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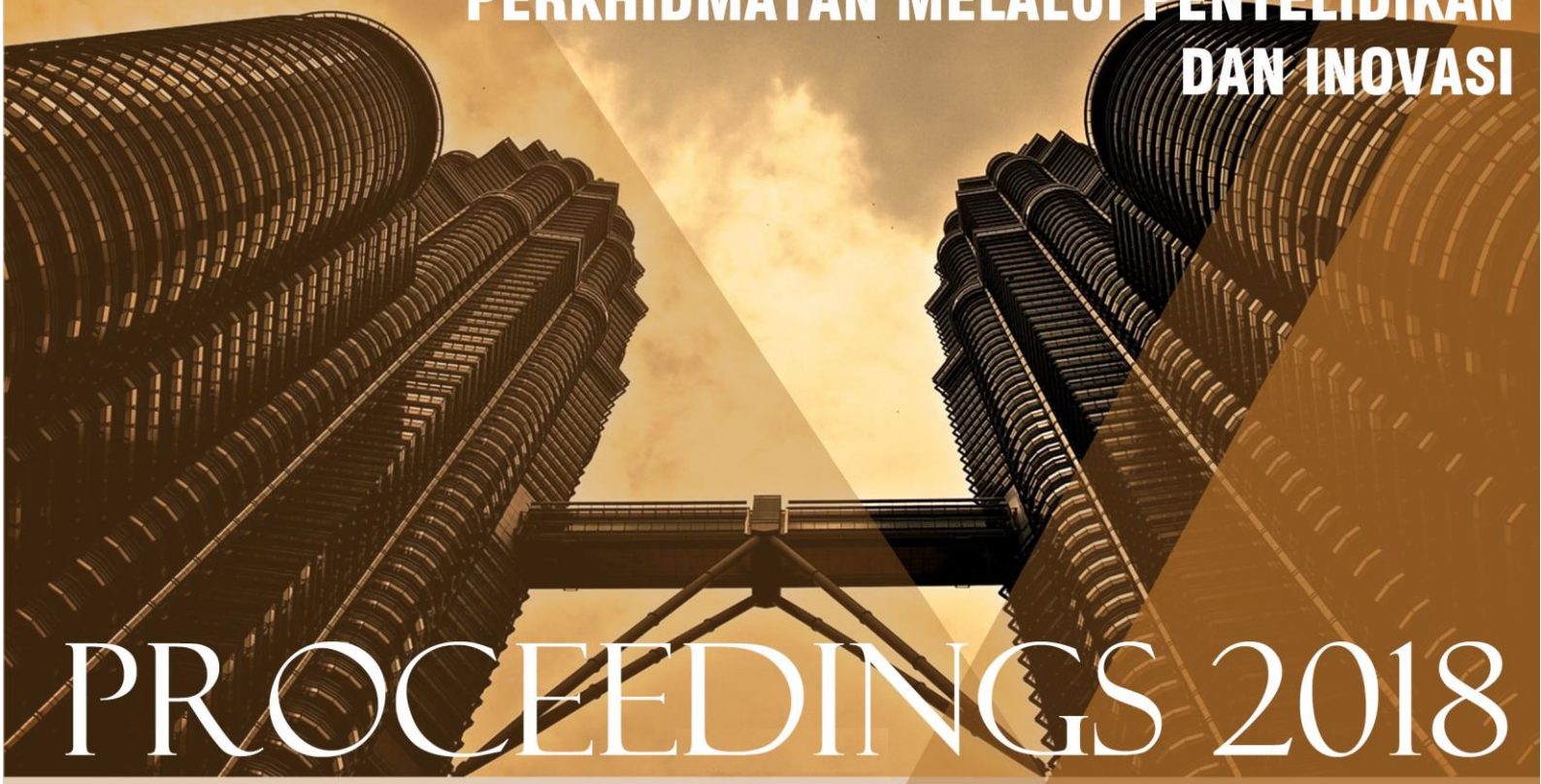
PENAMBAHBAIKAN SISTEM PENYAMPAIAN PERKHIDMATAN MELALUI PENYELIDIKAN DAN INOVASI



PROCEEDINGS 2018

ACKNOWLEDGEMENT

The organising committee would like to take this opportunity to express its thanks and appreciation to all of those who have contributed to the hosting and running of JKR Research Colloquium 2018 (JKRRC), including the authors, invited speakers, JKRRC delegates, staff members of The Centre of Excellence for Engineering and Technology Jabatan Kerja Raya (CREaTE), and exhibitors.

PREFACE

This book compiles selected proceedings of the JKR Research Colloquium 2018 (JKRRC 2018), organised by The Centre of Excellence for Engineering and Technology Jabatan Kerja Raya Malaysia (CREaTE) between August 28th and 29th, 2018. The proceedings are grouped into nine (9) engineering fields:

- Air Conditioning and Mechanical Ventilation;
- Thermochemical Cooling System;
- Total Asset Management;
- Solar PV Hybrid System Design;
- Building Energy Efficiency;
- Flexible Joint for Drainage System over Soft Ground;
- Mechanical Properties and Fracture Behaviour;
- Deep Tunnel Excavation Material Modelling; and
- Islamic Leadership Principles in Construction Project Management.

JKRRC 2018 aims to provide a platform that is conducive to fruitful networking and interaction; and ideas exchange of research results, innovation and latest technological advances between JKR researchers and its collaborative partners from both the academia and industry players. The theme "Improvement of service delivery system through research and innovation" expresses the significance of research and innovation in enhancing the service delivery system in the public service.

This book presents research findings from various engineering fields which will benefit researchers, practicing engineers, and advanced students alike. It is hoped that this proceedings would spur JKRRC 2018 delegate's interest in engineering research and development.

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A Comparative Study of the Mechanical Properties and Fracture Behaviour of Concrete with Steel Fibres and Concrete with Different Strengths

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Abstract

This study presents the results of an experimental program that compares mechanical properties and fracture behaviour under bending of concrete with steel fibres (CF) and different concrete strengths namely; C30, C40, C50 mixtures. Compressive strength, splitting tensile strength, modulus of elasticity, flexural strength and fracture energy of the specimens were determined. Notched beams were tested under three point bending test to examine the flexural and fracture energy of the concrete. The objective of this research is to investigate the effect and the contribution of steel fibres to the mechanical properties and fracture behaviour in the concrete of different strengths. The results show that the influence of steel fibers on splitting tensile, flexural and fracture energy is very significant. Steel fibres seem to improve the fatigue life of concrete and ensure the increase of the energy dissipation at failure.

Keywords: Concrete with steel fibre; Concrete with different strengths; Mechanical properties, Fracture behaviour.

1. Introduction

Steel fibres have been used as effective concrete reinforcements since 1960. Their usage has increased fairly in many applications of civil engineering construction such as in the construction of large industrial floor slabs, bridge deck overlays, marine structures, airport runways, pavements, highway and railroad bridge, spillways, dams, slope stabilizations, and many precast products (Bentur & Mindess, 2007; Błaszczyński & Przybylska-Fałek, 2015). Over the years, the ability of steel fibres in concrete in providing toughness, resistance to tensile stresses after cracking, enhanced tensile behaviour and better crack control properties has considerably increased the utilization of steel fibres. The presence of fibres in concrete seem to improve the fatigue performance of concrete whereby concrete will possess higher tensile stresses which guarantees a longer structural life resulting from the enhanced concrete toughness. Thus, steel fibres are able to produce better concrete performance for higher load levels (Islam & Alam, 2013).

There are several further improvements which can be seen resulting from inclusion of steel fibres in concrete such as the increased toughness or energy absorption capacity, tensile strength, fatigue resistance, and ductility (Rostasy & Hartwich, 1988; Taengua, 2013). Important parameters to be considered is the influence of the fibre types, fibre geometry, distribution, orientation, concentration and bonding properties of fibres within the concrete matrix (Van Zijl & Zeranka, 2012; Goud.E &Praveen, 2015). The effect of concrete

confinement with steel fibres can inhibit splitting failure and the dominant mode of failure will be shear pull-out failure (Yeih *et al.*, 1997). Since the application of steel fibres in concrete has found its way in the construction industry, it must be able to compete economically with existing reinforcing system.

Many researchers, as mentioned in the references, studied the influence of steel fibres on the mechanical properties and fracture behaviour of concrete; however, only a few research made comparative studies on concrete of different strengths. Therefore, the aim of this study is to produce basic data on the effects of steel fibres on the mechanical properties and fracture behaviour in order to improve structural design.

2. Experimental Study

The experimental program consisted of several different tests to characterize the performance of the concrete with steel fibres (CF) mix relative to the different concrete grade mixes namely C30, C40 and C50. The program includes mechanical properties testing such as the compressive strength, splitting tensile strength, flexural strength, and fracture energy determination and response. This investigation intended to evaluate and compare the fracture behaviour for three types of concrete mix, and CF.

2.1 Materials and mix proportions

Concrete mixes produced for this study were concrete of grades 30, 40, 50 and concrete with steel fibres (CF). Table 1 shows the material quantities required for 1 m^3 concrete. In this study, all concrete mixes are using similar types of aggregate, which is granite size 10mm and Portland cement. Concrete mix for CF is made from the same concrete mix of grade 40. The volume of steel fibre was 1% of the total volume of concrete added to the mixture in order to produce CF. As indicated in Fig. 1, the steel fibre used in CF mix was hooked-end shape, which was 0.55 mm in diameter and 35 mm long with aspect ratio of 64. The fibre manufacturer had specified minimum tensile strength value of 1100 MPa for the 35 mm long fibres that conform to ASTM A820 Standards. Table 2 summarises the fibre properties. The fraction of 1% of steel fibre was chosen for this study due to higher splitting tensile strength results observed after carrying out splitting test on specimens containing volume fraction of steel fibres of 0.25%, 0.5%, 0.75%, 1%, 1.25% 1.5% and 1.75%.

Table 1. Material quantities required for 1 m^3 concrete mixtures.

Concrete Mix	w/c	Cement (kg)	Water (kg)	Aggregate (kg)		Superplaticizer (kg)
				Fine	Coarse	
C30	0.55	425	235	875	810	1.06
C40	0.48	485	235	810	810	1.21
C50	0.42	490	205	810	875	4.9
CF	0.48	485	235	810	810	1.21

Material quantities required for 1m^3 concrete mixture

Fig. 1. Hooked end steel fibre geometries.

Table 2. Properties of hooked end steel fibre.

Diameter (mm)	0.55
Length (mm)	35
Density (kg/m^3)	7850
Tensile Strength (MPa)	1200
Elastic Modulus (GPa)	205

2.2 Mechanical properties test

The compressive strength, splitting tensile strength and modulus of elasticity of all the concrete mixes were determined in accordance with BS EN 12390-3-2009, (2009), BS EN 12390-3-2009, (2009) and BS EN 1881-121-1993, (1993), respectively. For all beams, the tests for determination of the flexural strength (f_{flex}) and fracture energy (G_F) were performed according to the recommendation of RILEM 50-FMC (1985).

The specimens were cast in steel moulds and compacted on a vibration table. All the specimens were de-moulded after 24 hours and cured in water for 28 days. At least three specimens of each concrete mix were tested under each type of loading condition at day 28. The beams prepared for the fracture energy tests were 550 mm in length and 150 mm x 150 mm in cross-section. Three cubes were used for compressive test; three cylindrical specimens each for the splitting test and modulus of elasticity test were prepared. Details of the tests and dimensions of the specimens are given in Table 3.

Table 3. Test methods and specimen size.

Test method	**Specimen**	**Dimensions (mm)**	**Parameters**
Compression	Cube	100 x 100 x 100	Compressive strength (f_{cu}), MPa
	Cylinder	ø100, h = 200	Modulus of elasticity (E), GPa
Splitting	Cylinder	ø100, h = 200	Splitting tensile strength (f_{st}), MPa
Three-point bending	Beam	150 x 150 x 550	Fracture energy (G_F), N/m Flexural strength (f_{flex}), MPa

The three point bending test of all specimens was done to estimate the flexural tensile strength and the fracture energy performance. The fracture energy (G_F) can be defined as the amount of energy needed to create one unit area of a crack. This test was performed by testing a simple supported beam under third-point loading using a closed-loop, servo-controlled testing system. The specimen used for this testing was prism shaped with dimensions of 150 × 150 × 550 mm notched at the mid-span of 5 mm width and 25 mm in depth. The notching point became the

weak area during testing, thus, initial crack originated from this location. Then, the deflection of the specimens was recorded. The Linear Variable Differential Transducers (LVDT) was mounted on the rigid frame that was fixed to the mid-width of the specimen as shown in Fig. 2.

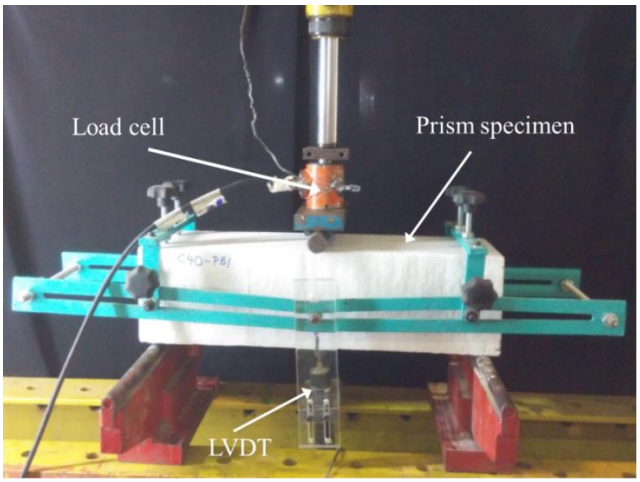


Fig. 2. Three point bending test setup.

The load was applied to the specimen at a constant rate of 0.3 mm/min until 2 mm deflection was reached. Then, the loading was continuously applied to the specimen at a constant rate of 1.5 mm/min until the deflection of 5 mm was reached. The testing was conducted in accordance to RILEM 50-FMC (1985) and BS EN 14651-2005 (2005). Based on those codes, the determination of the flexural tensile (f_{flex}) and fracture energy (G_F) can be calculated using Equation 1 and Equation 2, respectively (Bayramov, Taşdemir & Taşdemir, 2004):

$$f_{flex} = \frac{3PS}{2b(h - a)^2} \quad (1)$$

where:
P = the ultimate load
S = span
b = thickness
h = height
a = notch depth

$$G_F = \frac{W + (mgS\,\delta)/L}{b\,(h - a)} \quad (2)$$

where:

W = area under the load-deflection curve
m = weight of the beam
g = gravitational acceleration
L = length of the beam
δ = deflection of the beam (5 mm for fibred series).
Equation 2 contains the fracture energy supplied by beam weight. The area under the load-deflection curve was used to evaluate the fracture energy of all specimens, which is an

indication of the energy absorption capability of test specimens. The calculation of fracture energy for fibred series was specified until the cut-off point of 5mm deflection (Bayramov, Taşdemir &Taşdemir, 2004; Yardimci, Baradan & Tasdemir, 2014) as shown in Fig. 3.

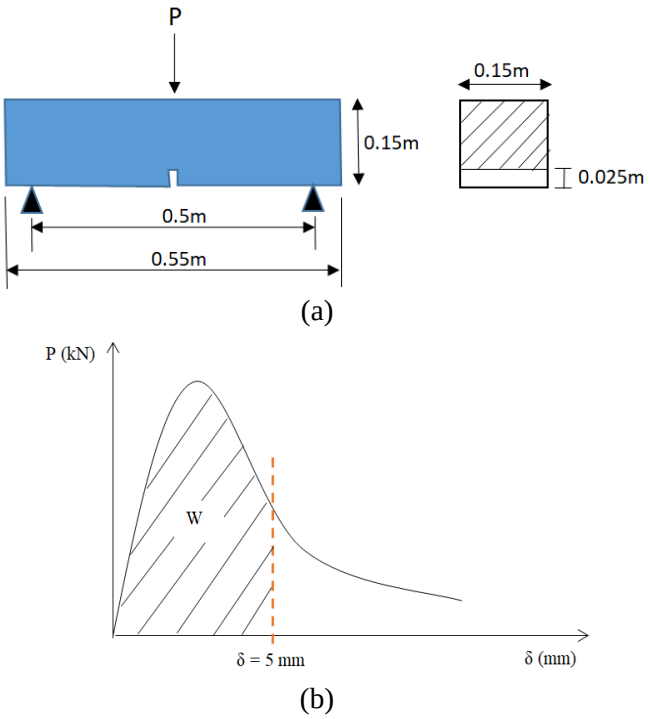


Fig. 3. Schematic representation of: (a) the test setup, and (b) evaluation of fracture energy.

3. Results and discussions

3.1 Compression and splitting test

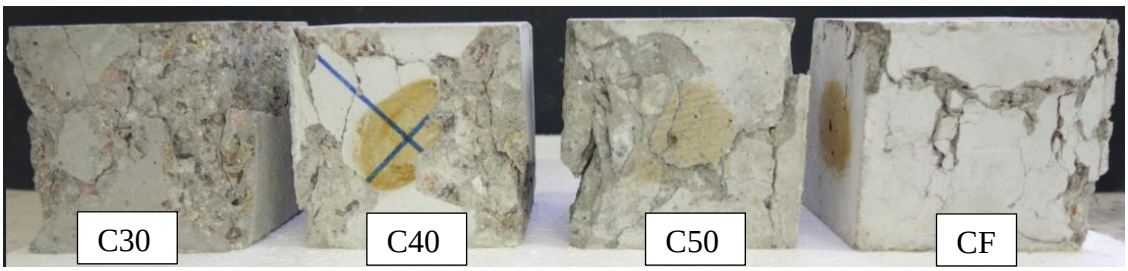
Table 4 shows the results obtained from the compressive, splitting tensile strength and modulus elasticity tests conducted on the specimens at the end of the 28 days curing periods. Normally, concrete strength is influenced by water to cement (w/c) ratio, as well as properties of coarse aggregate. Since the coarse aggregate used in all the concrete mixes are of the same type, therefore, the factor that influenced the concrete strength in all the specimens is the w/c ratio. The results show that lower w/c ratios will produce relatively stronger concretes; and higher w/c ratios will produce weaker concretes. Concrete C50 gained the highest compressive strength as it is produced by using the lowest w/c ratio (refer to Table 1). The compressive strength for CF was comparative less to those recorded for C40 and C50. According to Ahmed, Siddiqi and Yousaf (2007) and Arel and Yazici (2012), the addition of steel fibres to concrete has little contribution and is less significant on the compressive strength.

Table 4. Strength and fracture properties of specimens.

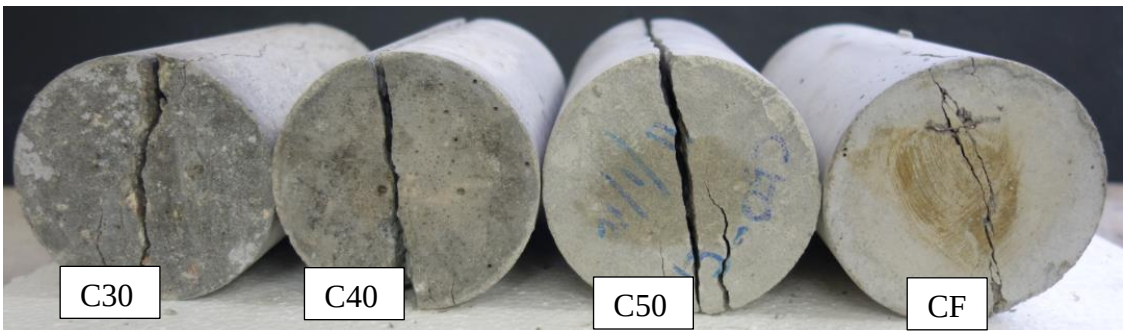
	Concrete code			
Mechanical Properties	C30	C40	C50	CF
Compressive strength (f_{cu}), MPa	31.70	44.74	58.20	49.85
Splitting tensile strength (f_{st}), MPa	4.06	5.57	5.60	7.60
Modulus of elasticity (E), GPa	19.8	25.4	30.8	28.2
Flexural strength (f_{flex}), MPa	6.40	7.60	9.30	10.75
Fracture energy (G_F), N/m	7589	8089	9356	9996

For splitting tensile test, the results show that CF specimen gained higher tensile strength, in the range of 36% to 87%, as compared to those recorded for C30, C40 and C50. This indicates that the presence of steel fibres in concrete promotes effective action in resisting and preserving the integration of the concrete, until high deformation, owing it to the bridging effect against the cracks contributed by the steel fibres (Rao & Rao, 2009; Khaloo *et al.*, 2014).

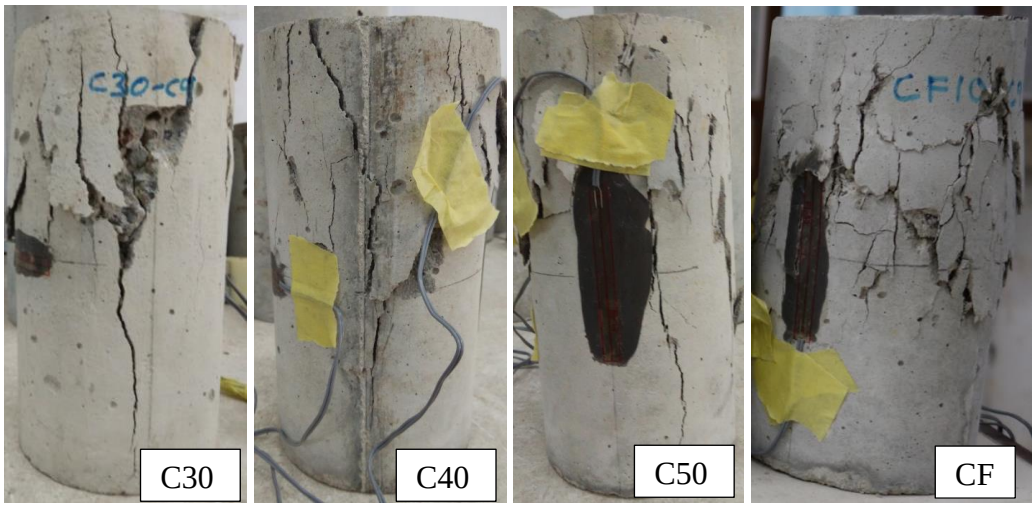
Meanwhile, the modulus of elasticity values for all the specimens were calculated using the stress-strain curves gained from the results of the compression test on the cylindrical specimens after the curing period (28 days). The results show that C50 produced higher elastic modulus compared to that of C40 and C30. This shows that C50 is more capable of sustaining from the proportionality of stress to strain (Haranki, 2009). Fig. 4 shows the failure mode of samples obtained from compressive strength test, splitting tensile test and elastic modulus test.



(a)



(b)



(c)

Fig. 4. Failure mode of specimens in (a) compression test, (b) splitting tensile test and (c) modulus elasticity test

3.2 Three-point bending test

This standard test method determines the amount of energy required to deflect and crack the beam specimens, with a central notch, when loaded at mid span. Generally, the flexural tensile strength of normal concrete (C30, C40, C50) differs to that of CF. The unreinforced concrete section, referred to as normal concrete, tends to resist tension force by its interlocking strength. Meanwhile, CF, which is reinforced by distributed steel fibres, resists the tension force through the steel fibres. Therefore, the significant enhancement in post-cracking behaviour of all specimens is strongly associated with the tensile strain at rupture.

Table 4 shows the flexural strength results for all concrete mix specimens. These are results of the stiffness of the materials in bending test, and the response of the maximum tensile stress value that can be sustained before the specimens fail. Results indicate that CF obtained higher flexural strength in the range of 16% to 68% as compared to that of concrete grade C30, C40 and C50. This indicates steel fibres in CF delay the bending failure in the concrete due to the strength of the bond that between steel fibres and concrete matrix. The fracture behaviour for CF shows the slow crack propagation due to progressive de-bonding of steel fibre in concrete. When the steel fibres are pulled out, and the interfacing shear stress reached the ultimate strength, the crack propagation become unstable and final crack occurred. The presence of steel fibres in concrete that can increase the flexural strength of concrete seems to be more significant (Gao, Sun & Morino, 1997).

Fig. 5 shows the characteristic load-deflection response under direct loading for all specimens prepared from C30, C40, C50 and CF. The load-deflection response was relatively linear up to the first cracking load, and then it became nonlinear till peak load. After peak load, the load dropped, followed by an asymptotic descending response exhibiting significant ductility before complete failure was observed. For C30, C40 and C50 specimens, there was no indication of first crack near the mid-span of the beam when the load was increased. At peak load, the stiffness of the specimen dropped. During the peak load, a few vertical cracks suddenly appeared at mid span of the specimen and immediately caused the specimen to break into two. It was also observed that there was no post-cracking behaviour demonstrated by the C30, C40 and C50 beams indicating brittle failure manner in this beam. The failure mode of the specimens

corresponded to the preformed notches. The failure mode for all specimens is presented in Fig. 6. For CF specimens, the gradual post-peak reaction was due to the delayed failure of the concrete matrix caused by the fibre pull-out occurrence and sewing effect of the fibres (Löfgren, 2005; Taengua, 2013). Fig. 7 shows the close-up of CF crack failure that indicates the sewing effect of the steel fibres.

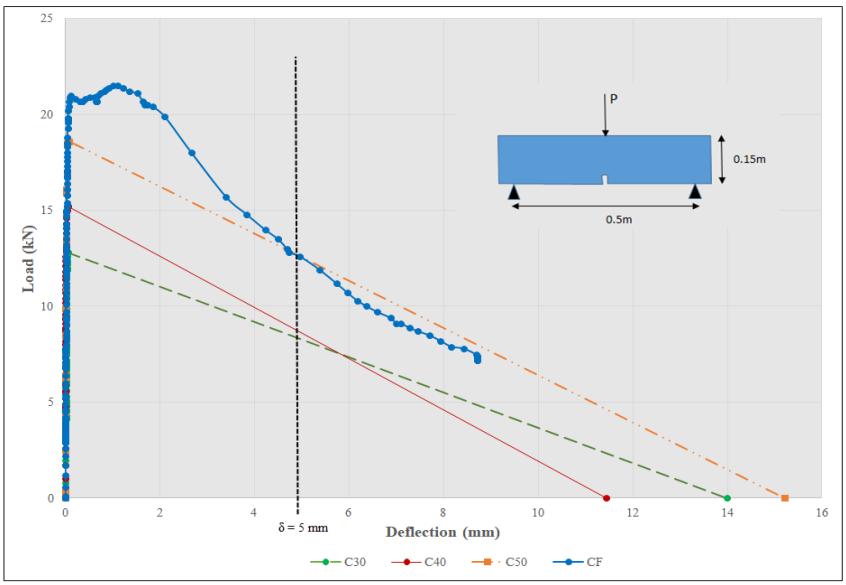


Fig. 5. Load-deflection relationship.

