TI is 7.35 x10^7 (aJ) which is lesser then type II and III which are 1.26 x10^8 (aJ) and 1.59 x10^8 (aJ), respectively.

In the damage localization stage (stage IV), the AE signals were generated at the boundary between the rebar and the concrete in the tension face; The higher energy in this stage, the higher the possibility of failure that will happen at that position (Bunnori et al., 2011).

At this region, all the cracks will start to localize into major cracks where the width of each crack will significantly widen. This observation is illustrated acoustically in Figure 8(d (i-iii)) and Figure 9, at this level of damage, where TIII beam had the highest value of the absolute energy of approximately 3.77 x 10^8 (aJ) and the location was near to 620 mm.

Up to the above discussion, Figure 8 show that the highest values of the Absolute Energy at each level of damage for all beams happened at the middle of X-position (flexural area or flexural zone), this fact confirmed that acoustically, all beams were failed in flexural mode, moreover this fact was confirmed visually in Figure 6 and Figure 7.



	Stage I	Stage II	Stage III	Stage IV
TI - (Depth) =20 cm	4.95E+05	1.63E+06	7.35E+07	8.87E+07
TII - (Depth) = 25 cm	7.60E+05	1.40E+07	1.26E+08	2.34E+08
TIII-(Depth) = 30 cm	1.78E+06	1.85E+07	1.59E+08	3.77E+08

Figure 9. Average of Cumulative Absolute Energy (aJ) for All Types at each level of damage

Overall, the resultssuggest that the AE system can be used as an instrument to detect and identify cracks, i.e. providing a warning on the development of distress and the growth of internal micro cracking at critical locations. Thus, AE can bea usefulfor structural health monitoringworks.

CONCLUSIONS

Based on the AE signal strength analysis presented in this paper, the following conclusions are made:

(1) From the observation for all concrete beams, it was found out that there were four stages of mechanical behaviour that will be experienced by the long beam before failure. These four stages are micro-cracking, localized crack propagation, distributed flexural cracking and finally the damage localization.
(2) The differences of crack locations between visual observation and AE sources were between 25 mm and 55 mm. So, AE could be considered as a promising technique to monitor and detect the location of cracks.
(3) Based on comparison between visual observation and the AE results for the three types of beams, it is found that the minimum of the cumulative absolute energy should exceed 1.63×10^6 (aJ), 1.4×10^7 (aJ), and 1.85×10^7 (aJ), for depths 20, 25, and 30 cm, respectively; the onset of the first crack occurs. Moreover, when the specimens experienced localization of damage, the absolute energy will increase dramatically by about five to seven times.
(4) As level of damage increases, values of the cumulative absolute energy increase.
(5) There are clear effects of beam depth on the cumulative absolute energy,where the cumulative values of this parameterincrease with increasing depth of beam.

Overall, the result shows that AE is a promising technique to monitor and detect the location of the cracks.

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REFFERENCES

Aggelis, D., Soulioti, D., Barkoula, N., Paipetis, A. & Matikas, T. (2011) Influence of fiber chemical coating on the acoustic emission behavior of steel fiber reinforced concrete. *Cement and Concrete Composites*.

Aggelis, D. G. (2011) Classification of cracking mode in concrete by acoustic emission parameters. *Mechanics Research Communications,* 38**,** 153-157.

ASTME976 (2010). Standard Guide for determining the reproducibility of Acoustic Emission sensor response. The American Society for Testing and Materials.

Bunnori, N. M., Lark, R. J. & Holford, K. M. (2011) The use of acoustic emission for the early detection of cracking in concrete structures. *Magazine of concrete Research,* 63**,** 683-688.

Chen, B. & Liu, J. (2007) Investigation of effects of aggregate size on the fracture behavior of high performance concrete by acoustic emission. *Construction and Building Materials,* 21**,** 1696-1701.

Chen, B. & Liu, J. (2008) Damage in carbon fiber-reinforced concrete, monitored by both electrical resistance measurement and acoustic emission analysis. *Construction and Building Materials,* 22**,** 2196-2201.

Degala, S. (2008) *Acoustic Emission Monitoring of Reinforced Concrete Systems Retrofitted With CFRP.* University of Pittsburgh.

Degala, S., Rizzo, P., Ramanathan, K. & Harries, K. A. (2009). Acoustic emission monitoring of CFRP reinforced concrete slabs. *Construction and Building Materials,* 23**,** 2016-2026.

Hassan, H. M., Farghally , S. A. & Ueda, T. (1991) Displacement at shear crack in beams with shear reinforcement under static and fatigue loading. *Japan Society of Civil Engineers, JSCE,* 15**,** 215-222.

Hassan, H. M. & Ueda, T. (1987.) Relative displacement along shear crack of reinforced concrete beam. *Proceedings of JCI,* 9**,** 699-704.

Henkel, D. & Wood, J. (1991) Monitoring concrete reinforced with bonded surface plates by the acoustic emission method. *NDT & E International,* 24**,** 259-264.