Based on results in Table 4, it can be deduced that the fracture energy for CF is higher than that of concrete C30, C40 and C50 specimens in range of 7% to 32%. It can clearly be seen that the increases of fracture energy for CF is due to the presence of steel fibres in concrete. CF specimen obtained high value of fraction energy and demonstrated a higher load carrying capacity after first cracking as compared to other concrete mix specimens because of the higher energy needed for steel fibres to pull-out and de-bond in the fracture process. It indicates that steel fibres were forming a bridge in the crack, which was delaying crack propagation (Bayramov, Taşdemir& Taşdemir, 2004; Yardimci, Baradan & Tasdemir, 2014)

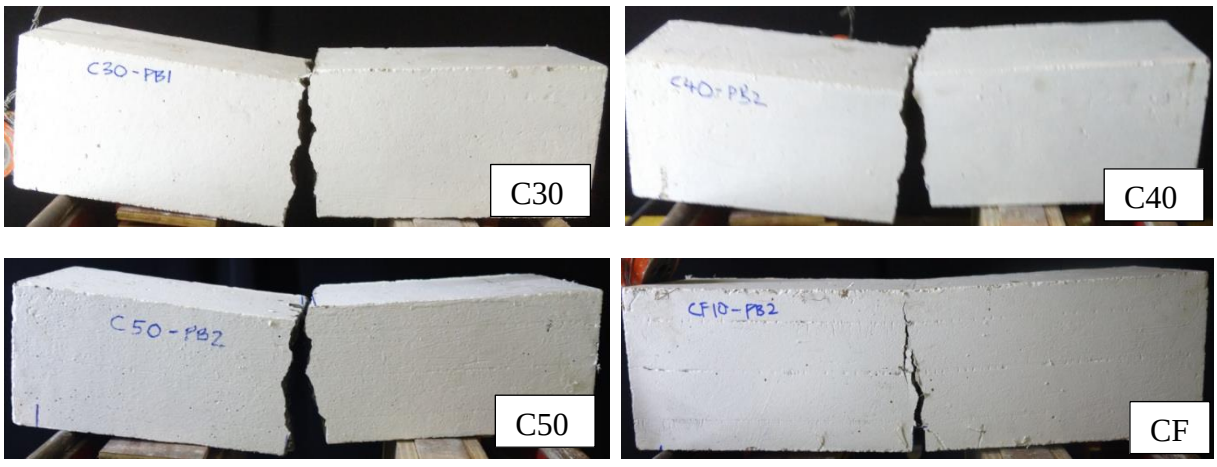


Fig. 6. Fractured specimens.

Fig. 7. Sewing effect of steel fibre in CF specimen.

4. Conclusions

The experimental results lead to the following conclusions:

(1) Compression test results indicate that the increment in compressive strength is dependent on the water cement ratios whereby lower water cement ratios will produce relatively stronger concretes, and higher water cement ratios will produce weaker concretes. The addition of steel fibres to concrete has little contribution and has minimal significance on the compressive strength.

(2) The presence of steel fibres in concrete gives advantage to CF specimen in that it generates higher splitting tensile strength as compared to that of the other concrete specimens. This proves that steel fibres can promote effective action in resisting cracks resulting from the steel fibre bridging effect against the cracks.

(3) For modulus elasticity, the higher result is dominant in higher concrete grade such as that is of C50. It shows that higher concrete grade is more capable of sustaining from the proportionality of stress to strain. Thus, there is no significant effect of fibre volume fraction on the modulus of elasticity.

(4) CF specimen shows higher value of the flexural strength in range of 16% to 68% when compared to that of the specimen of concrete grade C30, C40 and C50. This indicates that the steel fibres in CF delay the bending failure in the concrete due to the strength of steel fibres bonding with the through concrete matrix.

(5) Contribution of steel fibre in CF specimen has demonstrated high value of fraction energy and generation of higher load carrying capacity after first cracking. This shows that the higher energy is needed for steel fibres to pull-out and de-bond in the fracture process.

Therefore, it can be concluded that CF has more advantages compared to other concrete grades and is able to delay the crack propagation. Steel fibre has demonstrated that its presence in concrete improved the fatigue life of concrete and ensured increased in energy dissipation at failure and that it is suitable for use in mega structures especially for maximum deformability control of structures.

5. Acknowledgments

The authors wish to express their sincere thanks to Ministry of Education Malaysia (MOE), Universiti Teknologi Malaysia (UTM), Research Grant Vote No. 06H61 and 4L664 and Jabatan Kerja Raya Malaysia for making this study possible.

6. References

[1.] Ahmed, K., Siddiqi, Z. A. and Yousaf, M. (2007) 'Slippage of Steel in High and Normal Strength Concrete', *Pakistan Journal of Engineering & Applied Sciences*, 1, pp. 31–39.

[2.] Arel, H. S. and Yazici, S. (2012) 'Concrete – reinforcement bond in different concrete classes', *Construction and Building Materials*, 36, pp. 78–83. doi: 10.1016/j.conbuildmat.2012.04.074.

[3.] Bayramov, F., Taşdemir, C. and Taşdemir, M. A. (2004) 'Optimisation of steel fibre reinforced concretes by means of statistical response surface method', *Cement and Concrete Composites*, 26(6), pp. 665–675. doi: 10.1016/S0958-9465(03)00161-6.

[4.] Bentur, A. and Mindess, S. (2007) *Fibre Reinforced Cementitious Composites*. 2nd Editio, *Civil Engineering*. 2nd Editio. Great Britain: Taylor & Francis Group.

[5.] Błaszczyński, T. and Przybylska-Fałek, M. (2015) 'Steel Fibre Reinforced Concrete as a Structural Material', *Procedia Engineering*, 122(Orsdce), pp. 282–289. doi: 10.1016/j.proeng.2015.10.037.

[6.] BS EN 12390-3-2009 (2009) *Testing hardened concrete, Part3:Compressive strength of test specimens, British Standard Institution*. Brussels: BSI Standards Publication.

[7.] BS EN 14651-2005 (2005) *Test method for metallic fibred concrete — Measuring the flexural tensile strength (limit of proportionality (LOP), residual), British Standard Institution*. London: BSI Standards Publication. doi: 9780580610523.

[8.] BS EN 1881-121-1993 (1993) *Method for determination of static modulus of elasticity in compression, British Standard Institution*. London: BSI Standards Publication.

[9.] Gao, J., Sun, W. and Morino, K. (1997) 'Mechanical properties of steel fibre-reinforced, high-strength, lightweight concrete', *Cement and Concrete Composites*, 19(4), pp. 307–313. doi: 10.1016/S0958-9465(97)00023-1.

[10.] Haranki, B. (2009) *Strength, Modulus of Elasticity, Creep and Shrinkage of Concrete used in Florida*. University of Florida.

[11.] Islam, M. S. and Alam, S. (2013) 'Principal Component and Multiple Regression Analysis for Steel Fibre Reinforced Concrete (SFRC) Beams', *International Journal of Concrete Structures and Materials*, 7(4), pp. 303–317. doi: 10.1007/s40069-013-0059-7.

[12.] Khaloo, A. *et al.* (2014) 'Mechanical performance of self-compacting concrete reinforced with steel fibres', *Construction and Building Materials*. Elsevier Ltd, 51, pp. 179–186. doi: 10.1016/j.conbuildmat.2013.10.054.

[13.] Löfgren, I. (2005) *Fibre-reinforced Concrete for Industrial Construction - a fracture mechanics approach to material testing and structural analysis*. Chalmers University of Technology.

[14.] Rao, G. A. and Rao, A. S. (2009) 'Toughness indices of steel fibre reinforced concrete under mode II loading', *Materials and Structures*, 42(9), pp. 1173–1184. doi:

10.1617/s11527-009-9543-6.
[15.] RILEM 50-FMC (1985) ‘Determination of Fracture Energy of Mortar and Concrete by Means of Three- Point Bend Tests on Notched Beams’, *Materials and Structures*, 18(106), pp. 285–290. doi: 10.1007/BF02498757.
[16.] Rostasy, F. S. and Hartwich, K. (1988) ‘Bond of deformed reinforcing bar embedded in steel fibre reinforced concrete’, *The International Journal of Cement Composites and Lightweight Concrete*, 10(3), pp. 151–158.
[17.] Taengua, E. J. G. (2013) *Bond of Reinforcing Bars to Steel Fibre Reinforced Concrete (SFRC)*. Universitat Politecnica De Valencia (Spain).
[18.] Yardimci, M. Y., Baradan, B. and Tasdemir, M. A. (2014) ‘Effect of Fine To Coarse Aggregate Ratio on Workability and Fracture Properties of Steel Fibre’, 39(December), pp. 0–5.
[19.] Yeih, W. *et al.* (1997) ‘A Pullout Test for Determining Interface Properties between Rebar and Concrete’, *Advanced Cement Based Material*, 5(96), pp. 57–65.

Mechanical properties of Mengkulang Glued laminated (glulam) timber and laminated veneer lumber (LVL)

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Abstract

This paper presents the investigation of mechanical properties of glued-laminated timber (glulam) and laminated veneer lumber (LVL) manufactured from a tropical medium hardwood, Mengkulang (Heritiera s.p). The properties included bending stiffness; local and global modulus of elasticity (MOE local, $E_{m,l}$ and MOE global, $E_{m,g}$) and the strength (bending strength parallel to grain, f_m). Three samples comprising 7 glulam beams, 7 nos. of LVL flatwise beams (for bending flatwise) and 6 nos. LVL edgewise beams (for bending edgewise), were subjected to four point loading procedures according to Eurocode standards, BS EN 408: 2010 +A1: 2012. Besides, the moisture contents and densities were also determined as stated by BS EN 13183, BS EN 323: 1993 and BS EN 322: 1993 as well. Results specified Mengkulang glulam had the highest strength and stiffness among the others. The MOE global was higher than MOE local as discovered in the glulam sample, mainly due to the presence of the weak zone at the low bending stiffness. The LVL edgewise sample was proved to have greater values of stiffness and strength than that of the LVL flatwise. The LVL edgewise fracture beam could be observed as grain deviation at the tension zone whereas LVL flatwise exhibited horizontal shear failure. The glulam sample passed the requirement of delamination percentage and the shear strength according to MS 758. The results from experimental also showed that the bending strength and stiffness of glulam and LVL, manufactured from medium hardwood of Mengkulang species (strength group S.G.5) could be improved to the equivalent strength of heavy hardwood.

Keyword: ETP, glulam, LVL, Mechanical properties, Mengkulang

1. Introduction

The structural application of engineered timber products (ETP, Fig. 1) in Malaysia is now increasing since the first glulam was structured; Masjid FRIM was constructed in 1977. Nevertheless, the MTIB Exhibition Centre (Galeri Glulam) in Johor Baharu (Fig. 2) that was completed in 2012 has given a positive impact on the development of the ETP usage. The building was constructed using tropical hardwood glued laminated timber (glulam) manufactured from Resak and Keruing species as the main structures (Smedley et al., 2012). After the successful of the project, several building namely Crops for the future building in Semenyih, Malaysian Pavillion Expo Milano 2015, Walkway Taman Negara, Pulau Kukup, and Multipurpose Hall, TLDM Lumut were also constructed using tropical hardwood glulam (Fig. 2). Despite the constructions mentioned above, there are on-going studies undertaken by educational institutions and government bodies such as the MTIB, JKR and CIDB to develop data related to the properties of these products. The fact is, the mechanical properties required for the design are still inadequate and unstandardized, thus resulting in lack of interest and familiarity amongst designers and architects to understand the behaviour of these products (Ahmad, 2013). Other factors include the cost of products which are not as competitive to other materials such as lightweight steel and concrete whereby to some extent will affect the demand

in our local building construction. To expedite more usage of ETPs namely glulam and LVL, more data related to these materials properties need to be prepared and disseminated to the industry.

Reference to design (glulam) and laminated veneer lumber (LVL) structure is based on MS 544: Part 3: 2001 and MS 544: Part 12: 2006, respectively. However, the grade of stresses used for LVL and glulam refer to solid timbers' values as stated in MS 544: Part 2, whereby previous studies demonstrated that glulam and other ETP possess higher strength than its parent material (Wan Mohamad et al., 2011; Burdurlu et al., 2007; H'ng, 2003; Kretschmann et al., 1993and Abbot & Whale, 1987). For bending member that have higher stress on the top due to compression, and bottom member due to tension, glulam beam can be manufactured by laminating the higher strength of other timber species at the top and bottom layer, and this can enhance its strength and load capacity (Ismail, 2015). Thus, the requirement for actual characteristic strength is very crucial for designers to attain economic and optimum design whilst avoiding inaccuracies and over-designing structural members.

Present Malaysian standards adopted the BS 5268 that is referred to the permissible stress utilizing mechanical testing on small clear defects free specimens. Whereas, the Eurocode standard, EN 1995 approach the limit state design with the strength and stiffness of timbers based on tests on the structural sizes. Normally, structural size specimens exhibit higher results than small clear specimens due to presence of defects which can affect the strength (Puaad et al.,2016), Therefore, this research work aims to investigate the mechanical properties namely bending strength and stiffness of Mengkulang glulam and LVL according to BS EN 408: 2010 +A1: 2012.

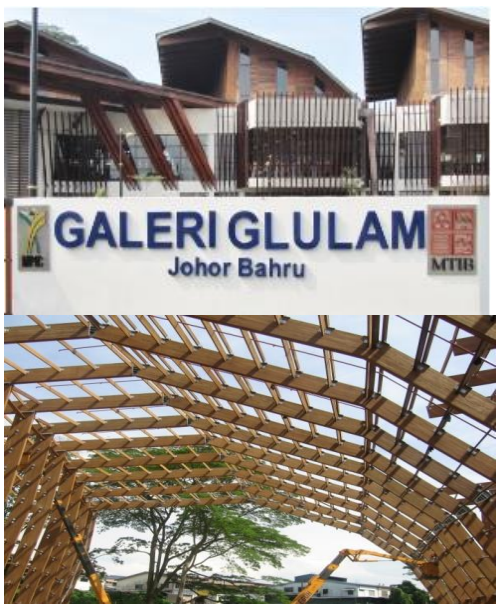
The experimental works of this research primarily include a series of bending tests to determine the local and global moduli of elasticity, and the bending strength parallel to grain (formerly known as modulus of rupture). The respective tests were conducted according to Clause 9.0, 10.0, and 19.0. The difference between the MOE local and MOE global is basically the bending behaviour since MOE local represent a pure bending deflection without shear, torsional or axial forces, while MOE global are incorporated with a combination of shear and bending deflection. Previous research conducted by Solli (2000) on over 200 numbers of samples demonstrated that there were good correlations between this two-stiffness modulus. However, the tension cross sectional area of a beam is reported to have a significant effect on the value of MOE global. (Sousa, Branco, & Lourenco, 2014).

This research also involved the quality control tests for Mengkulang glulam that includes delamination test and shear strength test according to MS 758.

(a) (b) (c)

Fig. 1. Engineered timber products: (a) Glued laminated (glulam) timber, (b) Laminated Veneer Lumber (LVL) and (c) Cross Laminated Timber (CLT) (source:www.apawood.org)

(a)



(b)

(c)

(d)

(e)

(f)

Fig. 2. (a) Masjid FRIM (1977) and TTTRC Glulam Bridge, Sarawak Forest Corporation (1997)
(b) The MTIB Exhibition Centre (*Galeri Glulam*), Johor Bahru
(c) Crops for the Future
(d) Malaysian Pavillion Expo Milano 2015
(e) Walkway Taman Negara, Pulau Kukup, Johor
(f) Multipurpose Hall, TLDM Lumut
(Source: http://www.mtib.gov.my)

2. Experimental

2.1 Material

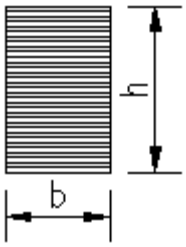
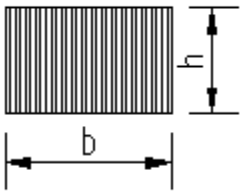
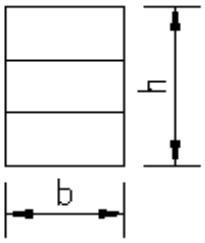
The species used to manufacture the beam specimen is Mengkulang (Heritiera sp.), a medium hardwood from the strength group of S.G.5. (Table 3, MS 544:2:2001). The timber can be visually identified by its colour of red-brown to dark red-brown. Its density is approximately 800 kg/m^3 at 19% moisture content and the specific gravity is 0.55. For most cases, timbers from the S.G.5 group are not intended for structural purposes (Muhammad, 2015). Nevertheless, there were several studies on the mechanical properties of ETPs manufactured from the S.G.5 group strength involving timber species such as Bintangor, Kedondong and Keruing in order to investigate their performance as structural members (Wan Mohamad et al., 2011 and Ahmad, 2013). The findings indicated those timbers to have good bending strength in meeting the standard requirement, and their bending properties were also influenced by the density of timber.

A local plywood factory manufactured the Mengkulang LVL based on the manufacturer's specification for wood based panel products. The product was the LVL board panels of about 50 mm thick x 1200 mm width x 2440 mm long. Each panel composed of thirty-three plies of 1.6 mm thick veneers with five cross lamination in-between that were glued together using weather boil proof type phenolic resin, namely Phenol Resorcinol Formaldehyde (PRF). This type of laminations can provide better dimensional stability than solid timber (H'ng, Ahmad & Tahir, 2012). Mengkulang glulam samples were produced by another commercial sawmill company to a required size of 85 mm width x 90 mm depth of beam member. PRF adhesive was used in joining three 30 mm thick lamination to form the 90 mm beam depth. All glulam and LVL samples were taken from one production source to ensure the uniformity of testing results.

2.2 Specimen Preparation

Glulam and LVL beam specimens were prepared in accordance to MS758:2001. The LVL panels were cut into specimen sizes using a table saw machine. Table 1 shows the specimen detail prepared for the test. All the specimens were conditioned at room temperature (27±2) °C with 55% relative humidity. This condition was not in accordance to the Eurocode, which specifies (20±2) ° C, and (65±5) % humidity since it would be difficult to achieve the standard environment in a tropical country. The samples were stored in laboratory as they would not be affected by climate changes.

Table 1. Samples numbers and dimension

	Mengkulang LVL (flatwise loading)	**Mengkulang LVL (edgewise loading)**	**Mengkulang Glulam**
No. of samples	7	6	5
Cross sectional dimension, b (mm) x h(mm)	 50 x 100	 100 x 50	 85 x 90
Total length = 19h	1900	950	1710
Span length, l = 18h	1800	900	1620

2.3 Apparatus and procedures

2.3.1 Bending Test

A two point load method, where the standard prescribed as 4-point bending with a simple supported beam and a centre-to-centre span as shown in Fig. 3 and 4 was configured and applied to all beam specimens according to BS EN 408:2010+A1:2012. The apparatus consists of a test machine, reaction-bearing plates, load bearing plates and two linear variable differential transformers (LVDTs) for measuring the vertical displacement. The lateral restraint was provided to prevent lateral buckling. The load on the beam was applied through a uniform displacement of the loading pistons at a rate not greater than (0.003 x h) mm/s. The maximum applied load should not exceed 40% of the estimated failure load, $F_{max,est}$ for the determination of local and global modulus. This estimated maximum load was obtained from preliminary tests carried out on the same species. However, as the bending strength parallel to grain is to be investigated in this research, the applied loading was increased until the failure of the beam occurred within 300±120 s.

During the test, LVDTs were connected to a data logger in which the readings were recorded by MEAS data file software installed in a computer. Data including loading time, load increment and displacements (w) was measured for both local and global MOE were then automatically converted into a Microsoft Excel spreadsheet file. The interpretation of results involved the plotting of load deformation graph for each specimen for the corresponded MOEs.

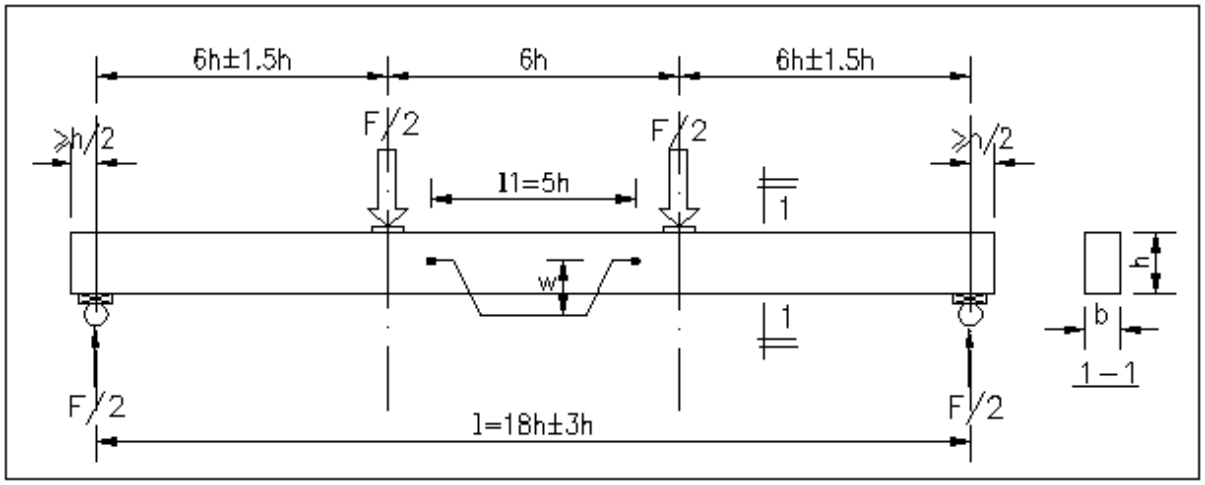


Fig. 3. Bending test set-up for local modulus of elasticity

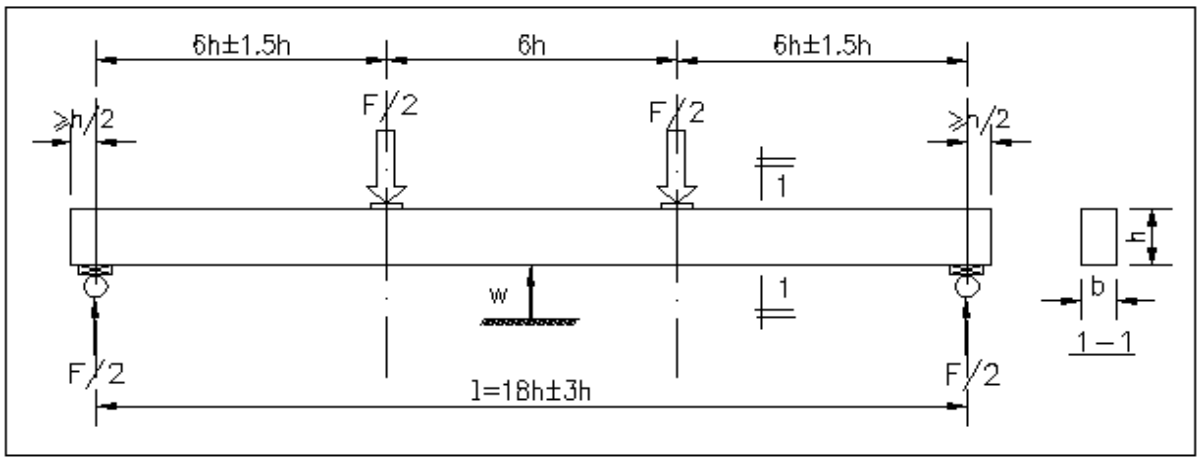


Fig. 4. Bending test set up for global modulus of elasticity

The section of the graph between 0.1Fmax, est and 0.4 Fmax, rst would be analysed with regression analysis. If the section obtained a correlation coefficient of 0.99 or higher, then the gradient for linear graph plotted would be taken to calculate Em,l and Em,g. The formulas provided in the standard for calculating the output parameters refer to the total loading force (F), which equals to F divided by 2 (F/2) when applying at the 1/3 span points. The calculation of global modulus of elasticity the shear modulus was considered as infinity.

The local and global modulus of elasticity ($E_{m,g}$ and $E_{m,l}$), bending strength parallel to grain (f_m) were determined using the respective equations below:

$$E_{m,l} = \frac{a{l_1}^2(F_2 - F_1)}{16I(W_2 - W_1)} \quad (1)$$

$$E_{m,g} = \frac{3al^2 - 4a^3}{2bh^3(\frac{W_2 - W_1}{F_2 - F_1} - \frac{6a}{5Gbh})} \quad (2)$$

$$f_m = \frac{3Fa}{bh^2} \quad (3)$$

Where:

$E_{m,l}$ = Local modulus of elasticity (N/mm^2)

$E_{m,g}$ = Global modulus of elasticity (N/mm^2)

f_m = Bending strength parallel to grain (N/mm^2)

$F_2 - F_1$= The increment of load on the regression line with a correlation coefficient of 0.99 or better (N)

$w_2 - w_1$= The increment of deformation corresponding to $F_2 - F_1$ (mm)

a = Distance between a loading position and the nearest support (mm)

I = Second moment of area (mm^4)

b = Width of the cross section, or the smaller dimension (mm)

h = Depth of the cross section, or the larger dimension (mm)

F_{max} = Maximum load (N)

G= Shear modulus determined by method given in Clause 11.1 or 11.2 of the code, or shall be taken as infinite (N/mm^2)

2.3.2 Moisture content and density

After the specimen were tested until failure, two test pieces of approximately 30 mm thick were cut from each of the specimen for the determination of moisture content and density. The methods for determining the moisture content conformed to BS EN 13183-1 and EN 323 using the Equation (4) stated below. The density is calculated by dividing the weight by the test piece volume. Reference was made to BS EN 322 for the density of LVL as well.

$$H = \frac{m_H - m_0}{m_0} \times 100 \qquad (4)$$

Where

m_H = Initial mass of the test piece (g)

m_0 = The mass of the test piece after drying at (103 ± 2) °C

2.3.3 Delamination Test of Glulam Specimen

For the delamination test, specimens with dimension of 75 mm in length, 85 mm in width and 90 mm in depth were immersed in water with a drawn vacuum of 70 kPa to 85 kPa for 5 minutes, followed by applied pressure of 500 kPa to 600 kPa for an hour. The vacuum pressure was repeated to make it a two-cycle procedure with a total time of 130 minutes. This test was conducted according to MS758:2001, which is similar to procedures adopted from the BS EN391:1995, but with adjustments made to meet the Malaysian requirements. Fig. 5 shows the preparation of the test vessel in the laboratory. The test specimens were dried at temperature range from 60°C to 70°C with a relative humidity less than 15% for approximately 21 hours to 22 hours. At the end of the drying period, the lengths of open glue lines on end grain surfaces of each test specimens were measured, and the total percentage of delamination is calculated using equations below:

$$Total\ delamination\ percentage = 100 \times \left(\frac{l_{tot.delam}}{l_{tot.glueline}}\right) \qquad (5)$$

Where,

$l_{tot.delam}$ = Delamination length of all glue lines in test piece (mm)
$l_{tot.glueline}$ = Centre length of glue line on the two end-grain surfaces of each test piece (mm)

$$Maximum\ delamination\ percentage = 100 \times \left(\frac{l_{max.delam}}{2l_{glueline}}\right) \qquad (6)$$

Where,

$l_{max.delam}$ = Maximum delamination length of one glue line in the test piece (mm)
$l_{glueline}$ = Length of one glue line, normally the width, b of the test specimen (mm)

Fig. 5. Test Preparation for the delamination test

2.3.4 Shear Test on Glue Lines

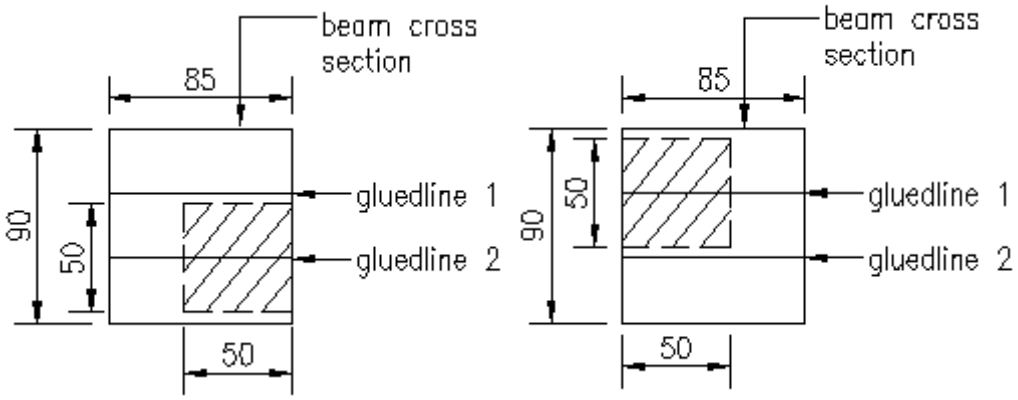
The shear strength of glue line parallel to the grain direction were determined in accordance with the MS 758:2001 and BS EN 392: 1995, but with necessary amendments to comply with the Malaysian requirements. All two glue lines of the three laminations were tested. The test pieces were cut from the bending test beam samples as shown in Fig. 6. A total number of 20 specimens were prepared with dimensions of 50 mm in width, depth and length. The test piece was subjected to a constant rate 0.01 mm/s to obtain a maximum load within or at least 20 seconds (Fig. 7). Percentages of the timber failure should be estimated immediately after the test and the shear stress strength was calculated using equation below:

$$f_v = k\frac{F_u}{A} \qquad (7)$$

Where,

f_v =shear strength
F_u = ultimate load
A =sheared area ($A = b \times t$)
k = modification factor, ie. $k = 0.78 + 0.044t$, t =thickness

It should be noted that the *k* factor was not considered in this calculation because the thickness in the grain direction of the sheared area is 50 mm.



a) Test piece no. 1 (b) Test piece no. 2

Fig. 6. Typical sample cuttings

Fig.. 7. Test setup for Block Shear test

3. Result and discussion

3.1 Bending strength and stiffness of glulam and LVL

The results of the maximum load of each beam, modulus elasticity and bending strength are tabulated in Table 2. Clause 5.4.3.3, BS EN 384: 2010 specifies that the values of bending strength for glulam should be adjusted to 150 mm depth or width by multiplying by the factor, kh as shown in Equation 8, with h defined as a beam depth during the bending test. Similarly, the value of bending strength for individual LVL edgewise specimen should be multiplied by the factor, km, corr, as in Equation 9 (BS EN 14374:2004).

$$k_h = \left[\frac{150}{h}\right]^{0.2} \qquad (8)$$

$$k_{m,corr.} = \left(\frac{b}{300}\right)^{s} \qquad (9)$$

Where,
b = Width of the tested specimen (mm) = height of beam, h
s = Size effect parameter, ie. $s = 2v - 0.05$, v is the coefficient of variation of test results

Table 2. Summary of bending properties for Mengkulang Glulam and LVL

		Modulus of Elasticity		**Bending strength parallel to grain**
Item	**Max Load (kN)**	**Global, $E_{m,g}$ (N/mm^2)**	**Local, $E_{m,l}$ (N/mm^2)**	**f_m (N/mm^2)**
GLULAM	35.00	17,823	16,989	101.90*
	22.96	17,135	19,944	64.24*
	25.09	15,267	17,143	71.99*
	30.09	15,676	14,651	86.39*
	28.17	20,038	15,414	81.96*
Mean	**28.26**	**17,188**	**16,828**	**81.3***
COV (%)	**16.5**	**11.1**	**12.1**	**17.7**
LVL/FLATWISE	14.7	10,035	13,860	52.92
	14.6	10,546	13,093	52.56
	13.69	9,855	12,618	49.28
	10.71	9,391	Invalid **[1]	38.56
	11.34	9,355	12,203	40.84
	13.74	9,332	11,611	49.46
Mean	**12.87**	**9,705**	**12,472**	**46.35**
COV (%)	**13.1**	**4.8**	**7.4**	**13.1**
LVL/EDGEWISE	21.52	13,319	14,295	66.14*
	22.00	11,873	13,838	67.61*
	20.98	12,060	15,414	64.48*
	16.62	12,182	13,410	51.08*
	19.65	12,020	15,878	60.39*
	19.79	12,688	Invalid**[2]	60.73*
Mean	**20.09**	**12,357**	**14,567**	**61.74**
COV (%)	**9.7**	**4.4**	**7.2**	**2.1**

Note: **[1]: invalid specimen due to R^2<0.99, **[2]: invalid specimen due to test error
* : values given have been multiplied by eithr k_h or $k_{m,corr}$

Table 3. Mean values of density and moisture content

Mengkulang samples	**Density (kg/m^3)**	**Moisture content (%)**
Glulam	714	13.0
LVL flatwise	584	13.6
LVL edgewise	674	12.8

From the Table 2 and bar charts as shown in Fig. 8 and 9, it can be observed that Mengkulang glulam obtained highest value for both modulus of elasticity (MOE) and the bending strength

parallel to grain followed by LVL Edgewise. The mean value of density and moisture content for each sample tabulated in Table 3 give similar results whereby the glulam exhibited the highest density among the three samples, while LVL flatwise had lesser density than that of the edgewise bending. This indicates that the density influences the bending performance of Mengkulang glulam and LVL. Although the samples are manufactured from the same species, bending properties of LVL flatwise and edgewise are much lower. The range is between 9000 to 20,000 N/mm2 for MOE global, 12,000 to 20,000 N/mm2 for MOE local, and 38 to 100 N/mm2 for bending strength. The significant differences are mainly due to the manufacturing process, whereby the Mengkulang glulam specimen is consisted of three layers of thick laminates bonded together to become a beam size of 85 mm wide and 90 mm thick. Whereas, the beam from timber LVL was made of 33 layers of thin veneers glued and compressed together into a timber panel, which is then cut into the beam size required. Thus, the presence of more lumen volumes is found in Mengkulang LVL rather than in Mengkulang glulam, resulting in less dense and lighter material. However, there are no significant difference between the two samples of LVL as they were made from the same source of production, regardless of random selections were made for testing the specimens.

Ahmad, H'ng and M.Tahir (Ahmad, 2013) discussed the influence of timber density on bending properties. The report states that LVL for high-density tropical timbers, as they have thicker cell walls and less lumen volume, it can influence the amount of adhesive penetrations resulted in insufficient bonding of the veneers, and subsequently lead to lower flexural capacity of the beam. The study also suggested tropical timbers of density less than 600 kg/m^3 would produce the optimum bending properties values as observed in LVLs made from Keruing, Kedondong and Bintangor species.

The coefficient of variations (COV) was determined and the results are as shown in Table 2. Higher variability was observed in bending strength for all samples instead of in MOE local and MOE global. The difference can be explained as the ultimate or maximum load governs the bending strength whereas MOE is dependent on the proportion of stress and strain limit. Furthermore, different mode of failures in the test specimens could also be considered in contributing to the load carrying capacity of the beams. Although the COV percentage of the MOE and bending strength in Mengkulang glulam ranged from 11 to 15%, the variability is still not exceeding 20%, thus can be considered acceptable according to BS EN 384: 2010.

Further analysis from this research, indicated the ratio of MOE local/MOE global for LVL flatwise and LVL edgewise were 1.29 and 1.18 respectively, which is in good agreement with the ratio of 1.17 reported by Ravenshorst and Van de Kuilen (2010) when the test conducted over the softwoods, temperate hardwoods, and tropical hardwoods. Higher ratio found in the LVL flatwise than in LVL edgewise was related to the variability (COV) of the test results. However, the ratio of MOE local and MOE global was less than 1.0, because of the occurrence of a zone with a low bending stiffness within the MOE local area (Ravenshorst et al., 2014) apart of the large variability of the test results.

Statistical analysis of two means of MOE local and MOE global are represented by the error bars in Fig. 6 and calculated using the standard error (SE) which equals to standard deviation (s) divided by the square root of number of measurements that made up the mean. The overlapped SE between the MOE global and MOE local for Mengkulang glulam sample specified that the difference was not statistically significant. The sample also had the largest error bars amongst the samples for both bending strength and stiffness, while the t-test analysis for paired two samples lead to the following results: The p-value for LVL flatwise and LVL

edgewise are 0.008 and 0.00006 which are less than p-value of 0.005 (at confidence level of 95%). Hence, the difference between MOE local and MOE global for both the LVL samples were significant. However, the p-value for glulam sample was 0.34 that is greater than 0.05, therefore the difference was not significant.

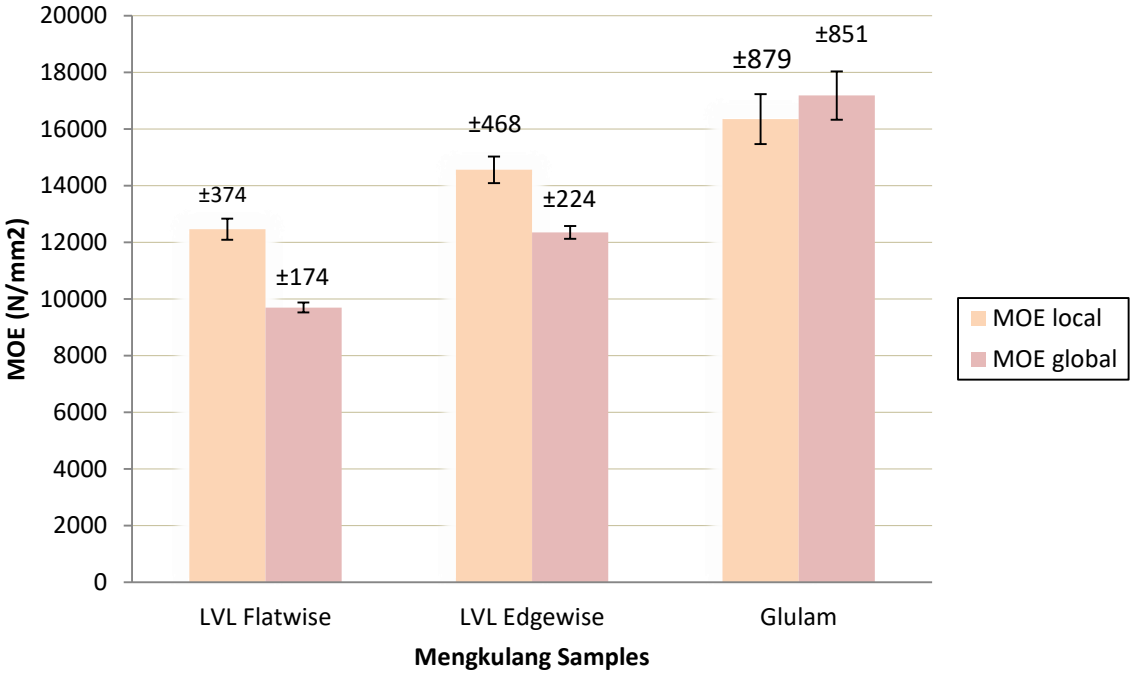


Fig. 8. Mean values of MOE local and MOE global with error bars

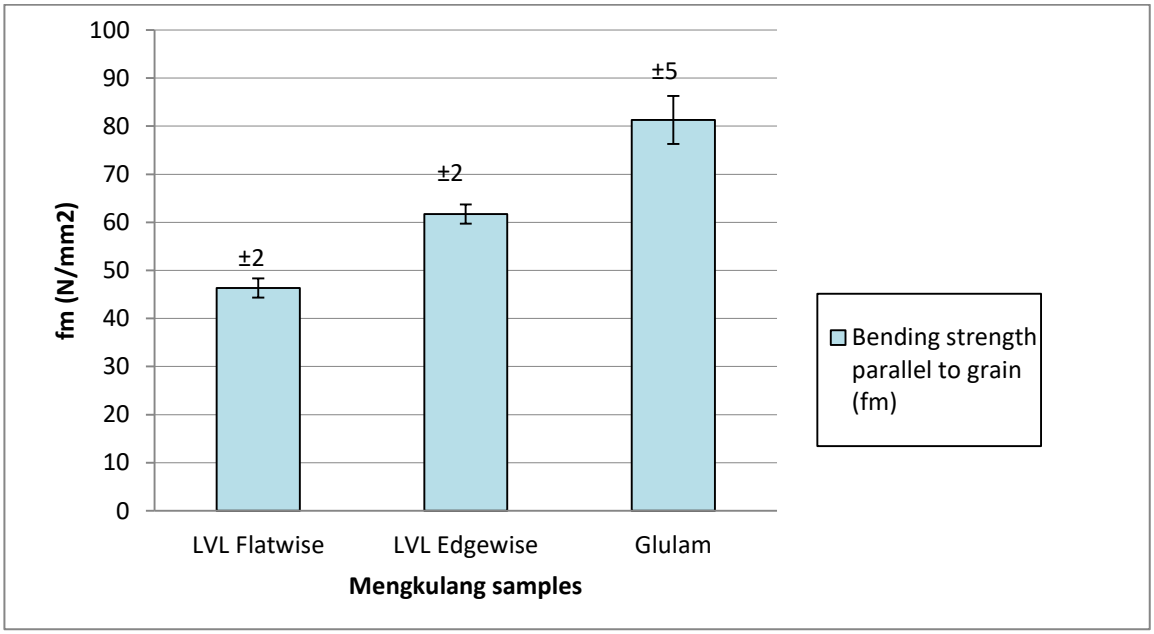


Fig. 9. Mean values of bending strength parallel to grain with error bars

Load versus displacement graphs were plotted and shown in Fig. 10 and 11, representing samples with almost similar results to the mean values. When the load applied was increased up to 40% of the estimated load, the displacement linearly increased proportionate to the load. This explained the elastic behaviour of the orthotropic material. Only one specimen of LVL flatwise failed to give regression of 0.99 when plotting the linear graph of 0.1F to 0.4F and was thus discarded. A slight decrease of displacement was detected in some of the specimens after

initial cracking or the first sound of breaking occurred, but it continued to the linear ramps increment, indicating the adequacy of ductility in the tension zone. When the load reached to the ultimate capacity and sudden failure occurred, the specimens have fractured in a brittle manner. The graphs from Fig. 8 also indicated Mengkulang glulam is the stiffest amongst the samples, while LVL edgewise was found to be stiffer than LVL flatwise.

Theoretically, different values between the local and global modulus of elasticity obtained from the bending test are most probably resulted from the shear deformation in the side parts of the beam and the zone with lower bending stiffness or is called a weak zone (Ravenshorst et al., 2014). This condition was discovered in the Mengkulang glulam samples when three specimens out of five being tested showed higher values of MOE local than MOE global. The existence of finger joints at the bottom layer near the mid span of the glulam beam contributed to this type of failure (refer Fig. 12 (a)). Besides that, shear failure at the horizontal plane can be seen in the mode of LVL flatwise as in Fig. 13(a). This type of failure might also be due to insufficient and incomplete bonding of veneers that already existed in the specimen that must be investigated further. The grain deviation is one of the well-known stiffness reducing factor for most tropical hardwood (Ravenshorst et al., 2014). It is generally known that performance of glulam and LVL are affected by many factors namely lamella thickness, lamella joints, lathe checks, loading direction and glue bond strength (Ahmad, 2013). For edgewise bending, the fracture of LVL was observed in the deviation of fibre grains at the tension zone of the maximum deflected area as in Fig. 14 (a). Similar failure was found for the glulam specimen as in Fig. 14 (b). However, there was also shear failure noticed at the edgewise specimen in which it might be due to the bonding performance of the veneers.

The glulam specimens in this study remained intact as one piece after reaching the maximum load showing the ability to absorb a certain amount of load in post-failure stage. At this stage, the laminations process significantly showed the brittle behaviour after ductile behaviour. Besides that, this process prevents the excessive tension cracks along the line.

According to MS544:2:2001 (Table 4), comparison of the grade stresses for various strength groups of timber, glulam and LVL species Mengkulang can be made, as stated that the bending parallel to grain for SG5 is between 6.8 to 12.1 N/mm2 (wet and dry condition) and modulus of elasticity are 6100 to 9100 N/mm2 (mean and minimum). Thus, based on the bending strength and modulus of elasticity of both glulam and LVL could be categorised as group SG1 and SG2 respectively. The strengths of glulam and LVL for this study are 3 times higher than the solid timber.

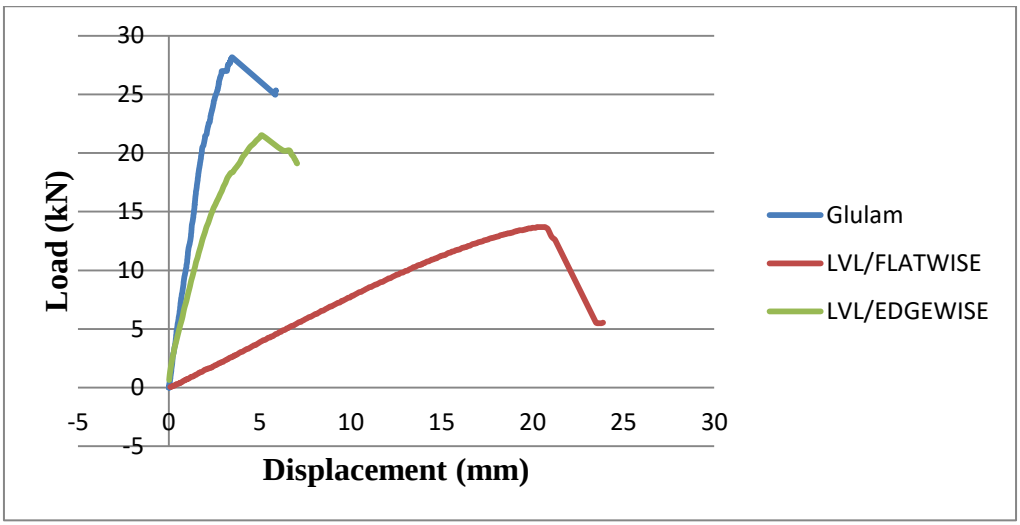


Fig. 10. Typical load versus displacement curve for MOE local

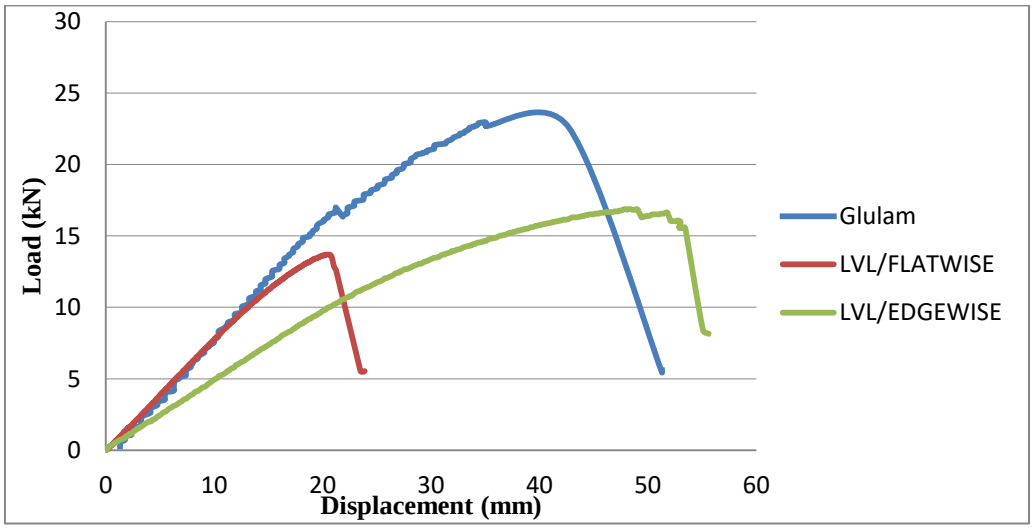


Fig. 11. Typical Load versus Displacement curve for MOE Global

(a) **(b)**

Fig. 12. (a)-(b) Failure of Glulam beam

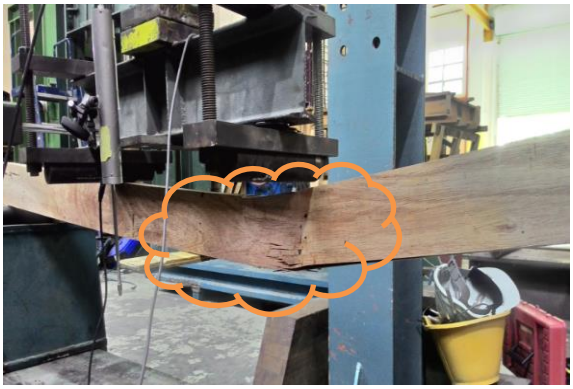
(a)

(b)

(c)

Fig. 13. (a) – (c) Failure of Mengkulang LVL Flatwise beam

(a)



(b)

Fig. 14. (a) – (c) Failure of Mengkulang LVL Edgewise beam

(c)

Fig. 14. (a) – (c) Failure of Mengkulang LVL Edgewise beam (cont.)

3.2 Delamination of glulam

Delamination, known as accelerated ageing test is used to proof the resistance against the climate exposure during lifetime of the glulam structural member. Test method A was selected to conduct the accelerated ageing test. According to MS758:2001, delamination test method A is a qualification test for glulam beams under class 1 for interior application and type 1 adhesive, phenol resorcinol being used during manufacturing of glulam member. This test method measures the openings of glue lines known as a delamination right after an accelerated ageing process in which the test specimens was submerged in water with vacuum and pressure, followed by fast drying at high temperature (Fig. 5). This accelerated ageing process causes stresses in wood perpendicular to the glue line, thus putting a strain on the joint. This strain on the joint will result in failure of the glue line that in turn would cause either delamination or creates cracks in the timber. The glulam beams are intended to be used as a roof truss member and could be categorized as an interior application. According to this standard, for method A, the total delamination percentage after treatment should be less than 5% of initial 2 cycles and less than 10% for extra cycles.

For these glulam beams, 20 specimens were subjected to accelerated ageing process. The results of the total delamination percentage of test specimens for glulam species Mengkulang after 3 cycles are shown in Fig. 15. Out of 20 specimens, only nine specimens exceed 10% of total delamination percentage. Glulam specimen species Mengkulang meet the requirement for the applications as interior members.

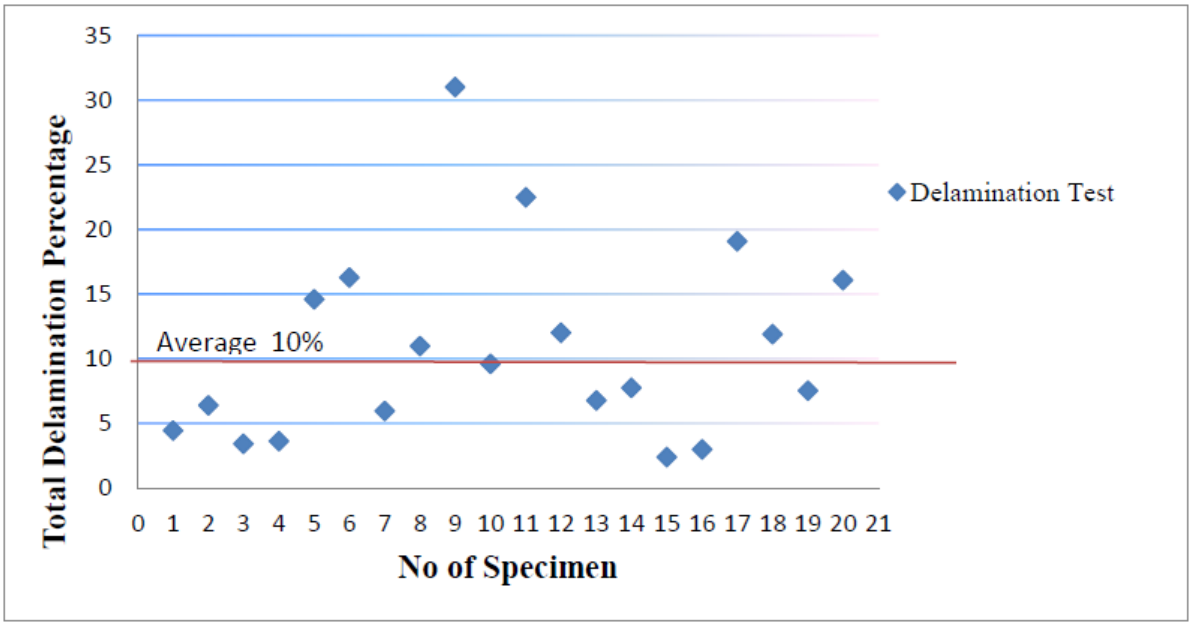


Fig. 15. Delamination percentage for Mengkulang Glulam

3.3 Shear strength of glue lines

The second test required for quality control of glulam is shear test of the glue line loaded in longitudinal direction. In addition to the delamination test, shear tests were carried out for specimens taken from the same Mengkulang glulam sample. Twenty specimens were prepared

for test. The strength of glue lines in glulam is determined by shear test. According to MS758: 2001 requirement, the shear strength of glue line shall be at least 6.0 N/mm^2 with 90% of minimum wood failure. The result of shear strength of glue line for glulam is tabulated in Table 4. All shear strength was higher than 6.0 N/mm^2 with estimated wood failure more than 90%, thus indicated that the glulam sample used in this research is valid for quality control and meets the requirements in MS 758:2001.