Huguet, S., Godin, N., Gaertner, R., Salman, L. & Villard, D. (2002) Use of acoustic emission to identify damage modes in glass fibre reinforced polyester. *Composites Science and Technology,* 62**,** 1433-1444.

Kabir, S., Rivard, P., He, D. C. & Thivierge, P. (2009) Damage assessment for concrete structure using image processing techniques on acoustic borehole imagery. *Construction and Building Materials,* 23**,** 3166-3174.

Lim, M. & Koo, T. (1989) Acoustic emission from reinforced concrete beams. *Magazine of concrete Research,* 41**,** 229-234.

Lovejoy, S. (2007) Applications of Structural Health Monitoring to Higway Bridges. Western Bridge Engineers' Seminar

Lou, X., Haya, H., Inaba, T., Shiotani, T. & Nakanishi, Y. (2004) Damage evaluation of railway structures by using train-induced AE. *Construction and Building Materials,* 18**,** 215-223.

Mahmood, A. (2008) *Structural Health Monitoring Using non Destructive Testing of Concrete.* Bachelor Thesis, National Institute of Technology

Matsuyama, K., Yamada, M. & Ohtsu, M. (2010) On-site measurement of delamination and surface crack in concrete structure by visualized NDT. *Construction and Building Materials,* 24**,** 2381-2387.

Miller, R.K. & Mcintire, P. (1987) Nondestructive Testing handbook. Vol. 5: Acoustic Emission Testing. *American Society for Nondestructive Testing, 1987*, 603.

Nair, A. & Cai, C. (2010.) Acoustic emission monitoring of bridges: Review and case studies. *Engineering structures,* 32, 1704-1714.

Ohno, K. & Ohtsu, M. (2010) Crack classification in concrete based on acoustic emission. *Construction and Building Materials,* 24, 2339-2346.

Ohtsu, M., Uchida, M., Okamoto, T. & Yuyama S. (2002) Damage assessment of reinforced concrete beams qualified by acoustic emission. *ACI Structural Journal,* 99.

Pollock, D. A. A. (2003) Acoustic Emission Inspection. *Member of MISTRAS Holding Group* .

Shah, S. G. & Chandra Kishen, J. (2010) Fracture behavior of concrete-concrete interface using acoustic emission technique. *Engineering Fracture Mechanics,* 77, 908-924.

Soulioti, D., Barkoula, N., Paipetis, A., Matikas, T., Shiotani, T. & Aggelis, D. (2009). Acoustic emission behavior of steel fibre reinforced concrete under bending. *Construction and Building Materials,* 23, 3532-3536.

Vidya Sagar, R. & Raghu Prasad, B. (2010) An experimental study on acoustic emission energy as a quantitative measure of size independent specific fracture energy of concrete beams. *Construction and Building Materials*.

Wan, K.T. & Leung, C.K.Y. (2007) Fiber optic sensor for the monitoring of mixed mode cracks in structures. *Sensors and Actuators A: Physical,* 135, 370-380.

Wittmann, F. (2002) Crack formation and fracture energy of normal and high strength concrete. *Sadhana,* 27, 413-423.

Yoon, D. J., Weiss, W. J. & Shah, S. P. (2000.) Assessing damage in corroded reinforced concrete using acoustic emission. *Journal of Engineering Mechanics,*126, 273-283.

Yun, H. D., Choi, W. C. & Seo, S. Y. (2010) Acoustic emission activities and damage evaluation of reinforced concrete beams strengthened with CFRP sheets. *NDT & E International,* 43, 615-628.

Zararis, P. D. (2003) Shear strength and minimum shear reinforcement of reinforced concrete slender beams. *ACI Structural Journal,* 100.

GUIDE TO AUTHORS

Aims and Scope:

The Malaysian Construction Research Journal (MRCJ) 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 MRCJ 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 11 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:

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CODIFICATION AND APPLICATION OF SEMI-LOOF ELEMENTS FOR COMPLEX STRUCTURES

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

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[1]Department of Civil Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia

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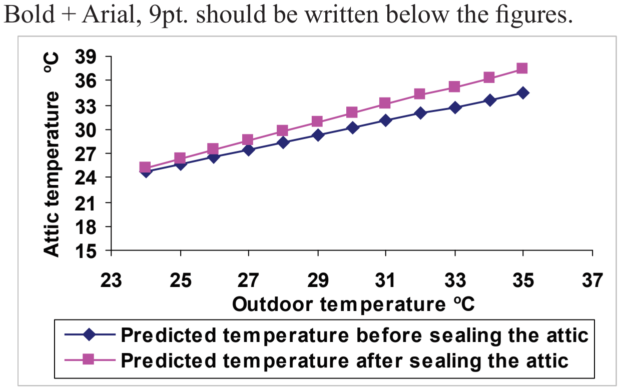

Figure 8. Computed attic temperature with sealed and ventilated attic

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

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Table 1. Recommended/Acceptable Physical water quality criteria

Parameter	Raw Water Quality	Drinking Water Qualiti
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 0.64 cm, first line left indent – 0.64 cm. 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 Analysing 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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