Table 4. Summary of Shear Strength for Glulam

Sample No/Shear Strength (N/mm^2)					Average
1	2	3	4	5	
16.80	13.58	14.78	17.58	17.68	16.08

Table 5 Shear Strength of Malaysia Hardwood

Shear Strength (N/mm^2) [**]			
Resak (SG4)	Kapur (SG4)	Merpauh (SG4)	Bintangor (SG5)
14.76	13.82	15.33	14.39

[**] Wan Mohamad et al, 2011

Based on the comparisons of the test results with report from Wan Mohamad et al. (2011) as presented in Table 4 and 5, it can be observed that there are no significant differences in the shear strength of glulam specimen. However, glulam from Mengkulang showed highest values of 16.08 N/mm^2, followed by Merpauh, Resak and Bintangor. Kapur showed the lowest value of 13.82 N/mm^2. Although Resak, Kapur and Merpauh are categorised in the same strength group, the shear strength of Kapur is much lower. Mengkulang contains relatively smaller pores and extractive content compared to Merpauh, Resak, Bintangor and Kapur that further restrict the penetration of the adhesives to the centre of glulam. Moreover, the density of timber did not affect shear strength, as it depends on the ability of laminations bonding. The performance of adhesive being used in the fabrication of glulam was observed and evaluated by means of shear test according to MS758:2001. A comparison with shear strength of LVL cannot be documented due to absence of data for LVL.

The results of shear strength tests are shown in Fig. 16 against the percentage of delamination test. There is no good correlation between the shear strength and the percentage of delamination. Thus, there is no effect of glue bond quality on the shear strength of glulam. Since bending shear evaluates the integrity of each layer of lamella, theoretically, any defects in the glue lines such as scarves joints, poor lamella joints and lathe checks would significantly affect the strength of glulam. In this study, no such defects influenced the shear strength of glulam. According to Vick as reported by H'ng (2013), adhesive used plays an important role in determining the shear strength of glulam. High shear strength indicates high glue bond quality. The shear strength does not affect by the density of timber, as it depends on the ability of laminations bonding.

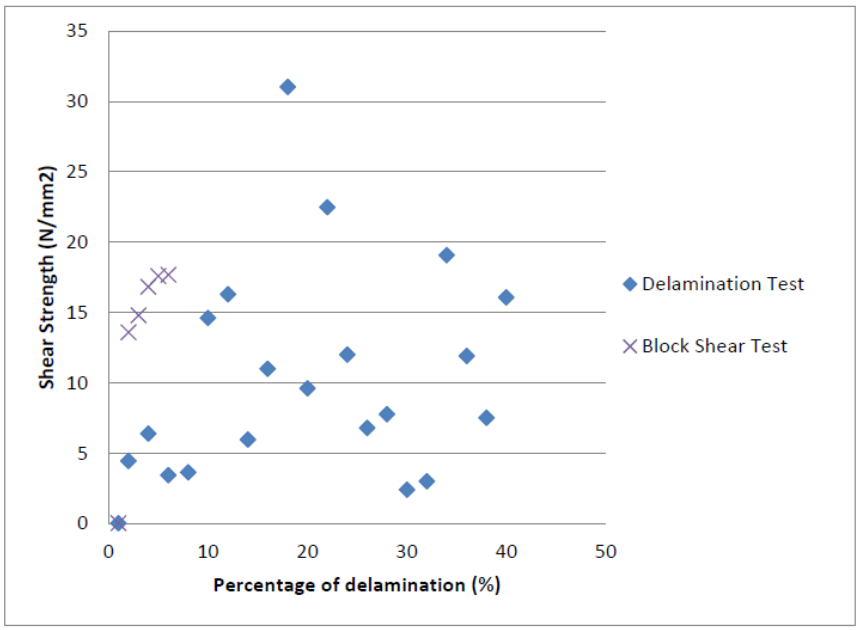


Fig. 16. Shear Strength versus Percentage of delamination

4. Conclusion

This paper presented a research on the bending properties of Mengkulang glulam and Mengkulang LVL (flatwise and edgewise bending). The bending tests were carried out according to BS EN 408: 2010+A1 clauses 10.0, 11.0 and 19.0 which is to determine the respective stiffness (ie. Local modulus of elasticity, $E_{m,l}$ and global modulus of elasticity, $E_{m,g}$), and bending strength parallel to grain (ie. Modulus of rupture, f_m). Besides, quality tests of delamination and shear strength test were also conducted for the glulam sample. The results obtained conclude that:

a. From the three Mengkulang samples of glulam, LVL flatwise and LVL edgewise, Mengkulang glulam exhibited the highest bending strength and stiffness.
b. Values of MOE local and MOE global for LVL edgewise were greater than that of LVL flatwise. The MOE local for both LVL flatwise and edgewise was also greater than MOE global.
c. The failure of Mengkulang glulam was due to the weak zone resulted from the presence of the finger joints near the mid span of the beam. The fracture observed also indicated failure of the grain deviation due to stresses at the tension zone.
d. For LVL flatwise, the fracture was mainly due to horizontal shear, while for LVL edgewise, the main failure was a tension failure.
e. Mengkulang glulam met the requirement for delamination test for bonding quality according to MS 758: 2001.
f. The shear strength of Mengkulang glulam is in compliance with MS 758: 2001.
g. Due to absence of data for the delamination test of Mengkulang LVL, the bonding quality was not discussed in this research. Further research should be considered in future.
h. Future research should emphasize on increasing the number of specimens to the required sampling numbers in order to obtain more sufficient and reliable data for subsequent development of characteristic strength of the ETPs manufactured from tropical hardwood.

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6. Referrences

[1.] Abbot, A.R, & Whale, L. R. J. (1987). An overview of the use of glued laminated timber (glulam) in the UK. Construction and Building Materials, (1(2), 104-110. http://doi.org/10.1016/0950-0618(87)90007-9

[2.] Ahmad, Z. (2013). Laminated Veneer Lumber made from tropical forest trees: Mechanical properties. UiTM Press, Shah Alam, Malaysia.

[3.] Aicher, S., Reinhardt. H.W. Delamination properties and shear strength of glued beach wood laminations with red heartwood. HolzRoh Werkst, Volume 64, 2007, PP 125-136.

[4.] BS EN 322: 1993 Wood-based panels-Determination of moisture content. British Standard Institute. SKU/ISBN: 058021057X

[5.] BS EN 323: 1993 Wood-based panels-Determination of density. British Standard Institute SKU/ISBN: 0580210588

[6.] BS EN 384: 2010 Structural timber — Determination of characteristic values of mechanical properties and density. British Standard Institute SKU/ISBN: 978 0 580 58145 8

[7.] BS EN 408: 2010+A1: 2012 Structural timber- Determination ofb some physical and mechanical properties. British Standard Institute

[8.] BS EN 13183 Moisture content of a piece of sawn timber- Determination by oven dry method. British Standard Institute. SKU/ISBN: 0580396851

[9.] Crawford, D., Hairstans, R., Alexander, J., & Bongers, F. (2012). Assessment of structural performance of Accoya wood for GluLam fabrication. In *World Conference on Timber Engineering* (pp. 496–501).

[10.] H'ng, P. S. (2003). Basic engineering properties of laminated veneer lumber (LVL) produced from tropical hardwood species. Unpublished. Universiti Putra Malaysia, Selangor, Malaysia.

[11.] H'ng, P.S, Ahmad, Z and Md. Tahir. P (2012). Laminated veneer lumber from Malaysian tropical timber, UiTm Press, Shah Alam.

[12.] H'ng, P.S, Md. Tahir,P. and Chin, K.L., (2010) Bending properties of laminated veneer lumber produced from Keruing (Dipterocarpus s.p) reinforced with low density wood species," *Asian Journal of Scientific Journal*, 3(2), pp 118–125

[13.] Ismail, S., Ahmad, Z. & Ibrahim, A. A review on structural response of hybrid glulam-coldformed steel roof trusses. *INCIEC 2015 Proceeding of the International Civil and Infrastructure Engineering Conference* (pp. 833-844)

[14.] MS 544 Part: 2 (2001) Code of Practice for the Structural Use of Timber Part 2: Permissible StressDesign of Solid Timber, Shah Alam, Malaysia, Sirim Berhad.

[15.] MS 544 Part: 12, (2006) Code of Practice for the Structural Use of Timber Part 12: Laminated Veneer Lumber for Structural Applications, Shah Alam, Malaysia, Sirim Berhad.

[16.] Muhammad, N.A., Ahmad, Z. & Ibrahim, A. A conceptual review of structural performance of Mengkulang laminated veneer lumber roof trusses. *INCIEC 2015 Proceeding of the International Civil and Infrastructure Engineering Conference* (pp. 783-796)

[17.] Puaad, M.B.F.M., Ahmad, Z. & Yamani, S.A.K. Bending strength properties of Malaysian tropical timber in structural size, (2015). *INCIEC 2015 Proceeding of the International Civil and Infrastructure Engineering Conference* (pp. 871-882)

[18.] Ravenshorst, G.J.P, de veries, Van de Kuilen, J.W.G Aspects of the difference between the local and global modulus of elasticity of structural (hardwood) timber, *Material and joints in timber structures*, Rilem 2014, Vol 9, (pp 773-783)

[19.] Ravenshorst, G.J.P, de veries, Van de Kuilen, J.W.G. (2010) Relationship between local and global modulus and dynamic modulus of elasticity for soft and hardwoods CIB W18-42-10-1, Dubendorf, Switzerland.

[20.] Smedley, D., Tiew, J., Roseley, A., Ahmad, Z., & Ansell, M. P. (2012). Innovative timber exhibition hall in Johor, Malaysia, constructed from indigenous hardwood using bonded-in moment-resisting connections. In *World Conference on Timber Engineering 2012, WCTE 2012. Vol. 1.* (pp. 502–503). Retrieved from http://opus.bath.ac.uk/34247/

[21.] Solli, K. H. (2000). Modulus of elasticity – local or global values. (2000) In *Proceedings of the 6th World Conference on Timber* (Vol. 408, pp. 1–6). Retrieved from http://timber.ce.wsu.edu/resources/papers/p65.pdf

[22.] Sousa, H. S., Branco, J. M., & Lourenco, P. B. (2014). Prediction of global bending stiffness of timber beams by local sampling data and visual inspection. *European Journal of Wood and Wood Products*, *72*(4), 453–461. http://doi.org/10.1007/s00107-014-0800-1

[23.] Wan Mohamad, W. H., Razlan, M.A, & Ahmad, Z, (2011). Bending Strength Properties of Glued Laminated Timber from Selected Malaysian Hardwood. *International Journal of Civil & Environmental Engineering*, IJCEE-IJENS Vol: 11 No: 04, (pp 7-12)

[24.] Wan Mohamad, W. H., Ahmad, Z., Yu Eng, T., & Abd Jalil, A. (2012). Bending strength of glulam from selected Malaysian hardwood timber. *World Conference on Timber (WTCE)*, Auckland , New Zealand, 15-19 July 2012 (pp 40–45)

Constitutive Material Model for the Rock Spall Prediction of Deep Tunnel Excavation

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Abstract

The prediction of spalling fallout is of concern when designing and constructing facilities for deep tunnel excavation. The purpose of this study is to model compressive stress-induced failure with appropriate material models and strength parameters for deep hard rock tunnel excavation. Numerical modelling is an effective tool to evaluate stability and to assist in predictive modelling of planned tunnel excavation situations. Three methods of constitutive material models are used, which is Generalised Hoek-Brown; Mohr-Coulomb; and Mohr-Coulomb with Cohesion Softening Friction Hardening (CSFH) in the numerical modelling for capturing the observed rock behaviour. Results of all approaches have been compared with actual ground conditions. The comparison revealed that the numerical models using the Mohr-Coulomb with CSFH provides most realistic match to the observations. This study also describes the laboratory experiments that are used to determine the mechanical properties of the rock mass sample obtained from Pahang Selangor Raw Water Transfer Tunnel Project.

Keywords: Constitutive material model; Numerical modelling; Spalling fallout; Hard rock; Deep tunnel excavation

1. Introduction

The excavation of deep tunnel opening disrupts the primary stress state, leading to stress redistribution and deformation of rock mass around the excavation boundary. The design concept applied to tunnel excavation relies on two major mechanisms, which are the in-situ stresses and the deformation. However, the mechanical behaviour and deformation mechanisms of the rock under high in-situ stress are different from those in low stress conditions. Overstressing usually occurs due to overburdened stress induced. The spalling fallout due overstressed rock can significantly influence the overall performance of tunnel excavation. Hence, research on Excavation Disturbed Zones (EDZ) in deep tunnel excavation is becoming increasingly important for understanding the mechanical behaviour of rock masses in tunnel design and construction.

The EDZ is defined as the zone immediately around the excavation boundary where these damage processes strongly affect physical, mechanical and hydraulic properties of the rock. Extensive studies have been performed to understand and predict the extent of EDZ, and in recent years, advances have been made in the understanding of the formation mechanism of EDZ [1-3]. It is generally accepted that in high in situ stress conditions, the excavation induced stress redistribution is the main cause for the formation of EDZ, which plays important role on the extent of EDZ than that of the excavation method.

Fallout or rock bust is the explosive failure of the rock surface that occurs when there is very large stress induced around the excavation opening [4], [5]. It occurs due to the instability of brittle and massive rock, caused by the continuously overstressing [6], [7]. The sudden rock burst will impose large dynamic loading towards the tunnel that is influenced by significant overburden stress [8], [9]. For instance, the rock burst was encountered in Pahang-Selangor tunnel at 1040 m of overburden, followed by spalling of rock from the tunnel walls [10]. Hence, the excavation in brittle rock at great depth may encounter problems such as non-violent spalling or intense rock burst.

This study is carried out to understand the fallout in brittle rock when the excavation is located at deep tunnel and the effect of the EDZ to the surrounding opening by using finite element method. Brittleness is a characteristic of many geomaterials in which the pre-existing heterogeneities among the mechanical and geometrical properties of the constituent materials. In the geotechnical engineering field, brittleness is normally understood as a material condition characterized by the situation reduced ability to carry load as the strain increases. It is one of the most important concerns for the pre and post construction of tunnel, as it might lead to rock burst or formation of break out zone if no proper supports are used to reduce the rock's brittleness [11].

Background of the study area

The Pahang–Selangor Raw Water Transfer Project includes the excavation of a 44.6 km-long with 5.2 m diameter circular tunnel. The water transfer tunnel project is located in the central area of Peninsular Malaysia (see Fig. 1.). The tunnel crosses the Titiwangsa Range, the main range of Peninsular Malaysia. The highest peak of this range is 2,183 m, and the tunnel route is approximately 1,350 m above sea level. The tunnel excavation used three TBMs (TBM-1, TBM-2, and TBM-3) for about 35 km of the whole tunnel length with a maximum depth of approximately 1,200 m.

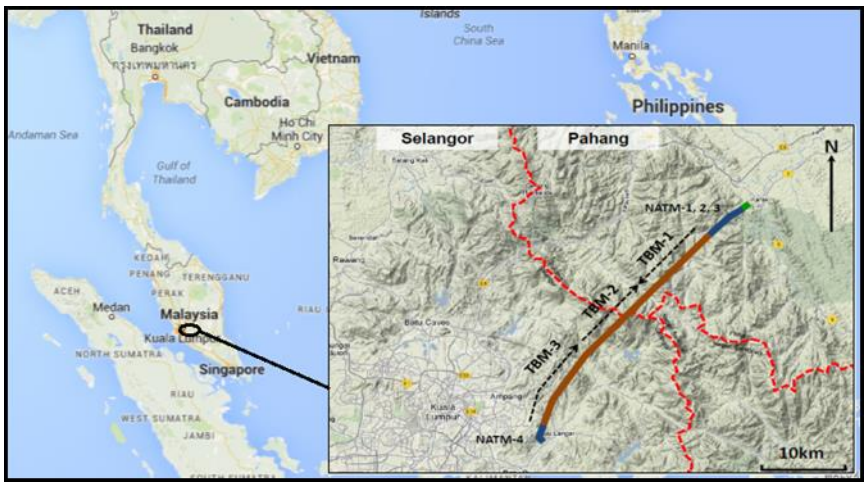


Fig. 1. Tunnel structure of Pahang Selangor Raw Water Transfer

There are three main types of granitic rocks along the transfer tunnel consisting of Kuala Lumpur Granite, Genting Sempah Microgranite and Bukit Tinggi Granite. TBM-1 was employed to completely excavate Bukit Tinggi granite, which is porphyritic and coarse grained, mostly fresh to slightly decomposed, and cut by the Krau Fault. TBM-2 was employed for all three granite types, with 75% of the drive being in Genting Sempah micro-granite and passing

through two major faults: the Bukit Tinggi Fault and Lepoh Fault. TBM-3 was employed for Kuala Lumpur granite, with small sections of Hawthorndon schist and several faults, such as the Tekali Fault and Kongkoi Fault [12].

During excavation, several rock bursts and spalling failures were generated on the sidewalls of the tunnel. The failures were not influenced by geological structures and the tunnel crown was mostly unaffected.

2. Methods

This section describes the application of laboratory test that is used to indicate the mechanical properties of the intact rock core specimens. The rock mass that is used for coring is from the construction site of Pahang-Selangor raw water transfer project. The right method of sample preparation is important because it will affect all test results. Therefore, the specimen preparation must be done consistently and in the correct manner to assure quality data. The method of drilling out the intact rock core specimens from the rock mass is by following the procedure of the raw cored rock sample. Based on the experiment data for the mechanical properties of rock, conditions of the underground excavation will be simulated in FEM software for the further analysis.

2.1 Laboratory test

Laboratory tests have provided mechanical properties of the intact rock core specimens. The rock mass that is used for coring is from the construction site of Pahang-Selangor raw water transfer project. The right method of sample preparation is important because it will affect all test results. All of the experiments done are in compliance with ASTM standards.

Ultrasonic Elastic Constants Test of Rock (ASTM, D2845 – 00).

This test is the essential procedure for determination of the ultrasonic velocity, measured in terms of travel time and distance of compression and shear waves in rock sample include requirements of instrumentation. Compression or shear wave velocities, ultrasonic values for elastic constants of intact isotropic rock specimens can be identified in this test and is also the main priority advantages of this ultrasonic testing. Three samples of each type of rock have been selected to determine the modulus of elasticity and the average value will be calculated for analysis.

Uniaxial Compressive Strength (UCS) Test (ASTM, D 2938 – 95).

The UCS (σ_{ci}) was chosen as input parameter for the Hoek Brown failure criterion because it was the most widely available parameter in the rock mechanics literature rock core specimen has to be ready with both the cross surface area are machined flat and the diameter to length ratio is complied with the standard which is 1:2. Then, the specimen was placed in a loading apparatus and axial load was continuously increased with constant increment of magnitude of load on the specimen until peak load and failure were obtained. Intact rock with higher strength can withstand strong impact force that cause on top of it without causing any of the deformation of the rock and fracture occurs on it.

2.2 Rock mass strength estimation

Reliable estimates of the strength and deformation characteristics of rock masses are required for almost any form of analysis used for the design of underground excavations. The most common ways of determining the rock mass strength is by failure criteria.

The Generalized Hoek-Brown criterion

The failure criterion establishes the strength of rock in terms of major and minor principal stresses and predicts the strength that correlates well with values determined from laboratory triaxial tests of intact rock. However, the intact rock core specimen does not represent the rock mass that generally contains joints, discontinuities and quality of rock. Thus, Hoek has done research about the failure criterion of intact rock through lab experiment while Brown studied the joint rock mass changes in model analysis. In most cases, it is practically impossible to carry out triaxial tests on rock masses at a scale that is necessary to obtain direct values of the parameters in the Generalized Hoek-Brown equation. Therefore, the failure criterion of rock started from the physical properties of rock by introducing aspects to reduce these intact rock properties into data that can represent the whole actual rock mass characteristics and condition (Hoek et al., 2002).

The Generalized Hoek-Brown criterion is non-linear and relates the major and minor effective principal stresses as equation below:

$$\sigma_1' = \sigma_3' + \sigma_{ci}\left(m_b \frac{\sigma_3'}{\sigma_{ci}} + s\right)^a \quad (1)$$

Where σ_1' is a major effective principal stress at the failure; σ_3' is minor effective principal stress at failure; σ_{ci} is uniaxial compressive strength of the intact rock material; m_b is a reduced value of the material constant; and m_i, s and a are constants which depend upon the characteristics of the rock mass.

3.2.2. *Mohr-Coulomb failure criterion.* The Mohr–Coulomb failure criterion represents the linear envelope that is obtained from a plot of the shear strength of a material versus the applied normal stress. This relation is expressed as:

$$\tau = \sigma \tan(\emptyset) + c (2)$$

Where τ is shear strength; σ is normal stress; $\emptyset$ is friction angle; and C is cohesion. The equivalent Mohr–Coulomb parameters, rock mass cohesion (c), and friction angle ($\emptyset$), can be obtained based on the Hoek–Brown envelope and a chosen a range of σ_3. In $\sigma_1 - \sigma_3$ space, the Mohr–Coulomb failure criterion is expressed as equation below:

$$\sigma_1 = \frac{2c\ cos\emptyset}{1-sin\emptyset} + \frac{1+sin\,\emptyset}{1-sin\emptyset}\sigma_3 \quad (3)$$

Where $(2c\ cos\emptyset)/(1 - sin\emptyset)$ is the unconfined compressive strength of the rock mass and $(1 - sin\emptyset)/(1 - sin\emptyset)$ is the slope of the failure envelope.

For deep tunnels, the maximum confining level ($\sigma_{3\,max}$) is from the following equation:

$$\frac{\sigma_3}{\sigma_{cm}} = 0.47\left(\frac{\sigma_{cm}}{\gamma H}\right)^{-0.94} \qquad (4)$$

Where σ_{cm} is the rock mass strength, σ_3 is minor principal stress at failure; γ is the unit of weight of the rock mass, and *H* is the depth of the tunnel below the surface.

Cohesion-Softening Friction-Hardening (CSFH)

Hajiabdolmajid [11] adopted a constitutive model in which the plastic strain-dependencies of various strength components in brittle failing rocks are considered. The process of spalling around underground openings cannot be directly compared with the shear banding process in laboratory compression tests, even though it also involves a process of cohesion loss and frictional strength mobilization. The cohesion component of strength is the predominant strength component at the early stage of brittle failure and cohesion loss is the predominant failure process leading to the observed brittle behaviour. The cohesive strength is gradually destroyed by tensile cracking and crack coalescence, and the residual cohesion (c_{res}) was set equal to 30% of the rock mass cohesion (c_m), while the residual friction angle ($\emptyset_r$) was set equal to the friction angle of the rock mass ($\emptyset_m$). The peak cohesion (c_{peak}) was determined using the Mohr-Coulomb criterion.

$$c_{peak} = \frac{\sigma_{ci}(1-sin\emptyset_m)}{2cos\emptyset_m} \quad (5)$$

Where c_{peak} is peak cohesion; $\emptyset_m$ is friction angle of the rock mass; and σ_{ci} is uniaxial compressive strength of the intact rock material.

Numerical modelling

For numerical modelling method, a "circle domain" Fig. 2 was used in order to decrease the number of elements compared to a rectangular shaped domain, and thus enables a finer discretization in the region closest to the boundary. The extent of the modelled domain was defined by an expansion factor of four in relation to the excavation dimension, to eliminate boundary effects. The domain was discretized with a finite element mesh of six-noded, triangular elements. A mesh gradation factor of 0.1 was used. The mesh setup in RS^2 ($Phase^2$ 9.0) is separated concerning element size on the excavation boundary (discretization density) and element sizes within the model domain (mesh density). The selection of regions with finer discretization was in this work based on results of elastic models where the extent and depth of regions with a strength factor (safety factor) less than one was identified. To avoid an abrupt change of element sizes in regions near the finer discretization region, a smooth change of element size was applied. The element size at the tunnel boundary (in the region of the predicted failure) was set to 0.01 m. In regions outside the predicted failed zone, the element side length was set to 0.2 m (except for close to the predicted failure, where it was set to 0.02 m).

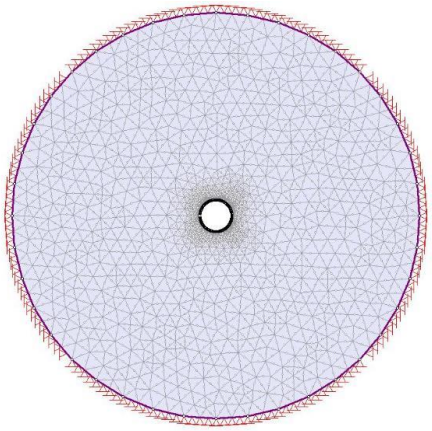


Fig. 2. Circle domain used for the modelling analysis

3. Result and discussion

The laboratory test results describe the mechanical properties of those rock samples. The mechanical properties of those rock samples include density test, ultrasonic pulse velocity test, unconfined compression test and poisson ratio test. The purpose of performing the density test is to obtain the dry density of the rock samples then for the ultrasonic pulse velocity test is to determine the elastic modulus of the rock samples. For unconfined compression test, this is to determine the ultimate stress that can withstand the rock sample. Poisson ratio test is to determine the coefficient of deformation from the rock samples.

The modulus of elasticity determined by using ultrasonic pulse velocity test results are shown in Table 1 below*:*

Table 1. Result of modulus of elasticity

Sample	**Distance from start to end (mm), Dp**	**Time (µs)**	**Compression Velocity = $\frac{\text{Distance}}{Time}$ (m/s)**	**Distance from top to bottom(mm), Ds**	**Time (µs)**	**Shear Velocity = $\frac{\text{Distance}}{Time}$ (m/s)**	**Modulus of elasticity, *E* (Mpa)**
1	99.5	19.6	5100	50.2	13.4	3734	54453
2	100.4	20.1	5750	49.8	13.1	3735	54462
3	99.6	19.8	4980	50.1	13.5	3752	54382

The results of physical properties of rock tested through experiments and the average value calculated for strength properties input parameter are as Table 2 below:

Table 2. Properties of intact rock

Sample	**UCS (MPa)**	**Modulus of Elasticity *E* (MPa)**	**Unit Weight (kN/m^3)**	**Poisson Ratio**
1	118	54450	2650	0.2
2	124			
3	126			

Intact rock with higher strength eventually can withstand strong impact force caused on top of it without causing any deformation of the rock and fracture that occurs on it. The samples of granite rock show a very high uniaxial compressive strength because of the condition of the rock mass that are homogeneous and the rocks actually have undergone almost negligible weathering. High strength of rock has low magnitude deformation at the excavation-disturbed zone.

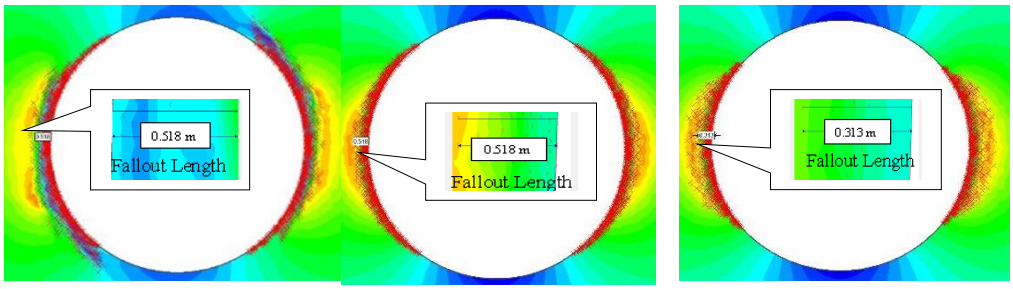
With the data obtained from laboratory test results of the intact rock samples, the analysis for strength properties had been carried out using RocData (Rocscience Inc., 2016). The material strength properties determined by RocData have been used as input for numerical analysis. The results are as shown in Table 3 below:

Table 3. Material strength properties

Sample	Generalized Hoek-Brown			Mohr Coulomb		Cohesion Softening Friction Hardening			
	m_b	s	a	Cohesion C (Mpa)	Friction Angle ∅	Peak Friction Angle $∅_{peak}$ (°)	Residual Friction Angle $∅_{res}$ (°)	Peak Cohesion, C_{peak} (Mpa)	Residual Cohesion, C_{res} (Mpa)
1	10.57	0.03	0.50	6.85	53.68	10	53.68	23.12	6.85
2	10.96	0.03	0.50	6.38	52.46	10	52.53	22.12	5.35
3	7.40	0.01	0.50	5.38	50.47	10	45.11	19.41	5.09

Numerical modelling

A comparison of fallout depth with different material models from the numerical analysis is shown in Fig. 3. Based on the results obtained amongst all the modelling method used, CSFH shows the closest fallout length when compared with the observed value. Generalised Hoek-Brown Criterion and Mohr-Coulomb Failure Criterion over-estimate the fallout length because it assumes that rock behaves perfectly elastic once its strain exceeded the yield point.



a) b) c)

Fig. 3. Result of fallout of Sample 1 using : a) Generalised Hoek-Brown Criterion, b) Mohr-Coulomb Failure Criterion and c) CSFH material method

The results obtained from three different methods of modelling are compared to the observed fallout as shown in Table 4 below. The result shows CSFH strength material method has better agreement with the observed fallout compared to Generalised Hoek-Brown and Mohr Coulomb. Generalised Hoek-Brown and Mohr-Coulomb Failure Criteria over-estimate the fallout length because it assumes that rock behaves perfectly once its strain exceeded the yield point.

Table 4. Comparing Modelling Result with Observed Fallout

Sample	Generalised Hoek-Brown (m)	Mohr-Coulomb (m)	CSFH (m)	Observed Fallout (m)
1	0.518	0.518	0.313	0.310
2	0.477	0.475	0.312	0.300
3	0.470	0.467	0.285	0.295

4. Conclusions

This study was carried out to evaluate the mechanical behaviour of rock when there is an opening at the rock mass under 500m deep below from the surface. RS^2 ($Phase^2$ 9.0), a commercial program that uses Finite Element Method as a calculation tool, has been selected to carry out the analysis.

The intact rock parameters were determined from the lab experiments have proven that both the rock types are strong rock consisting high compressive strength and generally fresh, slightly weathered. The Poisson ratio of 0.2 has proven that the rock experiences low strain changed when load was applied. Hence, the properties of both rock had been successfully achieved.

In the analysis process, Generalised Hoek-Brown Criterion, Mohr-Coulomb Criterion and CSFH material model have been selected for modelling. Generalised Hoek-Brown Criterion and Mohr Coulomb do not show a good agreement result with the observed fallout but CSFH method has better agreement with the observed fallout. Thus, a CSFH material model can be used for prediction of compressive stress-induced fallouts in deep hard rock underground excavation. This model is valid for prediction of failure and fallouts in hard rock masses with high quality (GSI>65; intact rock compressive strength>70Mpa).

5. Acknowledgements

The authors gratefully acknowledge the assistance and cooperation given by KeTHHA (Ministry of Energy, Green Technology and Water Malaysia) and Tokyo Electric Power Services Co., Ltd. (TEPSCO) to carry out this study successfully. This work was funded by the Fundamental Research Grant Scheme of the Ministry of Education Malaysia: Analysis of Rock Burst Behaviour under Overstressed Rock in Deep Tunnel Excavation across the Titiwangsa Range, Malaysia. Grant No.: 203/PAWAM/6071259.

6. References

[1.] M. A. Perras and M. S. Diederichs, “Journal of Rock Mechanics and Geotechnical Engineering Predicting excavation damage zone depths in brittle rocks,” vol. 8, pp. 60–74, 2016.

[2.] W. C. Zhu, J. Wei, J. Zhao, and L. L. Niu, “2D numerical simulation on excavation damaged zone induced by dynamic stress redistribution,” *Tunn. Undergr. Sp. Technol. Inc. Trenchless Technol. Res.*, vol. 43, pp. 315–326, 2014.

[3.] H. A. Corporation, “Experimental Study of Excavation Damaged Zone Assessment by Seismic Exploration Using Tunnel Blasting,” no. October, 2014.

[4.] C. Edelbro, “A quantitative comparison of strength criteria for hard rock masses,” vol. 22, pp. 57–68, 2006.

[5.] E. Hoek and P. . Marinos, “Tunnelling in overstressed rock,” in *Keynote address presented at EUROCK2009, Dubrovnik, Croatia, 29-31 October 2009.*, 2009, pp. 49–60.

[6.] Q. M. Gong and J. Zhao, “Development of a rock mass characteristics model for TBM

penetration rate prediction," *Int. J. Rock Mech. Min. Sci.*, vol. 46, no. 1, pp. 8–18, Jan. 2009.

[7.] H. Stille and A. Palmström, "Ground behaviour and rock mass composition in underground excavations," *Tunn. Undergr. Sp. Technol.*, vol. 23, no. 1, pp. 46–64, Jan. 2008.

[8.] W. D. Ortlepp, "The behaviour of tunnels at great depth under large static and dynamic pressures," *Tunn. Undergr. Sp. Technol.*, no. 16, pp. 41–48, 2001.

[9.] M. S. Diederichs, P. K. Kaiser, and E. Eberhardt, "Damage initiation and propagation in hard rock during tunnelling and the influence of near-face stress rotation," vol. 41, pp. 785–812, 2004.

[10.] T. Kawata, Y. Nakano, T. Matsumoto, A. Mito, F. Pittard, and A. A. S. Azman, "The Relationship between TBM Data and Rockburst in Long-Distance Tunnel , Pahang-Selangor Raw Water Transfer Tunnel , Malaysia," *8th Asian Rock Mech. Symp.*, no. October, 2014.

[11.] V. Hajiabdolmajid, P. K. Kaiser, and C. D. Martin, "Modelling brittle failure of rock," *Int. J. Rock Mech. Min. Sci.*, vol. 39, no. 6, pp. 731–741, Sep. 2002.

[12.] A. Kusaka, K. Kawata, N. Isago, and H. Mashimo, "Static Loading Tests and Numerical Analysis of the Effects of Risk Mitigation Measures for Rock Tunnels against Earthquakes," no. October, 2014.

Flexible Joint for Drainage System at Settlement Areas

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Abstract

Ground settlement may induce continuous damage to the drainage system, leading to failure of the joint between rainwater downpipe and the perimeter drain, damage or cracks on sumps, perimeter drains and main drain. A review on the existing Public Works Department drainage system design specification showed that there are no details of joint that could sustain soil settlement. There was also no specified test to detect the subsequent damage due to the settlement. This paper aims to identify the best features for flexible joint, which can ensure the functionability of the drainage system under short and long-term soil settlement throughout its design life. The interest is focused on the detail of the joint and features to cater for the turbulence effects due to water flow in the rainwater down pipe. The material used is the polyvinyl chloride (PVC) flexible pipe hose which is commonly used in timber industry and as fume extraction component. Based on manual test, the elongation of the material is found to be four times the original length. The factor of safety for estimating the minimum length of the vertical part of the joint is taken as 2.5. This length is dependent on the annual settlement rate of the area. Test is also conducted to detect any damage or leakage to the drainage system after the installation of this flexible joint at Politeknik Sultan Idris Shah, Sabak Bernam, Selangor. From the test, it was found out that there was no leakage or damage to the drainage system after the recorded settlement of 25 mm and six months installation.

1. Introduction

Construction of infrastructure such as drainage system over soft soil has been a challenge to infrastructure engineers due its insufficient bearing capacity, excessive post construction settlement and unstable excavation and embankment forming (Mohamad et al., 2016). Soil settlement, which is defined as soil deformation due to the applied stress is affected by ground water level. If the ground water level is high, the fill material may become buoyant, thus affecting the total surcharge loading and the soil stability. Insufficient pre-consolidation works to accelerate consolidation settlement as a preventive method would also lead to failure and instability of structure due to post construction settlement and differential settlement (Lat et al., 2018)

The common design approach for the drainage system built over backfilled soft soil, particularly perimeter drain, is to design it as suspended system to the building apron. However, this approach has not solved the overall problem particularly at site where the settlement is very much active. It is observed that the drainage system failure normally occurs at rigid joints, which connect the rainwater down pipe to the discharge at the perimeter drain or the distribution pipe. Even though the perimeter drain is suspended to the apron, the failure will still occur at the joint parts to the sump.

Failure of drainage system at settlement areas could also occur in buried drainage pipe that served as main drain. In principle, this system is flexible and designed to deform and derive

strength from the supporting backfill and adjacent undisturbed soil. Mode of failure is characterized by excessive deflection, actual buckling pressure being greater than critical buckling pressure and excessive tensile stress from over pressurization (Babu et al., 2010). Most flexible pipes, either steel, PVC and HDPE could tolerate deflection up to 2 to 5% of pipe diameter without developing any structural problems, as stated by Moser (1990) and Stephenson (1976).

2. Case Study: Politeknik Sultan Idris Shah, Sabak Bernam, Selangor

2.1 Project Background

The construction of 43 blocks of Politeknik Sultan Idris Shah (PSIS) at Sabak Bernam, Selangor was commenced in 2000 and completed by 2003. The project was designed and supervised by Project Management Consultant (PMC). Severe soil settlement occurred and damaged the infrastructure system within the compound of the campus. Public Works Department of Malaysia was appointed by the Ministry of Education to investigate and provide technical assessment on the soil settlement problem at PSIS on September 2013. Geotechnical report was issued for the soil investigation works, laboratory tests and settlement monitoring at PSIS on January 2016.

The soil settlement analysis was carried out using Terzaghi methods showed that the settlement is still active, and the balance of settlement until it reached stability ranges from 1427 mm to 2882mm. After 13 years of construction, the recorded settlement ranged from 400 mm to 700 mm. The report also showed that immediate settlement has occurred and the primary settlement is still ongoing. The settlement is deemed to be stable when it reaches 90% of the settlement, which has been estimated to take place in 220 to 370 years. This duration was due to the filling load, the thickness of the soft soil and the high water table at site i.e. 0.00 m to 0.4 m from ground level (PWD, 2016).

2.2 Drainage system problem

At PSIS, the water from the rainwater down pipe is discharged to the main drain via buried distribution pipe or to the soak away pit (Fig. 1 and Fig. 2). Only two blocks in this campus were equipped with perimeter drain. From the report, the damage to the drainage system components was listed as in Fig. 3. The broken rainwater downpipe due to the rigid joint damage were 1205 cases, broken joint to distribution pipe (205 cases) while differential settlement of the main drain is six cases and two cases of damaged perimeter drain.

Fig. 1. Damage to the existing drainage system due to soil settlement at Politeknik Sultan Idris Shah, Sabak Bernam, Selangor.

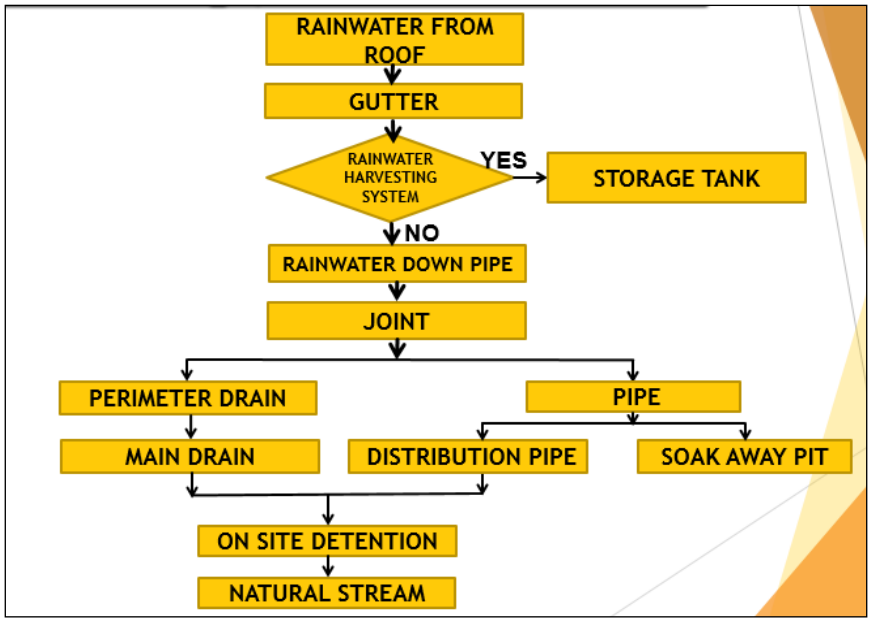


Fig. 2. Flow of water

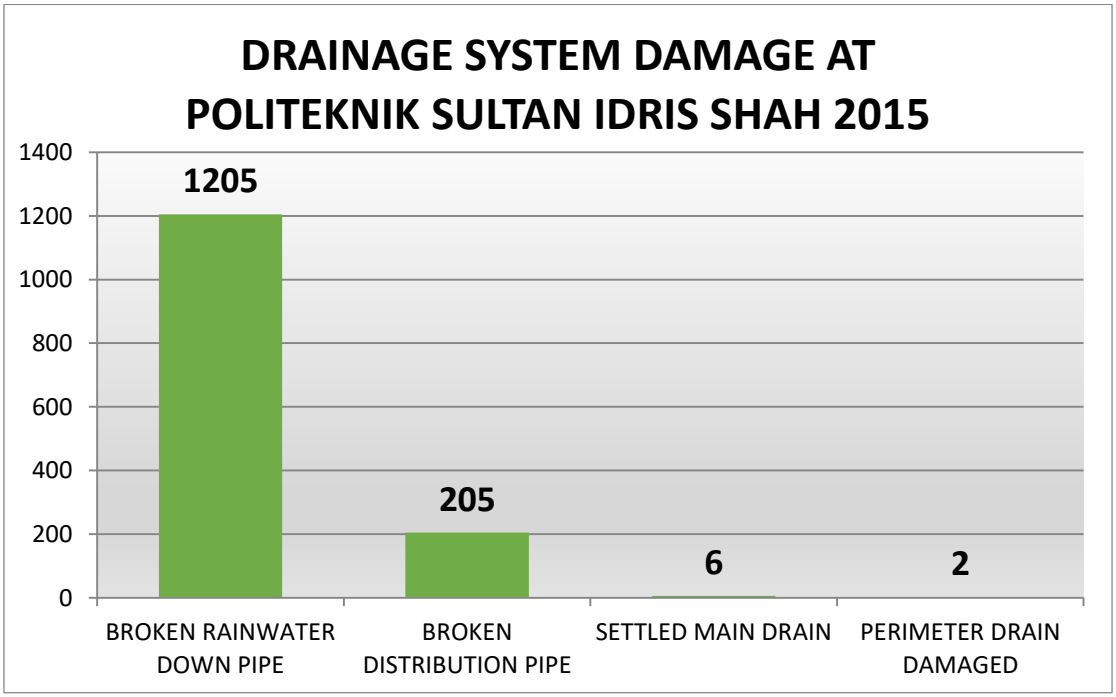


Fig. 3. Drainage system damage at PSIS for year 2015 (PWD, 2016)

Maintenance report by the PSIS Maintenance and Development Unit showed the recurring mode of repair works to the drainage system, hence it is uneconomical to replace the damaged drainage pipeline, broken rainwater downpipe or perimeter drain using the normal design practice. Since the major cause of failure is at the rigid joint, innovation of this component is the key to the successful drainage system design at the settlement area. The joint must be *flexible* to accommodate the movement of the soil. The building perimeter drain will be substituted with PVC drainage pipes as the main drain.

3. Design consideration for flexible joint

3.1 *Material*

The rigid joint is replaced with a flexible joint that can accommodate soil settlement throughout its design life. The material of the joint, however, must be light enough as to minimize the soil deformation due to the applied stress. Since the flexible joint will be connected to the buried non-pressure pipe, it is very important that the material must not be degradable or easily corroded by the soil acidity. This material must also sustain the differential settlement to the difference in building and infrastructure loading.

PVC has been chosen for the material since it has good corrosion resistance, is lightweight and cheap besides it was the material used for rainwater down pipes. Expected life of a PVC pipe may exceed 100 years, as per established by Lanchashire (1985), Hulsmann (2004), Boersma and Breen (2005), Breen (2006) and Burn etal., (2005). It is observed that PVC pipes may last 100 years of operation even at 7 bar (102) psi and 60˚C (Boersma and Breen, 2005). Folkman (2015) reported that PVC pipe meeting proper standards and if properly installed would have a life in excess of 100 years.

The prototype of this joint was established using PVC flexible hose, which is normally used in fume extraction. This hose (Fig. 4) could be readily cut into designated length based on the localized annual settlement rate.

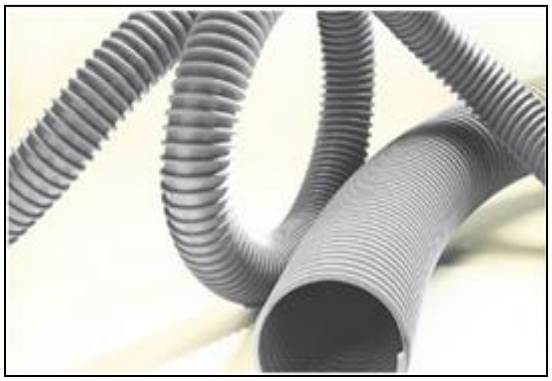


Fig. 4. Flexible pipe hose

3.2 *Minimum length*

Length of the vertical part of flexible joint is the crucial part in the overall component since the minimum length must exceed the total settlement of the corresponding area throughout the design life of the joint (Fig. 5). The minimum length of the flexible joint is calculated by applying the Factor of Safety. This is carried out via manual tensile test in which the maximum elongation of the proposed material is obtained as shown in Fig. 6. In the case of PVC flexible hose, the hose can elongate up to 4.0 times its original length. The F.O.S is then applied as 2.5.

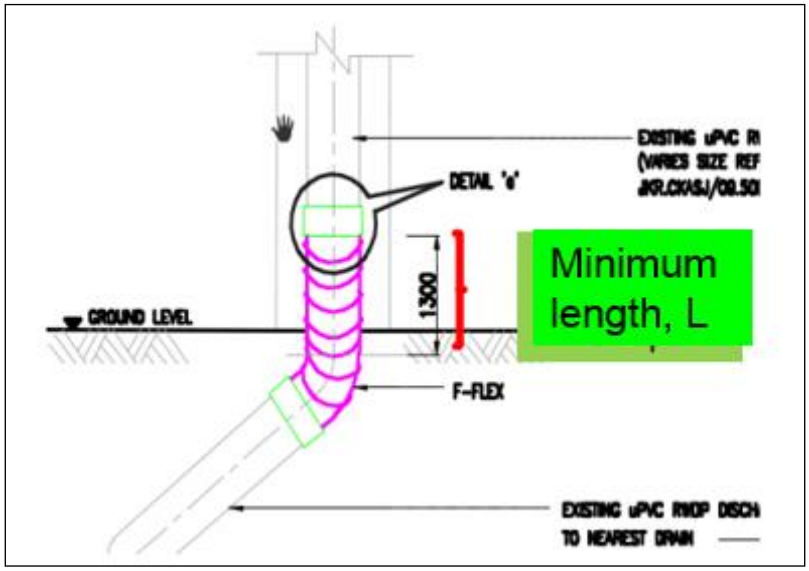


Fig. 5. Minimum length of the flexible joint to accommodate soil settlement

Fig. 6. Manual tensile test

For the settlement case of PSIS, Sabak Bernam, the minimum length for the vertical part of the flexible joint is estimated as follows:

Sample length = 300 mm
Length after tensile test = 1500 mm
Elongation % = $\frac{(1500\text{ mm}-300\text{mm})}{300\text{ mm}} \times 100\%$
= 4.0
Take Factor of Safety as 2.5

Annual settlement rate = 3-10 mm/year
Product warranty =10 years
Total settlement throughout product design life =10 mm/year x 10 years = 100 mm
Minimum length =$\frac{\text{Total settlement}}{\text{F.O.S}}$ =$\frac{100\text{ mm}}{2.5}$
=**40 mm**

3.3 *Effect of turbulence in pipe*

One of the critical design issues of pipe system is the turbulent bubbly flow in vertical circular pipes such as rainwater down pipe. Investigations carried out by Ervin and Tryggvason (1997) and by Tomiyama(1998) showed that the radial residence of the bubble very much depends on the diameter of the pipe. Since the flexible joint will be connected at the edge of rainwater down pipe to the distribution pipe, this effect should be reduced to avoid the flexible joint failure. The effect of the turbulence in pipe is minimized by installing a strainer as an *energy dissipator* at the top of the flexible joint, which reduces the water velocity (Fig. 7)

Fig. 7. *Energy dissipator* (strainer) installed in the rainwater down pipe

3.4 *Connection*

During the prototype development stage, the flexible joint is designed connected to the rainwater down pipe using screw and sealant as shown in Fig. 8. This design has been improved by using coupler that eliminates the possibility of leakage and simplifies the maintenance procedures by eliminating reapplication of sealant.

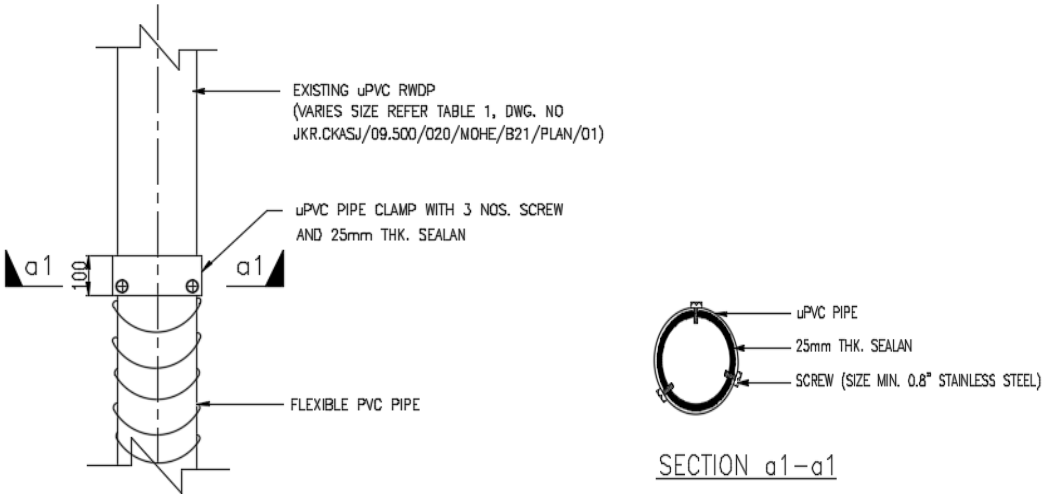
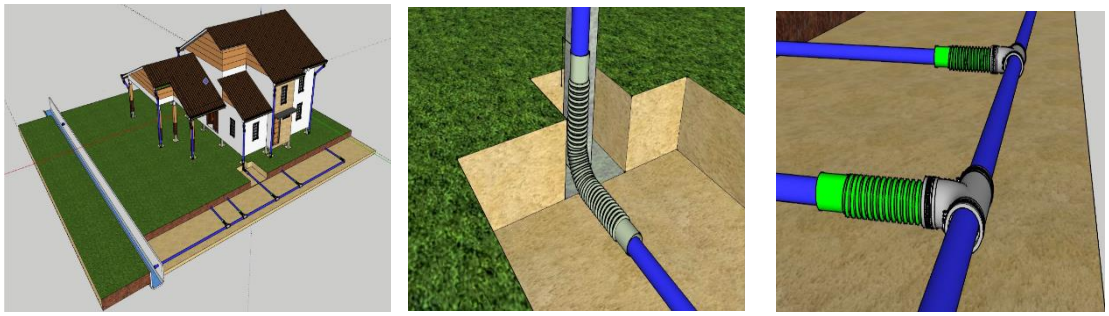


Fig. 8: Initial Connection detail

4. Flexible Joint Installation

The schematic diagram of the proposed drainage system with flexible joint is shown in Fig. 9.



(a) (b) (c)

Fig. 9. The schematic diagram of flexible joint installation

All rainwater downpipes in the building are connected by the flexible joint to the distribution pipe that acts as the main drain as shown in Fig. 9 (a and b). The flexible joint is also installed at the joint between individual PVC pipes to the main drain (Fig. 9c) to provide more flexible points to cater for different settlement that could lead to a backflow in the drainage system.

The flexible joint was installed in all 43 blocks in PSIS as shown in Fig. 10.

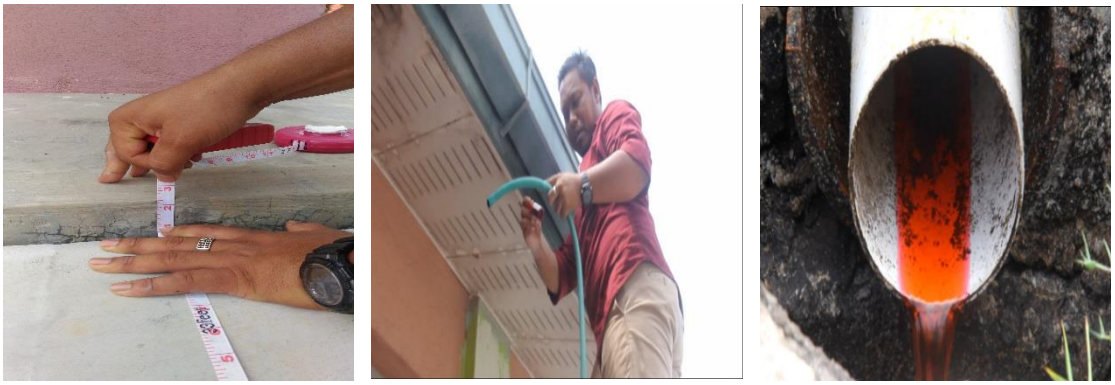
Fig. 10. The installation of the flexible joint

5. Testing

Testing of this system is done twice i.e. after installation (zero settlement) and six months (settlement recorded) after installation. A review on the existing PWD Standard Specification of Building Works 2014 showed that there is no testing method as part of the acceptance criteria for rainwater downpipe installation. The settlement is recorded by measuring the distance (if any) between the apron level and the sediment wall top level (Fig. 11a). A known volume of water (taken as 5.0 litre), denoted as V_{pre} is discharged through the rainwater down pipe (Fig. 11b). Food colouring is added to produce coloured water (Fig. 11c). A container is set at the discharge point. The volume of discharge is measured. The collected volume, V_{post} is compared with the initial volume. The initial volume equals to the initial volume indicates that there is no leakage in the drainage system. The test results are shown in Fig.s 12 and 13.

The test showed that the system is functional and there is no significant loss of water volume. Assumptions made of this test include expected minor loss due to friction; therefore, minor loss

of 0.5ml is acceptable. All of the water poured on the gutter will flow though the rainwater down pipe. Significant water loss of more than 0.5 ml indicates possibility of flexible joint failure.



(a) (b) (c)

Fig. 11. Flexible joint fuctionability test

BLOK	LOCATION	SETTLEMENT (mm)	INITIAL WATER VOLUME, VOL_{pre} (10^{-3} m^3)	DISCHARGE VOLUME, VOL_{POST} (10^{-3} m^3)	
MUSOLLA	SUMP 1	0.00	5.0	4.85	NO LEAKAGE
	SUMP 2	0.00	5.0	4.70	NO LEAKAGE
CANTEEN	SUMP 1	0.00	5.0	4.90	NO LEAKAGE
	SUMP 2	0.00	5.0	4.80	NO LEAKAGE
	SUMP 3	0.00	5.0	4.70	NO LEAKAGE

Fig. 12. Test results after installation

BLOK	LOCATION	SETTLEMENT (mm)	INITIAL WATER VOLUME, VOL_{pre} (10^{-3} m^3)	DISCHARGE VOLUME, VOL_{POST} (10^{-3} m^3)	
MUSOLLA	SUMP 1	25.00	5.0	4.80	NO LEAKAGE
	SUMP 2	10.00	5.0	4.65	NO LEAKAGE
CANTEEN	SUMP 1	0.00	5.0	4.85	NO LEAKAGE
	SUMP 2	0.00	5.0	4.80	NO LEAKAGE
	SUMP 3	0.00	5.0	4.75	NO LEAKAGE

Fig. 13 Test results six months after installation

6. Conclusion

Designing a sustainable drainage system at settlement areas posed a new challenge to the infrastructure design engineers particularly at areas where the settlement is not expected to reach stability in due time. In the case of ground settlement at Politeknik Sabak Bernam, flexible joints were installed between the rainwater down pipe to the distribution pipe. The features for flexible joint which can ensure the functionability of the drainage system under short and long term soil settlement throughout its design life were discussed such as guidelines for material selection, minimum length of the joint, turbulence effect reduction method, and connection detail. The test conducted after the instalment of the joint and after six months installation has shown that there is no significant water loss i.e. there is no leakage of the system.

7. References

[1.] N.O. Mohamad, C.E. Razali, A.A.A. Hadi, P.P. Som, B.C. Eng, M.B. Rusli, F.R. Mohamad, "Challenges in Construction Over Soft Soil- Case Studies in Malaysia," in Soft Soil Engineering International Conference, Langkawi, 2016, vol. 136, pp. 1-8.

[2.] D.C. Lat, N. Ali, I.B.M .Jais, B. Baharom, N.Z.M. Yunus, S.M. Salleh and N.A.C Azmi, " Compressibility of Sabak Bernam Marine Clay," in International Conference on Innovative Technology, Engineering and Sciences, Pekan, 2018, vol.342,pg1-11.

[3.] G.L. Sivakumar Babu, A. Srivastava, "Reliability Analysis of Buried Flexible Pipe Soil System," J. Pipeline Syst. Eng. Pract., Vol.1 no. 1, pp 33-41., 2010.

[4.] A.P. Moser. *Buried Pipe Design*. Mc Graw Hill, New York,1990.

[5.] D. Stephenson. *Pipeline Design for Water* Engineers. Elsevier Science, New York.1976.

[6.] Public Works Department of Malaysia, "Laporan Geoteknik bagi Kerja-kerja Penyiasatan Tanah, Uian Makmal dan Pemantauan Mendapan di Politeknik Sultan Idris Shah, Sabak Bernam, Selangor Darul Ehsan," 2016.

[7.] S.J. Lanchashire, "In Service Durability of UPVC Water Mains," Plastic Pipes VI Conference, York, 1985, pp. 15.1-15.8

[8.] T. Hülsmann and Reinhard, E.N., "70 years of experience with PVC pipes," 13th World Pipe Symposium, Milan, Italy, 2004.

[9.] A. Boersma and J. Breen, "Long term performance prediction of existing PVC water distribution systems," 9th International Conference PVC, Brighton, 2005.

[10.] J. Breen, "Expected Lifetime of Existing Water Distribution Systems-Management Summary," TNO Report MT-RAP-06-18692/mso, April 2006.

[11.] S.L. Folkman, "Validation of the Long Life of PVC Pipes," TEPPFA Forum, Brussels, 2015.

Implementation Framework of Green Building for Malaysian Government Building: KKR2 Study

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Abstract

The purpose of this study is to develop the Implementation Framework of Green Building for Government Project. Implementation of Green Building Design is very important in Malaysia to conduct and execute green government project. The research intended to answer the questions about the factors involve in the development of the framework, the significant relationships between the factors involved in the Implementation Framework and whether there is significant relationship exists between the factors in implementation framework. Thirty respondents were selected from multilevel project team KKR2 including engineers, assistants engineers, technical assistant, stakeholders, contractors and consultants. In conclusion, the study answered pertaining questions regarding the factors involved in development of Implementation Framework of Green Building through quantitative research and hypothesis testing.

1. Introduction

The building that we live, work and play interact with our environment, affecting storm water run-off, energy and water consumption, transportation patterns, and indoor air quality. Recognition of the role that buildings have in our environment has led to significant efforts to design, build and maintain more sustainable structures (Parris, 2010). Green building practices includes environmentally responsible and resource efficient, promote building practices that conserve energy and water resources, preserve open spaces, minimise emission of toxic substances, harmonise with the local climate, traditions, culture and the surrounding environment, sustain and improve the quality of human life, maintaining the capacity of the ecosystem at local and global levels. Benefit of green building to the environment is that it saves energy use from 24% up to 50%, CO^2 emissions from 33% up to 39%, water use 40% and solid waste reduction of 70% for each green building (Turner, C. & Frankes, M,2008). Besides benefiting the environment, green building also contributes to the building stakeholders by enhancing health and productivity, reducing environmental impact, environmentally effective use of materials, lowering electric and water utility costs and gives long term economic return. In relation to the tittle, the main purpose of this study is to determine the factors involved in the development of the Implementation Framework of Green Building Design for Malaysian Government Buildings, significant relationships between the factors involved and significant relationship between the factors in the framework. The analysis is conducted based on quantitative research and hypothesis testing.

2. Problem Identification

The sixth Prime Minister of Malaysia, Dato' Sri Haji Mohamad Najib bin Tun Haji Abdul Razak has announced that by 2020, Malaysia will reduce carbon emission rate up to 40 % from the current rate in 2005 parallel with Malaysia's commitment in United Nations Climate Change Congress 2009 (COP 15) in Copenhagen on 17 December 2009. The way buildings are designed in Malaysia will affect the energy consumption required. There is difficulty to justify the implementation of green building in government projects. Existing guidelines and Code of Practise on Energy Efficiency and Renewable energy to achieve low carbon building in the market such as MS1525, Dasar Teknologi Hijau and Development and publication of EE in Buildings Guidelines does not indicate the strategies or method to implement green building for government projects. Besides that, in Malaysia, there is only Green Building Index, which is the rating tool for Green Building and private initiatives.

Public Works Department of Malaysia is the largest implementer of government buildings and projects in Malaysia. The Public Works Department has implemented excellent and best practices of project management procedures and guidelines.

In addition to initiatives and commitment of Public Works Department to deliver outstanding Green Building Projects as mentioned in the Public Works Department Key Performance Indicator in the Strategic Framework 2012-2015. This Implementation Framework is a starting point and beginning role of Public Works Department as the Implementers of Green Building Projects for the Government of Malaysia.

3. Research Objectives

The introduction and the problem statement above led to the formulation of the research aim and objectives. The broad aim of this research is to introduce or establish implementation framework of green building for government building. In accordance with the research aim, the pertaining objectives of this study are, a) to determine the control factor/ critical areas to focus on the green building design, b) to assess current project team/ staff perception in implementation of green building project, c) To integrate green building factors as rating tools in existing design and project management procedure and d) To build implementation framework of green building design for government building.

4. Propose Conceptual Framework for Implementation Framework of Green Building Design for Malaysia Government Building

The suggested framework (Fig. 1) is derived from the analytical literature review of the study, which consists of concept process phases and in depth review of previous study conducted from previous research. This framework consist of three factors involving project management procedure/ guideline/ government policies, type of project execution (design and build or conventional) and project staffs perceptions.

5. Pilot Test Conducted at Kompleks Kerja Raya 2 (KKR2) Project

Pilot test was conducted on 12 April 2015 to test on reliability, validity of the instrument used and Inferential Analysis Correlation Pearson to test on the hypothesis that has been developed. The pilot test were conducted with 30 respondents selected from multilevel project team including engineers, architects, quantity surveyor, assistants engineers, technical assistant, stake holders, contractors and consultants from Kompleks Kerja Raya 2 Project Team,

Cawangan Kerja Bangunan Am', PWD Headquarters, Kuala Lumpur. All the questionnaires reviewed accordingly to ensure all the questions are answered.

Table 1 shows profile of respondents from pilot test according to designation grade, age, gender, race and education. Overall, there were six supporting staff respondents, meanwhile management staffs were three respondents and professional staffs were 21 respondents. Meanwhile for age of respondent, three respondents are at age 19-24 years old, 13 respondents are at 25-40 years old, 12 respondents are at 41-56 years old and two respondents at 57-60 years old. In terms of gender, 18 of respondents were male and 12 were female. For race, 27 respondents were Malay, one Chinese and two Indians. Meanwhile in terms of respondent's education level, one respondent had education level until primary and secondary school, respectively, 24 respondents possess university level education and three respondents had other education level.

6. Pilot Test Data Analysis

For the pilot test, data is analysed using "*Statistical Package For Social Science"* (SPSS). Analyzing technique used be used is descriptive analysis and inferential analysis. Descriptive analysis consists of percentage and frequencies respondent feedback and the strength for every variable. Inferential Analysis used is correlation Pearson Techniques. Besides that, coding process and recoding the data is essential before the data analysis is done. Pearson Correlation is used to conduct statistical analysis to test the hypothesis.

Reliability test analysis for the KKR2 project pilot test

After the data is collected and reviewed, the quality of data collected should be tested. Data is reliable when the test to measure the same element is repeated and produces similar results (Salkind, 2006 in Mohd Khairul Nizam, 2007). In addition, reliability test was conducted to measure the stability of the instrument used. For This research, Cronbach alpha near to 1, the highest reliability the instrument was used. The rule of thumb for Cronbach alpha value by Hair et al. (2007) was employed as guidelines to show the strength for every test and measures as shown in Table 2.

Hypothesis Testing for KKR2 Project Pilot Test Study

There are five main Hyphothesis developed to answer all the pertaining relationship between l the independent variables and dependent variables in the theoretical Framework. The Hyphothesis are:

7. Inferential Analysis

Pearson correlation is used to analyse the inferential statistics in this research.

Pearson Correlation

In this pilot test, relationship between dependent variables and independent variables was measured. To determine the relationship, correlation coefficient, r, was analysed to determine the strength between the variables. Criteria set by Davis (1971, as cited in Mohd Khairul Nizam (2007) was referred to evaluate the directions or strength of that relationship. Table 3 shows the strength of the relationship and the value of correlation coefficient, r as mention by Davis (1971).

Pearson Correlation result in KKR2 Pilot Test Study
Pearson Correlation result in KKR2 pilot test study shows:

Hyphothesis 1 : There is significance relationships between project management procedures/ guidelines with implementation framework of Green Building .

Figures and tables

Table 1. Respondent demography profile

Demography	Frequencies	Percentage
Designation grade		
Professionals	21	70
Management	3	10
Supporting Staff	6	20
Age		
19-24 years	3	10
25-40 years	13	43.3
41-56 years	12	40
57-60	2	6.7
Gender		
Male	18	60
Female	12	40
Race		
Malay	27	90
Chinese	1	3.3
Indian	2	6.7
Education		
Primary School	2	6.7
Secondary School	1	3.3
Universities	24	80
Others	3	10

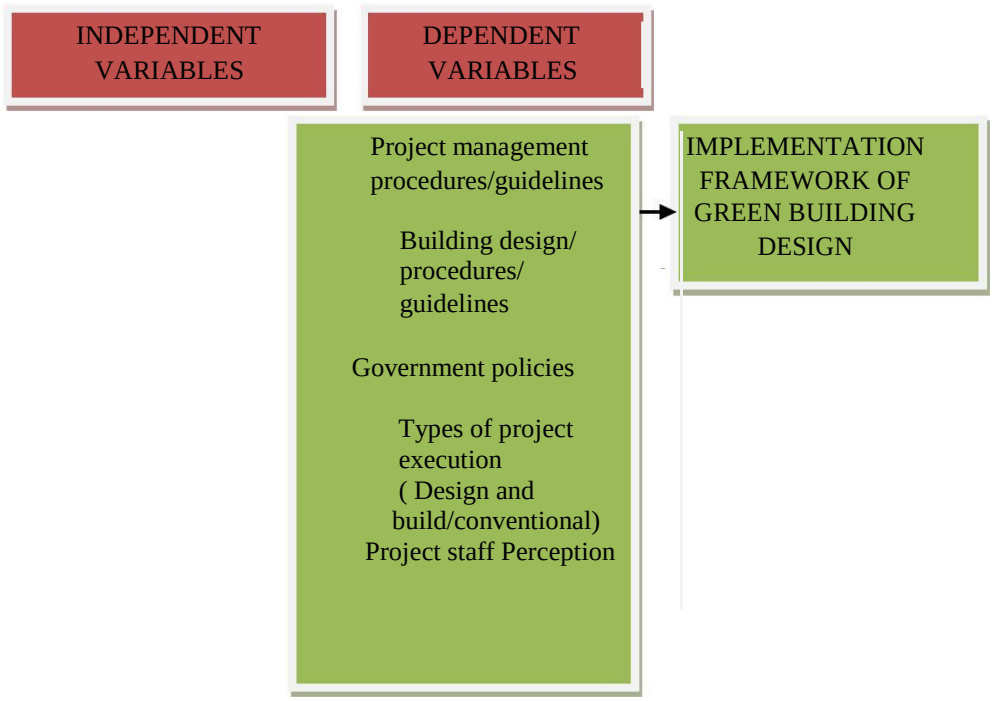

Fig. 1. Conceptual Framework

Table 2. The reliability test result conducted at KKR2 Project

Alpha	**Relationship strength**
< 0.6	Strong
0.6 - < 0.7	Medium
0.7 - < 0.8	Good
0.9 - < 0.9	Very Good
0.9	Excellent

Table 3. Case processing summary

		N	%
Cases	Valid	30	100
	Excluded (a)	0	0
	Total	30	100

a List wise deletion based on all variables in the procedure.

Table 4. Reliability Statistic

Cronbach's Alpha	N of Items
0.922	55

Table 5. Item-Total Statistic

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Age	113.8667	502.257	.341	.921
Gender	114.9000	504.093	.463	.921
Race	115.1333	517.430	-.125	.923
Education	113.3667	509.068	.181	.922
Design	114.8000	525.269	-.299	.926
Grade				
Q7	114.3333	491.609	.411	.921
Q9	114.7000	489.321	.687	.919
Q10	114.9333	492.064	.613	.919
Q11	114.7000	492.769	.558	.920
Q12	114.3667	487.482	.607	.919
Q13	114.6000	482.248	.786	.918
Q14	113.4333	484.599	.230	.929
Q15	114.6000	491.559	.605	.919
Q16	114.5000	485.638	.724	.918
Q17	113.6000	510.248	.106	.923
Q18	114.0000	495.586	.556	.920
Q19	113.8000	502.717	.210	.923
Q20	113.6333	507.689	.148	.923
Q21	113.6667	513.057	.021	.924
Q22	114.4667	489.775	.596	.919
Q23	114.4333	479.771	.718	.918
Q24	114.4000	481.628	.709	.918
Q25	113.8333	496.557	.396	.921
Q26	113.9333	494.133	.397	.921
Q27	114.4000	496.938	.508	.920
Q28	114.0333	496.102	.389	.921
Q29	113.8000	501.200	.301	.922
Q30	113.6000	507.283	.127	.923
Q31	113.4000	517.352	-.078	.925
Q32	113.4000	510.731	.043	.925
Q33	114.5333	489.085	.690	.919
Q34	114.3000	494.010	.542	.920
Q35	114.2667	497.651	.608	.920
Q36	114.4000	500.731	.457	.921
Q37	114.3667	490.033	.692	.919
Q38	114.4667	508.740	.210	.922
Q39	114.5333	491.085	.716	.919
Q40	114.2333	502.668	.306	.921
Q41	113.8000	504.648	.208	.922
Q42	114.0000	499.931	.376	.921
Q43	114.2333	496.668	.530	.920
Q44	114.3000	485.528	.678	.918
Q45	113.9667	488.447	.518	.920
Q46	114.2000	484.993	.710	.918
Q47	113.9000	501.472	.310	.921
Q48	113.9667	495.895	.437	.920
Q49	114.2333	495.564	.530	.920
Q50	114.5333	489.568	.642	.919
Q51	114.3667	497.206	.482	.920
Q52	114.3333	503.471	.393	.921
Q53	114.3000	496.838	.523	.920
Q54	114.0667	484.961	.648	.919
Q55	113.9333	482.271	.628	.919
Q56	114.1333	489.499	.535	.920
Q57	114.2000	500.717	.292	.922

Table 6. Hypothesis Testing

Research Hypothesis	Statistical Analysis
Hypothesis 1: There is significant relationship between project management procedures/ guidelines with implementation framework of Green Building.	Pearson Correlation
Hypothesis 2: There is significant relationships between Building design procedures/guidelines with implementation framework of Green Building.	Pearson Correlation
Hypothesis 3: There is significant relationship between government policies with implementation framework of Green Building.	Pearson Correlation
Hypothesis 4: There is significant relationship between types of project execution with implementation framework of Green Building	Pearson Correlation
Hypothesis 5: There is significant relationship between project staff's perception with framework of Green Building Implementation.	Pearson Correlation

Table 7. Comparative between Relationship Strength with Correlation Coefficient, r

r value	Relationship strength
± 0.70 or higher	Very high
± 0.50 until ± 0.69	High
± 0.30 until ± 0.49	Medium
± 0.10 until ± 0.29	Low
± 0.01 until ± 0.09	Very Low
0.0	No relationship

Table 8. Correlation for Hypothesis 1

		Project management design procedure	Green building design framework
Project management procedure	Pearson Correlation	1	.930(**)
	Sig. (2-tailed)		.000
	N	30	30
Green building framework	Pearson Correlation	.930(**)	1
	Sig. (2-tailed)	.000	
	N	30	30

** Correlation is significant at the 0.01 level (2-tailed).

Table 9. Correlation for Hypothesis 2

		Project management design procedure	Green building design framework
Building design procedure	Pearson Correlation	1	.930(**)
	Sig. (2-tailed)		.000
	N	30	30
Green building framework	Pearson Correlation	.930(**)	1
	Sig. (2-tailed)	.000	
	N	30	30

** Correlation is significant at the 0.01 level (2-tailed).

Table 10. Correlation for Hypothesis 3

		Government policy	Green building design Framework
Government policy	Pearson Correlation	1	.661(**)
	Sig. (2-tailed)		.000
	N	30	30
Green building framework	Pearson Correlation	.661(**)	1
	Sig. (2-tailed)	.000	
	N	30	30

** Correlation is significant at the 0.01 level (2-tailed).

Table 11. Correlation for hypothesis 4

		Type of project execution	Green building design framework
Type of project execution	Pearson Correlation	1	.830(**)
	Sig. (2-tailed)		.000
	N	30	30
Green building framework	Pearson Correlation	.830(**)	1
	Sig. (2-tailed)	.000	
	N	30	30

** Correlation is significant at the 0.01 level (2-tailed).

Table 12. Correlation for hypothesis 5

		Perception	Green building design framework
Perception	Pearson Correlation	1	.809(**)
	Sig. (2-tailed)		.000
	N	30	30
Green building framework	Pearson Correlation	.809(**)	1
	Sig. (2-tailed)	.000	
	N	30	30

** Correlation is significant at the 0.01 level (2-tailed).

8. Conclusions

According to the pilot test result conducted with KKR2 Project Team, the test result shows positive result with the hypothesis developed and formulated between Project Management Procedures/ Guidelines, Building Design Procedures/Guidelines, Government Policies, Types of Project Execution and Project Staff Perception with Implementation Framework of Green Building. Therefore, the result shows there is significant relationship between Project Management Procedures/ Guidelines, Building Design Procedures/Guidelines, Government Policies, Types of Project Execution and Project Staff Perception with Implementation Framework of Green Building. The comprehensive well- defined Project Management Procedures/ Guidelines, Building Design Procedures/Guidelines, Government Policies, Types of Project Execution and the clear, positive perception of the Project Staff Perception ensure the effectiveness and success of Implementation Framework of Green Building for Government Building. Implementation framework of green building for Malaysian Government Building is important in addition to ensure the success of Public Works Department as implementers of Green building for Malaysian Government Projects. This framework is also important for Malaysia to have a clear and systematic execution/implementation of green government project in Malaysia.

9. References

[1.] U.S. Environmental Protection Agency. (October 28, 2009). Green Building Basic Information. Retrieved December 10, 2009, from http://www.epa.gov/greenbuilding/pubs/about.htm

[2.] R. Hopkins, 2002. *A Natural Way of Building.* Transition Culture. Retrieved: 2007-03-30.

[3.] X. Mao, H. Lu, & Q. Li, (2009). *International Conference on Management and Service Science,2009. MASS 09., 1-5.*

[4.] U.S. Environmental Protection Agency. (October 28, 2009). Green Building Home. Retrieved November 28, 2009, from http://www.epa.gov/greenbuilding/pubs/components.htm

[5.] WBDG Sustainable Committee. (August 18, 2009). Sustainable. Retrieved November 28, 2009, from http://www.wbdg.org/designsustainable.php

[6.] T. Hegazy, (2002). Life-cycle stages of projects. Computer-Based Construction Project Management, 8.

[7.] S. Pushkar, R. Becker, & A. Katz (2005). A methodology for design of environmentally optimal buildings by variable grouping. *Building and Environment*, 40. doi:10.1016/j.buildenv.2004.09.004

[8.] J.R. Simpson, Energy and Buildings, Improved Estimates of tree-shade effects on residential energy use, February 2002. Retrieved:2008-04-30.

[9.] California Integrated Waste Management Board. (January 23, 2008). Green Building Home Page. Retrieved November 28, 2009

[10.] M. Thomas Parris (2007): *Green Buildings, Environment Science and policy for Sustainable Development,* 49:1,3-7

[11.] C.Turner, & M. Frankel, (2008), *Energy performance of LEED for new Construction Building*, Final report.

[12.] P.A. Andersen, J.F. Andersen, & J.P Garrison (1978).Singing apprehension and talking apprehension: The development of two constructs. Sign Language Studies, 19,155-186.

[13.] P.H Andrew, & R. T. Herchel, (1996), *Organization Communication: Empowerment in Technological Society.*Boston : Houghton Mufflin.

[14.] A.T. Sulaiman (2001). Faktor-faktor yang menentukan Keberkesanan Komunikasi: satu kajian di Jabatan Kastam Diraja Malaysia, Negeri Pahang. Tesis Sarjana. Universiti Utara Malaysia.

[15.] Y.P. Chua, (2006). Kaedah dan statistik penyelidikan: Asas statistik dan penyelidikan (Buku 1). Malaysia: McGraw Hill Education.

[16.] Y.P.Chua, (2006). Kaedah dan statistik penyelidikan: Asas statistik dan penyelidikan (Buku 2). Malaysia: McGraw Hill Education

[17.] J.F Hair, Jr., A.H. Money, P. Samouel & M. Page (2007). Research method for business. England: John Wiley & Son Ltd.

[18.] M.K.N.Ibrahim, (2007). Hubungan ciri-ciri personaliti dengan menghadapi perubahan organisasi. Sintok: Universiti Utara Malaysia

[19.] U.Sekaran, (2000). Research Method for Business: A Skill building Approach (3rd edn). New York. John Wiley and Sons Inc

Total Asset Management:
Engineering Economic of HVAC Replacement in Malaysia

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Abstract

This research presents the development of a guideline that could be used to select the best option for building asset replacement specifically for government ownership. Building life cycle management should be transparent and cost efficient. Hence, decisions taken during the life cycle of the buildings should be based on clear justification. One of the major issues in facility planning is the determination either to refurbish or replace the existing asset. In fact, government assets have to be economically managed by knowing the holding cost, so that it can be retained for a long period. The objective of this study was to establish the relationship between asset decision-making factors and replacement costs. The real replacement project of Heat, Ventilation, and Air Conditioning (HVAC) system in government building was selected in this study. The methodology of this research employed the use of a triangulation method that is the combination of both quantitative and qualitative analysis. Eleven experts in the 1st phase of the study validated literature review and theoretical framework of the study. In order to establish the relationship between asset decision making and replacement costs, the comprehensive analysis in the 2nd phase of the study was implemented via the means of archive documentations and interviews of 61 HVAC project in 12 states within Malaysia. Lastly, 3 real case studies that were based on the HVAC project were used in the 3rd phase of this research for the purpose of validating the asset model which is referred to as: Asset Replacement Cost Decision Making Model (ARCDM). The result of this study provides raw evidences to support existing replacement cost decision making in government sector are based on Competency and Self Confidence of the human factors. In addition, ARCDM can be used by government as a guideline or tool in wise decision making for building replacement related activities.

Keywords: Engineering Economic Analysis (EEA), HVAC System, Replacement Cost, Decision Making, PLS-SEM Analysis, Malaysian Government.

1. Introduction

Facility management that was previously perceived as operation and maintenance of buildings has been transformed. Recently and as of 2017, it has evolved to a higher level whereby facility managers (FMs) now ensure that built environments (such as residential, commercial, industrial and institutional) functions satisfactorily, involving people, financial, technological and managerial expertise. Due to the fact that facility management covers multi disciplines, this field is subject to numerous and constant changes. The practice and standard of facility

management varies significantly between developed and developing countries around the world.

Various websites and blogs on facility management have outlined challenges and top trends that have significant impact on its future. The highlighted key areas are new environment, new technology, focus on green and wellness, security and health risk management as well as the Return on Investment (ROI) (Lum, Y. L., 2017).

Facility management is very complex. The multiple disciplines and constant changes necessitate a holistic professional approach to ensure proper functioning of the built environment. Cost-effective facility management results in low lifecycle costs through reduced operations and maintenance costs, extended lifespan of facilities, improved indoor environmental quality and sustainability of assets (Roslan Md Taha, 2017).

Therefore, from the development of FM above, there are two key words in future trends; Return of Investment (ROI) and Decision Making (DM). The time has come to give attention to the search for factors that affect decision making because errors is decision making are costly. Therefore, it is a significant loophole in cost decision making in facility management.

Furthermore, one of the procurement principles in Malaysia is 'Value for Money'. Government procurement should yield the best returns for every Malaysian Ringgit spent in terms of quality, quantity, timeless, price and source. The other four principles are public accountability, transparency, open fair competition and fair dealing (Ministry of Finance Malaysia, 2017).

1.1 *Background of study*

The term 'Replacement project' as used in this paper is defined as a work on existing buildings that comprises of rehabilitation, modernization, renovations, improvements, adaption, additions, repairs, renewal and retrofitting. Furthermore, 'Replacement Cost' definition in this paper is the amount it would cost to replace an asset at current price. It is the cost of replacing the asset in order to obtain the level of services enjoyed when the asset was initially acquired. It is important to note that because the asset is in poor condition, the government would probably decide against replacing the asset.

Based on Immovable Asset Management Manual (2012) and Government of Malaysia - *Tatacara Pengurusan Aset Tak Alih Kerajaan,* TPATA (2012), the government has analysed the results of the assessment for asset modelling by using two methods that are the situation and performance evaluation assets. Setting and measurement of the physical condition level or the performance rating of assets is divided into five sections, namely the level that marks the achievement and criteria. Five parts of the level and achievement are as follows:

1. 1 (very weak): KPI < 40 % -Level 1
2. 2 (weak): KPI (40-49%) -Level 2
3. 3 (moderate): KPI (50-69%) -Level 3
4. 4 (good): KPI (70-90%) -Level 4
5. 5 (excellent) : KPI > 90% -Level 5

The criteria of level 1 represents weak asset, not working to meet the design objectives and legislation, no characteristic of sustainability, the security level is very low, level of economic and asset utilization is very weak. Criteria of level 2 represents weak asset, working to meet the design objectives and legislation, no characteristic of sustainability, the security level is very low, and the level of economic as well as the use of bad asset is also low. The criteria for level 3 represents asset condition in a moderate level, functional design to meet the goals and legislation, availability of the characteristics of sustainability, the level of security that is simple, economical and asset utilization levels that are simple. Assets in good condition, function that meets design objectives and legislation, characterized satisfactory preservation, very high level of security, economic levels and better asset utilization are the criteria for level 4. Lastly, the criteria of level 5 represents that asset condition is very good, function meets design objectives and legislation, the characteristics of a sustainable high level of security is available, and the level of economic as well as optimal asset utilization is optimum (TPATA, 2012).

Fig. 1. JKR.PATA.F8-5: Asset *Building Evaluation Procedure (Page 136: Item 5. Carta Prosedur E2, TPATA 2012, Malaysian Government)*

Fig. 1 shows the form of decision making for building replacement. There are no cost analysis data on this form. Cost analysis is needed for the decision makers as a guideline to make wise decisions in building replacement. Asset modelling is the generic term used in the Government

for computer modelling of decision making factor and replacement costs. Historically, decision-making has always been modelled separately from the replacement cost. This paper is done in order to capture the relationship between those two or standalone model. The decision made in Asset Management of Malaysia is different based on their agencies initiatives and competency of officers. There are needs for standardization of asset cost analysis. The study on costs of replacement will be discussed in the next section.

1.2 *Costs of Replacement*

This section presents literature analysis conducted on previous work related to replacement cost of existing building. Journal and conference papers published from year 2000 until 2017 were reviewed.

Anthony Andrew (2000) examined the way valuers work for Central Government apply the RICS Appraisal and Valuation Manual (the Red Books) to its definition of depreciated replacement cost valuation and its effects on Government Policy on public sector listed buildings, capital charging and Inner City Regeneration. In 2002, El-Haram and Horner identified 24 factors affecting housing maintenance cost and conducted a survey among 50 local authorities and housing associations to determine the most important factors. The study concluded that 'high tenant expectations', 'budget constraint', 'improper use of property' and 'right to buy policy' were the most important factors.

Furthermore, Al-Khatam in 2003 conducted a literature review on the factors affecting the cost of maintenance in buildings. The review identified 34 factors, classifying it into seven major groups, namely 'engineering services', 'labour', 'building materials', 'environment', 'management and administration', 'budget and finance' and 'building user behaviour'. Based on the literature review, it was concluded that the major causes for high cost of maintenance in buildings are absence of local material standards and specifications, concern about the initial cost by owners, poor supervision and management of maintenance projects, poor scheduling, absence of standardized maintenance contracts and faulty design as well as construction.

Focusing on identifying the main key performance indicators in the maintenance of hospital facilities, Shohet et al., in 2003 identified four key performance indicators to increase the efficiency of hospital maintenance. These indicators include performance management, composition of labour, efficiency of maintenance and organizational effectiveness.

Ali in 2009 conducted a survey of 200 building managers on the factors affecting the cost of building maintenance. Factors included 'existing building condition', 'building age', 'complaints received regarding building performance', 'client's request', 'availability funding', 'safety and health requirements'. The study concluded that the cost of maintenance is affected mainly by 'condition of building' and 'complaints about building performance. Meanwhile, Flyvbjerg et al., in 2009 indicated that planning of major infrastructure project is usually carried out with some faults. Projects are usually completed with time and cost overruns, and benefits shortfalls. The main reasons for this situation are honest mistakes, unexpected events, forecasting errors and deception.

Furthermore, Ali et al., in 2010 identified the critical factors affecting the maintenance cost in housing projects. In total, 31 building managers were surveyed to assess the most critical factors. The study indicated that the most important factors are 'expectation of tenant', 'building material', 'building services', and 'building age 'and 'failure to execute management at the right time. In addition, Love and Li in 2010 investigated the costs, magnitude and causes of the rework of two major construction projects. The study concluded that the contract value for the cost of rework in the two projects were 3.15 and 2.14 percent of the overall contract values. The identified causes for rework were 'errors and omissions in contract documentation' and 'changes initiated by the client and end-user'.

There are buildings with special design characteristics and with some special functions; unfortunately, these specialities are hard to maintain. These are normal due to deterioration and aging factors. Therefore, it is of much importance that a thorough study is carried out to develop a guideline for the determination of maintenance cost on the special buildings (N. Mohd-Noor, 2011).

C. Shapiro (2012) stated that cost was first analysed broadly by major improvement category (energy efficiency, health and safety, code and cosmetic) and then explored in more detail at the energy efficiency level. While actual costs were higher than estimated costs in each major category, the biggest differences were associated with code and cosmetic improvements. When comparing actual and estimated costs for energy efficiency upgrades, the most significant differences were in the mechanical system category. On the average, actual costs for mechanical system improvements (HVAC, domestic hot water, and mechanical ventilation combined) were 27% higher than the initial bids. Although many other factors may have also contributed, underbidding was the most apparent reason for this discrepancy..

According to M. Banazadeh (2013), various retrofit strategies will have reasonable comparability and loss estimation will ease decision process for stakeholders with accessible information. The results of methodology allow stakeholders and decision makers to communicate easily according to expected economic benefits. Meanwhile, Kušar, Kovač and Šelih in 2013 stated that management of the building stock is constantly gaining attention, predominantly due to the large investment required to construct it and maintain it. Increasingly, especially in more developed countries, special efforts are aimed at the existing assets, as their number continuously increases.

A series of interviews with the facility manager of 40 public and private hospitals in the eastern province of Saudi Arabia was conducted to determine the factors affecting the cost of maintenance in hospitals. The most important factors from the perspective of public hospitals are 'transfer of problems from the construction phase to maintenance phase for resolution', 'lack of coordination between the construction and maintenance group', and 'lack of quality control measures during the installation of system'. Meanwhile, the most important factors from the perspectives of the private hospital are 'duration of the maintenance contract' and 'the method of classifying maintenance contractors', 'error conducted during the design of the project' and 'lack of feedback from the maintenance group to the design team' (Mohammad A. Hassanain, 2013);

Moreover, Sarah Bell in 2014 stated that estimating the costs and impact of refurbishment or demolition is complex, uncertain and subjective. The typical cost indicators used in assessing the refurbishment and demolition projects are Capital Expenditure or CAPEX (the cost of fixed assets): Operational Expenditures or OPEX (the costs of goods and services) and capital investment appraisal (understanding the value of an investment over time).

For example, in Ontario, Canada, Ministry of Education hires independent, third party facility inspectors to get detailed information. Each team is comprised of two engineers; one with expertise in building design and construction, and the other with expertise in building systems (e.g. mechanical and electrical systems). The inspectors review essential structures and systems for each school building. They also review wear and tear to building interiors. Based on the findings of each school inspection over a five-year period, the ministry can determine a school's repair and renewal costs. The cost of school's repair and renewal needs are then compared against the cost of rebuilding that same school from the scratch. Results of this comparison showed that fixing a school or rebuilding it gives the school its FCI (Facility Condition Index), which is measured in percentage. A School with a low FCI rating needs less repair and renewal work as compared to a school with higher FCI rating (Pang Soo Mooi, 2017)

According to Ingenieur (2017), cost-effective facility management results in low lifecycle costs through reduced operations and maintenance costs, extended lifespan of facilities, improved indoor environmental quality and sustainability of assets. The new trends that are focused towards cost effective facility management can be achieved by the continuous improvement of the existing practices and consistent compliance with the Ministry of Finance's principle, which is 'Value for Money'. Therefore, cost decision making is a significant study in Malaysia's facility management.

In this paper, independent variables are Competency, Skill & Experience, Individual Profile, Self Confidence, Level of Commitment, Stakeholders, User, Existing Building Condition, Building Age, Performance Evaluation, Energy Efficiency, IT System, Security Risk, Life Cycle Cost, Funding Availability, Policy, Safety and Health, Achievement, Informed Decision Making, Information Database, and Change of Business Function. Generally, these data are related to the dependent variables of this study that is referred to as the replacement cost of HVAC system.

1.3 *Scope and Limitation of the Study*

Fig. 2 shows the Document Structure Management of Government Assets composed of four levels, namely policy (*Dasar)*, manual (*Manual*), management procedures (*Tatacara*) (land, property, building, infrastructure assets, movable assets and asset life) and supporting documents (*Dokumen Sokongan*) (standards, specifications, codes of practice, guidelines). Therefore, this study will improve the supporting documents as a reference in the implementation of operational procedures management of government assets. Figure 2 shows the limitation of the study that is limited to level 4 of the document only (supporting document) (*Tatacara Pengurusan Aset Tak Alih Kerajaan*, 2012).

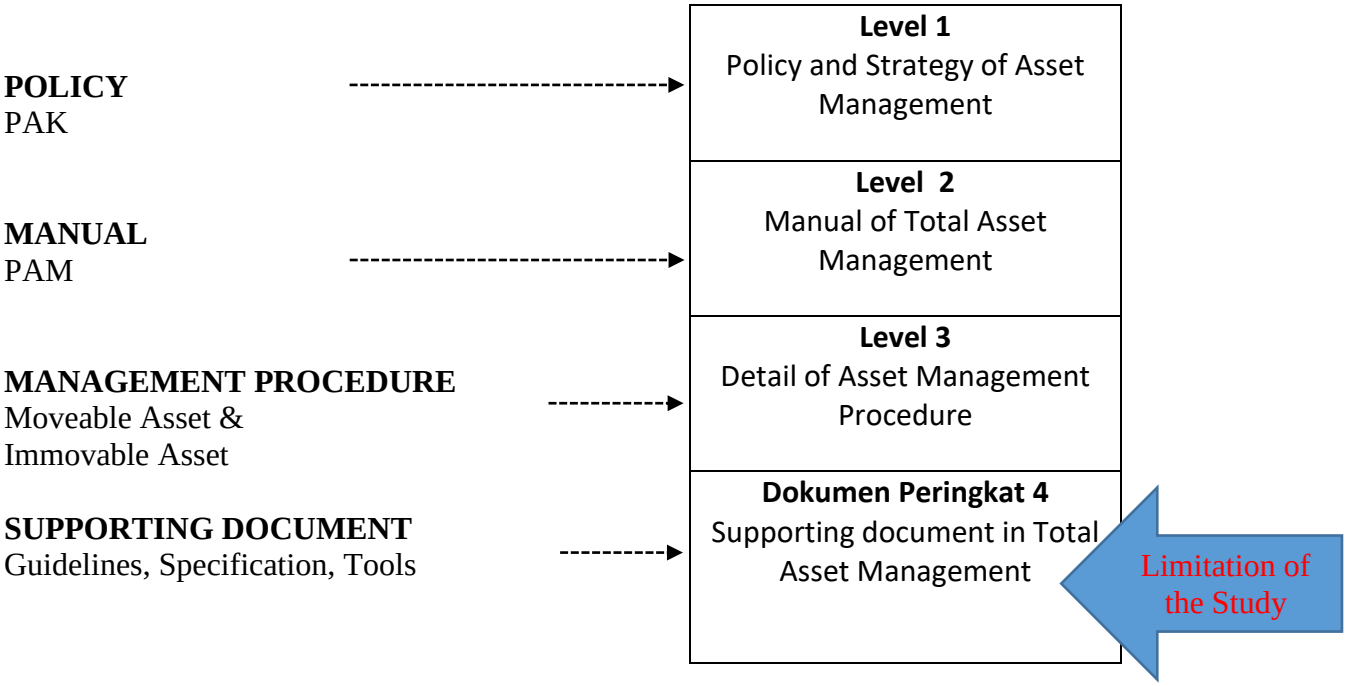


Fig. 2. Document Structure Management of Government Assets
(Page 1, Total Asset Management Manual 2009, Government of Malaysia)
(Page 4, TPATA 2012, Government of Malaysia)

The purpose of this paper is to establish the relationship between human, technical and organizational factors in asset decision making with replacement cost. Therefore, the hypotheses outlined in this study are as follows:

H_o: There is no statistically significant relationship between human factors and cost
H_1: There is statistically significant relationship between human factors and cost

H_o: There is no statistically significant relationship between technical factors and cost
H_1: There is statistically significant relationship between technical factors and cost

H_o: There is no statistically significant relationship between organizational factors and cost
H_1: There is statistically significant relationship between organizational factors and cost

2. Research method

This study employed the approach of a mixed method consisting of both qualitative and quantitative analysis. The method of data collection in this research was through interview and semi structured interview. Data was gathered through expert's interview at the 1st phase of study and semi structured interview with the decision makers in HVAC replacements field of the government sector in Malaysia during the 2nd phase. PLS-SEM analysis was used in this study. The 1st phase was to validate the theoretical framework while the 2nd phase was to establish the relationship between asset decision making and replacement cost. Table 3 shows the objectives and method of this study.

Table 1. Flow of Research Methodology

OBJECTIVES	METHOD
To identify and define the research problem, objectives and hypotheses.	Previous research and documents related to decision making and replacement costs were reviewed.
To develop the conceptual/theoretical framework.	Findings of previous research and relationship between variables were studied.
To obtain and to collect complete raw data with information from respondents.	Collect information from: 1. Head Office JKR Malaysia 2. Branch Asset Management JKR 3. JKR State Mechanical
To test the validity of the theoretical framework and get information on respondent size and refurbishment projects in Malaysia.	Expert interview with 20 Decision makers Superintending Officers. However, after 11 experts, the answer was consistent and saturated.
To establish the relationship between asset decision making and replacement costs.	Semi structured interviews with 61 selected projects and 61 selected Decision Makers.
To test the hypotheses determined in the early stage of the study.	Statistical Analysis using PLS-SEM.

Face to face interviews were conducted in all the stages of data collection. The interview employed had no specific procedure or guideline to follow. Some of the questions were structured while others were unstructured, depending on the purpose of the study. The main reason for having interviews is to obtain in-depth understanding about the problems faced by decision makers while handling the decision making process of refurbishment projects as well as methods to overcome the problems by the decision makers. It was important to obtain these understanding before the final model could be designed, to have a clearer picture of the actual implementation of replacement projects. This procedure would ensure the final model remain focused on the actual problems.

The first phase was concentrated on factors and variables related to replacement cost decision making. Subjective data from asset management experts were gathered from eleven different top government officers (Subject Matter Experts) in government agencies for the purpose of data validation. The objectives of this phase were to evaluate current existing level of asset replacement decision-making practice and to validate independent variables (those have significant relationship with the asset replacement decision making). The first phase involved the factors of independent variables as shown in the literature review, which included human, technical and organization factors. Generally, these data are related to dependent variables of this study that is the replacement cost of HVAC system.

The second phase was conducted upon completion of the first phase. The objectives are (1) to identify significant factors on replacement cost decision making as perceived by the groups of respondents, (2) to determine the relative importance of these factors and (3) to establish the relationship between decision-making and replacement costs.

The second phase used semi-structured questionnaires and interview, whereas questionnaires were distributed to 61 selected respondents of decision makers. The group of respondents identified in this study were engineers working in the government agencies who were directly involved in decision making on the implementation of projects. The questionnaire survey consisted of variables perceived to have effects on replacement cost of the project. This questionnaire survey was prepared based on extensive literature review and interviews of experienced practitioners involved in the implementation of public projects.

From the JKR Workshop Annual Report 2016 (Public Work Department), there is only an average of 60 projects per year for the refurbishment project of HVAC system that costs RM 200,000.00 and above. These data collection took approximately six months to select the projects that fulfil all the requirements and in order to set the appointments. From all over the states within the Peninsular of Malaysia, only 61 decision makers agreed to allocate their time for the interview and completed the project documentation. The rest were not able to complete project documentations. Some of them could not be contacted because they were unavailable when the researcher contacted. Therefore, 61 respondents of decision makers in this study can be considered sufficient to obtain an adequate range of views and opinions in the area of study. During the course of the interviews, the author found that the response reached saturation point with no new information, after 30 interviews. However, the interview process continued until all 61 respondents were interviewed for having a better confirmation of the subject matter.

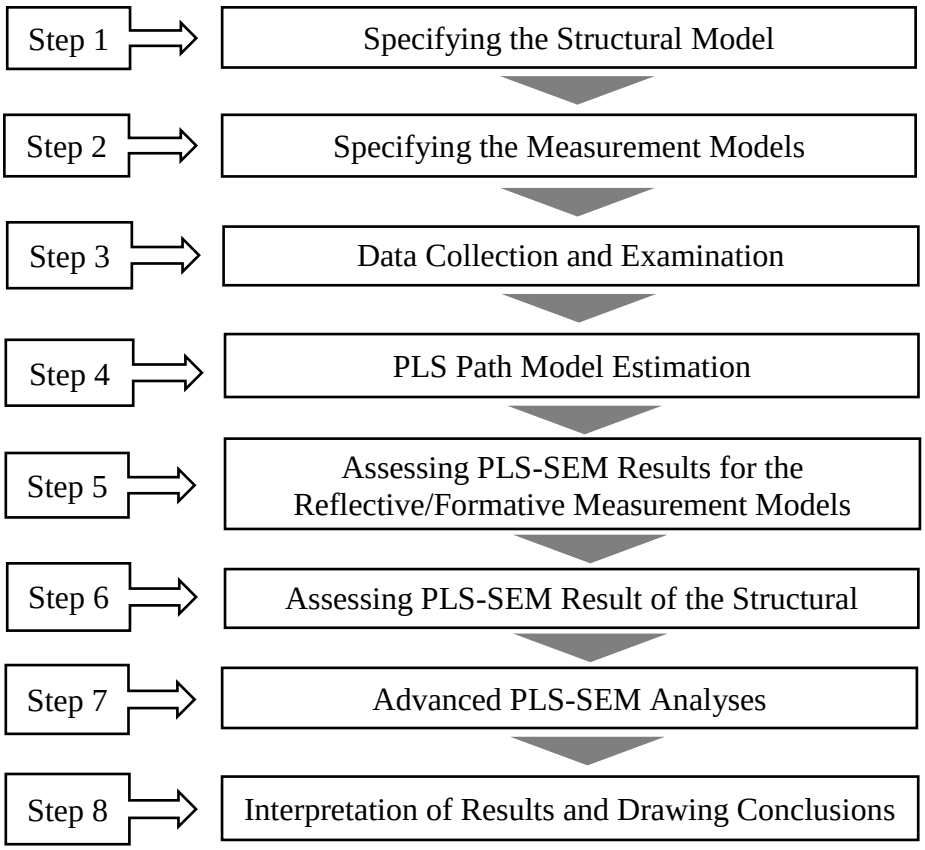
Interviews were carried out over a period of 6 months.. The minimum duration of the interview recorded was approximately 30 minutes and the maximum was about 1 hour. All interviews took place at the respondents' workshop. During the interview, the researcher took precautions especially to prevent bias in the questions asked and to limit the conversations.

During the interview, the researcher also took the opportunity to refer to some of the archived documentations of completed replacement projects. By means of this, information was obtained from 61 relevant replacement projects that could be used as project cases to back up some of the explanations during the analysis of the final findings for the present study. Archive documents were referred as examples during the interviews. This leads to a clearer example pertaining to the issues discussed. Among the issues identified is inaccurate information of asset that is reflected on the amount of replacement costs in a contract document.

In conclusion, it is important to note that a thorough formulation of the research design is an important element in any social science research. An understanding of basic social science methodology is also an important ingredient in producing quality as well as robust research findings. The present study used triangulation techniques in the research methodology, which combined both qualitative and quantitative approaches. The triangulation technique used was sufficient to obtain the required information that could be used to validate the theoretical framework using statistical analysis. Two stages of data collection methods were used including literature review and the validation interview that provided a response of 11 experts, followed by semi-structured interviews questionnaire survey of 61 decision makers together with a review of archived documentation. Limitation of the study and rationales for the decision made in designing the research were discussed. Finally, PLS-SEM techniques, which covered both qualitative and quantitative analysis, were described.

Partial Least Squares Analysis – Structural Equation Modelling (PLS-SEM)

SPSS version 23 was used for data quality checking and Smart PLS version 3 was used for partial least square structural equation modelling (PLS-SEM) to analyse the reliability and validity of the measurement model and structural model. The data collected has a sample size of 61 without any missing values, outliers, and illogical observations. Structural Equation Model (SEM) is one of the instruments used for analysis between endogenous and exogenous constructs, as well as looking for a relationship in one model. There are eight steps to conduct PLS-SEM as showed in Fig. 3.



Source: Joseph F. Hair et al., 2014

Fig. 3. Systematic Application PLS-SEM Procedure

3. Findings

Finding 1: General Information of the Respondents

The demographic information as demonstrated in Table 2 recorded six main characteristics of main survey participants:

Table 2. Information of Respondents

Items	Sub- Items	Frequency (N)	Percentage (%)
Position	Management Technical	5 56	8 % 92 %
Age	20-30 31-40 41-50 51-60	4 7 44 6	7% 11 % 72 % 10%
Gender	Male Female	54 7	88% 12 %
Field Background	Mechanical Electrical Civil	59 1 1	96% 2% 2%
Working Experience	2 years 5 Years 10 Years	8 23 30	13% 38% 49%
Sector	Business Expert JKR State Management Special	1 7 52 1 0	2% 11% 85% 2% 0%

The demographic information as demonstrated in Table 2 categorises six main characteristics of main survey participants which are 'Position', 'Gender', 'Field Background', 'Working Experience', 'Sector' and also the 'Age' of them.

The first segment is related to their position, which involves two main parts of management and technical parts respectively. The technical division recorded the highest frequency of 56 people compared to the management division with only five respondents. The second characteristic is gender, which involved an overall figure of 61 respondents. This survey involves men with a recorded frequency of 54 while the remainder of seven were women. Respondents from the mechanical field recorded the highest frequencies of 59, followed by electrical and civil fields each recording a frequency of only one respondent, respectively. Most of them with a specific figure of 30 respondents have over 10 years of working experience, while those with working experience of about 5 to 10 years were 23 respondents and the rest with a minimum of 2 to 5 years working experience included eight respondents. Several sectors were involved in this survey. Among them are Business, Expert, JKR State, Management and Special Sector. The information obtained showed that the sector of JKR State recorded the highest frequency of 52 respondents. Additionally, the Expert Sector has also recorded a frequency of seven respondents, followed by the Business and Management Sectors each recording a frequency of one and lastly the Special Sector recorded zero frequency.

Finally, the most important aspect of this survey is the average age of all respondents involved. The average age of respondents in the range of 41-50 years recorded the highest frequency of 44 followed by the age range of 31-40 years that included seven respondents. In addition, the respondents involved in the survey also consisted of an age range of 51-60 years old and a total of 6 respondents and 4 others in the 20-30 years age range.

Based on selected projects, the second phase employed semi-structured questionnaire survey where the questionnaires were distributed to 61 selected respondents. The group of respondents identified in this study were:

1. Head of Mechanical Workshops which are working in the government agencies who were directly involved in decision making on implementation of projects.
2. Engineers or Managers who were involved in the tender board of decision making of those projects.
3. Assistant Engineers or Senior Technicians who were involved in the inspection and who also prepared proposals for HVAC replacement.
4. Director of the Tender Board or Members of the Tender Board.

Very importantly, the selection of respondents was based on the projects selected. The replacements of HVAC system consist of repair, retrofit, upgrade, maintenance, replace and renovation of the system. The selection was based on the limitation and scope of the paper. Therefore, the details of the project are listed down in Table 3 below:

Finding 2: List of HVAC Replacement Projects and Replacement Costs

Table 3. Lists of Replacement Project of HVAC System

No.	Project Serial Number of HVAC System (Centralized Unit)	Type of Replacement (Repair, Retrofit, Upgrade, Replace, Renovation)	Year	Cost (RM)
1.	0001	Replace	2013	218,500.00
2.	0002	Replace	2014	1,613,000.00
3.	0003	Replace	2014	855,400.00
4.	0004	Replace	2013	3,603,000.00
5.	0005	Repair	2013	407,000.00
6.	0006	Upgrade	2014	660,000.00
7.	0007	Upgrade	2014	580,000.00
8.	0008	Upgrade	2012	3,268,000.00
9.	0009	Replace	2016	342,698.00
10.	0010	Repair	2015	327,646.00
11.	0011	Replace	2014	288,300.00
12.	0012	Replace	2016	484,000.00
13.	0013	Replace	2015	239,600.00
14.	0014	Repair	2016	408,800.00
15.	0015	Replace	2015	488,500.00
16.	0016	Replace	2016	379,500.00
17.	0017	Replace	2014	492,470.00

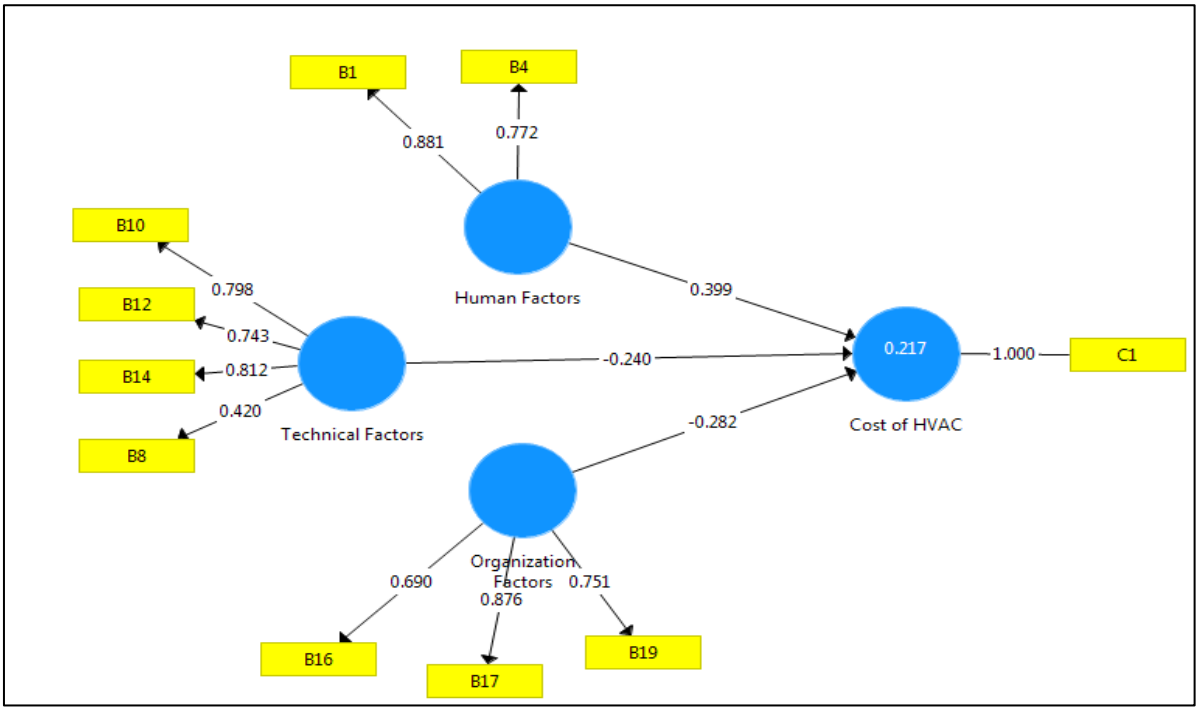
18.	0018	Upgrade	2013	445,780.00
19.	0019	Upgrade	2015	354,880.00
20.	0020	Upgrade	2014	492,800.00
21.	0021	Replace	2016	235,849.00
22.	0022	Repair	2016	467,000.00
23.	0023	Replace	2016	460,000.00
24.	0024	Upgrade	2016	207,700.00
25.	0025	Repair	2016	449,090.00
26.	0026	Upgrade	2016	250,000.00
27.	0027	Repair	2016	455,500.00
28.	0028	Upgrade	2015	342,100.00
29.	0029	Replace	2015	985,130.00
30.	0030	Replace	2016	462,450.00
31.	0031	Repair	2016	355,060.00
32.	0032	Repair	2015	417,340.00
33.	0033	Repair	2014	3,281,281.00
34.	0034	Replace	2012	824,000.00
35.	0035	Retrofit	2016	5,715,050.00
36.	0036	Replace	2012	1,998,034.00
37.	0037	Repair	2014	1,046,316.00
38.	0038	Renovation	2013	1,165,000.00
39.	0039	Upgrade	2015	200,000.00
40.	0040	Repair	2016	295,848.00
41.	0041	Upgrade	2015	355,000.00
42.	0042	Repair	2016	826,800.00
43.	0043	Replace	2016	289,650.00
44.	0044	Replace	2016	268,000.00
45.	0045	Repair	2016	420,210.00
46.	0046	Maintenance	2015	462,700.00
47.	0047	Replace	2016	460,000.00
48.	0048	Repair	2015	160,950.00
49.	0049	Repair	2016	158,400.00
50.	0050	Upgrade	2015	1,922,552.00
51.	0051	Replace	2016	675,800.00
52.	0052	Maintenance	2016	286,710.00
53.	0053	Upgrade	2016	470,100.00
54.	0054	Repair	2016	295,101.00
55.	0055	Upgrade	2016	259,700.00
56.	0056	Upgrade	2015	282,800.00
57.	0057	Repair	2015	289,400.00
58.	0058	Replace	2016	510,920.00
59.	0059	Replace	2016	290,440.00
60.	0060	Retrofit	2011	4,500,000.00
61.	0061	Retrofit	2012	497,075.00

The selection criteria of the project were as follows: 1) Replacement project of HVAC system that consists of maintenance, repair, retrofit, upgrade, replace, renovation works of the system 2) The size of refurbishment projects handled based on contract value that is more than RM 200,000.00 3) Project from year 2011 until 2016.

Among the most important elements of the building are its building systems that comprise heating, ventilating, air conditioning, electrical, plumbing, fire protection, and vertical transportation. Irrespective of either a new or an existing building, these systems represent its lifeblood and nervous system. The cost of a new facility or a renovation is highly dependent on the type and extent of the building systems added. Complex heating, ventilating, and air conditioning (HVAC) systems can represent significant cost items.

Mechanical costs are also subject to wide variation above and below the normal percentages occurring in new construction. Where complex climate control systems and extensive fire extinguishing system are necessary, mechanical construction cost will become significant percentages of the total construction budget. Mechanical cost together with architectural costs therefore are the two key variables to be examined in assessing the economic feasibility of retrofit construction, while demolition and structural costs seem not to differ significantly between new and retrofit construction (Garcia-Diaz, A., & Smith, J. M., 2008)

Finding 3: Asset Modelling on Replacement Costs



Legend:

Human Factors	Technical Factors	Organization Factors
B1 = Competency B4 = Self Confidence	B8 = Asset Condition B10 = Performance B12 = Risk B14 = Life Cycle Cost	B16 = Policy B17 = Safety & Health B19 = Informed Decision

Fig. 4. Asset Modelling on Replacement Cost

Based on the statistical analysis by PLS-SEM in Fig. 4:

1. There is statistically significant positive relationship between human factors and cost
2. There is statistically significant negative relationship between technical factors and cost.
3. There is statically significant negative relationship between organization factors and cost.

From the results above, only the human factor has significant relationship with replacement cost decision making of HVAC system. 'Competency' and 'Self-Confidence' of the Mechanical Engineer are the keys element in HVAC decision making.

4. Discussion

With respect to Finding 1, Finding 2 and Finding 3, the relationship between replacement costs and decisions making of HVAC system is based on the competency and self-confidence of mechanical engineers. Basically, engineers solve problems and formulate alternatives to take advantage of opportunities. Their training endows them with the engineering expertise to provide technical solutions. Engineering Economic Analysis (EEA) offers the tool required to evaluate solutions by engineers according to their competency merits. These tools are further integrated into a decision making process in order to ensure that the wise solution is chosen. The steps in Engineering Economic Analysis (EEA) are as follows:

a) Define of the Scope of Replacement Projects and Recognize the Opportunity.

In order to solve a problem, the problem must be identified, along with the characteristics of its desired solution. The decision making process cannot commence unless this steps occurs. In addition to solving problems, engineers provide methods with advantage of opportunities be taken. Whereas in cases where problems such as the failure of a piece of equipment, may abruptly present themselves; investment opportunities are often more subtle. To find these opportunities, the engineer must examine the technical capabilities available and creatively seek additional applications of those capabilities. This is parallel with the result stating 'Competency of Manager' as a critical factor in decision-making.

b) Generation of Replacement Alternatives

Once a problem or opportunity has been defined, alternative solutions must be identified as well. Identifying these solutions requires creativity, training and skills of an engineer, as this phase involves all engineering solutions to be designed for subsequent economic evaluation. A rich collection of possible solutions will make it more likely for an economically viable option to be found. To broaden the perspective and allow various solutions to be explored, engineers generally form teams. This process also requires discipline, as one must refrain from passing final judgement on a particular solution. This phase is concerned with generating alternatives, not evaluating them. That does not mean that the design process should accept solutions that do not meet technical specifications. However, judgement must be used in such a way that feasible alternatives are not eliminated too early in this creative process.

There is a fine line between generating a large number of feasible alternatives and generating the number of alternatives that can be feasibly analysed with the resources available. While it

seems best to generate as many solutions as possible, as this ultimately ensures a good decision, the resources available to analyse the alternatives are limited. Therefore, production of a reasonable set of alternatives is compulsory. This requires engineering judgement to identify outlandish proposals and make sure that they are eliminated early, so as not to waste limited resources.

c) Development of feasible alternative cash flows and information gathering.

Once the alternatives have been identified, they must be researched on. There are wide range of factors that may be considered in evaluating the economic benefits and costs of engineering proposals, including all expected receipts and disbursements. In addition to investing the associated cash flows, the research process includes gathering relevant information in order to make an informed decision. Risks of a physical and economic nature may be involved and must be evaluated. This includes calculating the probability of the success and likelihood of failure. All other benefits and cost of an alternative, even those that cannot be easily expressed in terms of money, must be identified. The replacement was deemed cost effective compared with the repair of the existing system. The latter is a benefit that is not easily quantified monetarily, but surely influences the decision.

Cost estimation is generally considered the most complicated step of the decision making process, as all of the cash flows are expected to occur in an uncertain future. The error can often be reduced, but it can never be eliminated. These estimates, and their uncertainty, are the subject of economic scrutiny in the next decision-making step.

d) Evaluation of Scope and Costs of Replacement

The cash flows defined in the previous step are rigorously analysed to determine the economic viability of an alternative. The focus here is to examine the differences between alternatives, not their similarities. This text offers specific instruction in these methods of analysis under situations of certainty, uncertainty, and risk in environments that are either static or dynamic. In addition to the analysis of economic factors, non-economic attributes associated with each alternative are also examined. When possible, these could also be converted into monetary terms.

e) Selection and implementation of the Project

Once all the alternatives have been analysed economically, the optimal choice is selected. As noneconomic factors weight into the decision, it is the job of the engineer to exercise judgement in the final decision-making. This may lead to the implementation of an engineering solution, the delay of an investment until a later date, or the decision to forgo investment completely, if economic success is far from guaranteed. Based on Figure 3, Asset Modelling on Replacement Cost shows that the decision on the selection of the replacement projects is based on the competency and self-confidence of the mechanical engineer. The formula is as below:

HVAC RC = 0.399 x {0.881(Competency) + 0.772(Self Confidence)}

Competency: Range from 5 (High competency) to 1 (Lack of competency)
Self Confidence: Range from 5 (High confidence) to 1 (Low confidence)
Value Range : 3.30 to 0.66
Coefficient Value : 0.399

RCDM Value	Decision Making
RCDM > 1.32	Accept the replacement
RCDM = 1.32	Indifferent
RCDM < 1.32	Reject the replacement

f) Post implementation analysis and evaluation

Choosing a solution does not complete the decision process of the asset. After the solution is implemented, the project must be tracked, and periodic decisions are to be made as to the choice of continuity. It has been mentioned earlier that investment decisions are made concerning an uncertain future. As the future unfolds, the direction of the project may need to be adjusted in order to capitalize on opportunities. This may entail accelerating or delaying stages of the project, or even abandoning the project altogether. These decisions can be made smartly only if the project is closely watched after a solution has been implemented. Projects that provide information for future investment decisions were also identified. Estimates required in new economic analyses are usually derived from previous estimates, just as previous designs provide input for new designs in the engineering design process. Thus, close tracking of costs and revenues associated with a project will provide a database of information that can be used to improve the accuracy of future predictions. The result is linked to step a, step b and step c of the decision making process for future decisions. Generally, a decision is taken from conception to completion in these six steps. To ensure rigorous analysis of asset, each step must be completed. Fig. 5 illustrates the Economic Engineering Analysis (EEC).

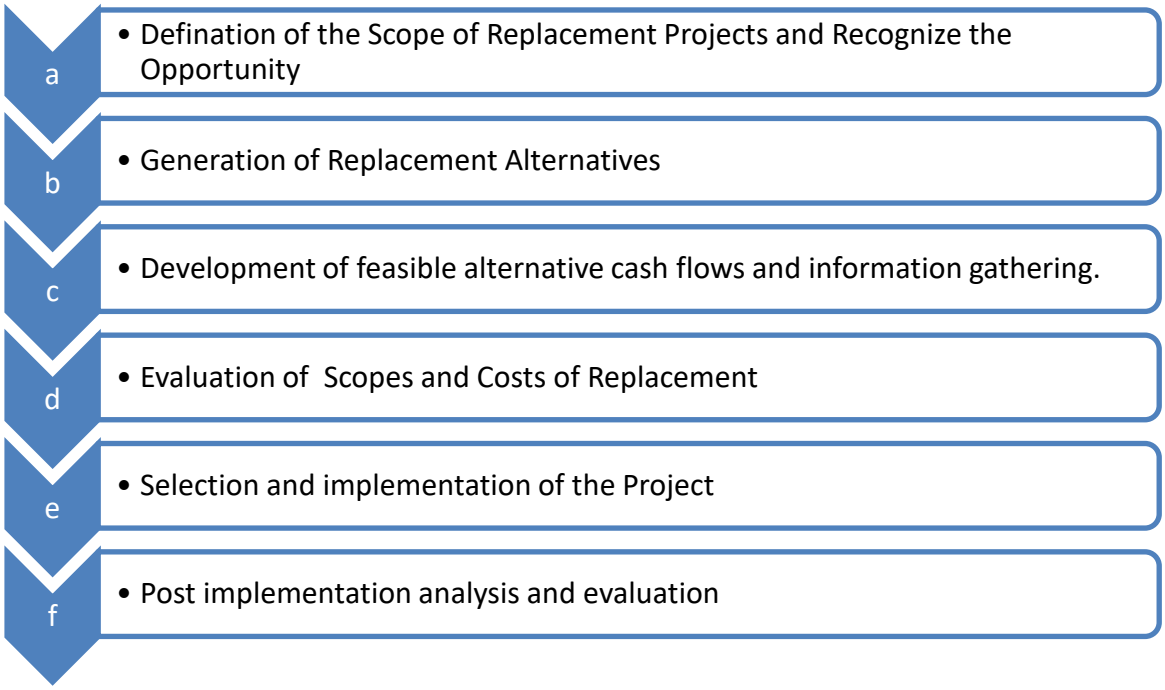


Fig. 5. Flow of Engineering Economic Analysis (EEC) in HVAC Replacement.

5. Conclusion

The main contribution of the study is the development of engineering economic decision analysis especially for engineers who are involved in HVAC system. In this study, it is called 'Engineering Economic Analysis' (EEA). On a general note, it takes years of study and practice to become a competent engineer; capable of providing technically feasible and efficient solutions in his specific field. This includes studying general subjects, such as mathematics, energy and physics, and topics specific to each engineering discipline, such as Heat, Ventilation and Air Conditioning System (HVAC) for mechanical engineers. In this study, the authors assume that technical solutions are readily available or have been designed as those solutions are discipline specific. The result shows raw evidences that the competency and self-confidence of the engineer are the key factors for cost decision making of replacement projects.

Every engineering solution, whether designed by a mechanical engineer or other professionals, has financial consequences. For example, the cost of implementing and maintaining solutions, as well as the revenues or savings impacts from implementing the solution are the consequences. In a real scenario, a mechanical engineer may consider numerous options of air conditioning system in the building, including the centralized system or the split unit system. Costs to maintain the specific HVAC system must also be estimated. The other cost decision making factors such as life span of equipment, costs of repair, dependable comfort, warranty coverage, future refrigerant availability, money saving efficiency, long term comfort and long term savings must also be estimated. Therefore, the analysis is no longer discipline specific, and the role of engineering economy becomes clearer.

6. References

[1.] Ali, A.S(2009),"Cost decision making in building maintenance practice in Malaysia', Journal of Facilities Management. Vol. 7No.4, pp. 298-306.

[2.] Al-Khatam, J.A. (2003), "Buildings maintenance cost', M.Eng.report, Construction Engineering and Management, King Fahd University of Petroleum and Minerals, Dhahran.

[3.] C.Shapiro,R.Aldrich, and L.Arena (2012), "Retrofitting Air Conditioning and Duct System in Hot, Dry Climates", Consortium for Advanced Residential Buildings (CARB).

[4.] El-Haram, M.A. and Horner,M.W(2002), Factor affecting housing maintenance cost', Journal of Quality in Maintenance Engineering, Vol. 8 No.2,pp.115-123.

[5.] Flyvbjerg,B. (2009),"Survival of the unfittest: why the worst infrastructure gets built-and what we can do about it', Oxford Review Economic Policy, Vol.25 No.3, pp. 344-367.

[6.] Garcia-Diaz, A., & Smith, J. M. (2008). *Facilities planning and design*. Pearson; New Jersey.

[7.] Immovable Asset Management Manual, Tatacara Pengurusan Aset Tak Alih Kerajaan, TPATA 2012, Government of Malaysia.

[8.] Joseph F. Hair et al., (2014), A Primer On Partial Least Squares Structural Equation Modelling (PLS-SEM), SAGE Publication Ltd.

[9.] Kušar, M., Kovač, M.S. & Šelih, J. (2013). Selection of efficient retrofit scenarios for public buildings. *Procedia Engineering*, 57, 651-656.

[10.] Love,P.E.D. and Li,H.(2000), "Quantifying the causes and costs of rework in construction', Construction Management and Economics, Vol.18 No.4, pp. 479-490.

[11.] Lum, Y. L. (2017). Top trends in facility management. *The Ingenieur*, Vol. 71. Lembaga Jurutera Malaysia.

[12.] M.Banazadeh, H.Parvini Sani and M.Gholhaki (2013), Decision Making Analysis For Seismic Retrofit Based on Risk Management", Asian Journal of Civil Engineering (BHRC) Vol.14, No.5, Pages 735-746.
[13.] Ministry of Finance Procurement Principle (2017), Government of Malaysia.
[14.] Mitchell, S. (2017). *Embracing facility management life-cycle innovations in circular economy*. 3rd Malaysia-Europe Facilities Management Conference, Kuala Lumpur, 26th September.
[15.] Mohammad A. Hassanain. (2013), "Factor affecting maintenance cost of hospital facilities in Saudi Arabia", Property Management, Vol.31 Issue: 4, pp.297-310.
[16.] Mohd Noor, N., Hamid, M.Y., Abdul Ghani, A.A. & Haron, S.N. (2011). Building maintenance budget determination: an exploration study in the Malaysia Government Practice. *Procedia Engineering*, 20, 435-444.
[17.] Policy of Asset Management, Dasar Pengurusan Aset Kerajaan, DPAK (2009), Government of Malaysia.
[18.] Pong Soo Mooi (2017). Facility management. *The Ingenieur*, Vol. 71, Lembaga Jurutera Malaysia.
[19.] Roslan Md Taha. (2017). Facility management. *The Ingenieur*, Vol. 71. Lembaga Jurutera Malaysia.
[20.] Shohet, I.M.,Lavy-Leibovich,S. and Bar-On,D.(2003), Integrated maintenance monitoring of hospital building", Construction Management and Economics, Vol.21 No.2,pp. 219-228.
[21.] Total Asset Management Manual, Manual Pemgurusan Aset Keraajaan, TAM (2009) Government of Malaysia.

Air Conditioning and Mechanical Ventilation System And Acoustic Comfort In Buildings

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Abstract

The acoustical environment of a workplace is typically given very little attention or is always overlooked during project planning and design of buildings. The functionality and aesthetics of the workspace are usually the primary focus of the designer. Providing a comfortable environment for office occupants contributes significantly to their optimum performance and eliminates symptoms associated to sick building syndrome. In modern green office concepts, workplace comfort is a combination of factors that includes day lighting and electric lighting, indoor environmental quality, temperature, humidity level and acoustics. The disturbance on ears in the workplace can come from traffic noise outside, mechanical equipment in adjacent spaces, air conditioning system, copiers, telephones, and voices within the workplace. However, this article only discusses issues relating to acoustic comfort control strategies in Air Conditioning and Mechanical Ventilation System (ACMV) that are usually encountered in buildings. Some success rectification works in ACMV system noise and vibration problems are presented as case studies.

***Keywords*:** ACMV system; acoustic comfort; workplace; noise; vibration.

1. Introduction

Thermal comfort is the main goal for mechanical engineers at Public Work Department, Malaysia (PWD) in the process of designing and preparing the technical specification of Air Conditioning and Mechanical Ventilation System (ACMV) in various buildings project. At the same time, it is very important to keep the background noise of the ACMV system low to a level that ensures comfortable working environment for office building occupants. The degree of occupants' satisfaction is determined by many factors, for example, occupants in meeting and conference rooms, auditoriums or recording studios will only tolerate a very low level of background noise. On the other hand, high levels of background noise are acceptable and even desirable in certain situations, such as open-plan offices where a certain amount of speech and activity masking is essential. The ideal background noise should be a balance distribution of sound energy over a broadband frequency range with no dominant band of noise, smooth and steady with no audible tones such as whine or rumble and few fluctuations in noise pressure level.

Acoustic comfort means having the right level and quality of sound to use the space as intended especially for office buildings. People are more productive and happier when they are not distracted by noises from outside or surrounding. Human's perception to sound and loudness is a subjective measure. A comfortable environment can be created by controlling objective measures like sound pressure level (in decibel), reverberation time, the sound reflection and damping properties of materials such as acoustic panels on ceilings and walls. Acoustic environment can manipulate a person's ability to work. A person's productivity will decrease

when he is in a noisy and uncomfortable workplace and vice versa; productivity can be enhanced by being in an environment that supports easy verbal communication (Hodgson, M, 2008). Noisy and uncomfortable working space will also create disturbances, impair concentration and eventually result in stressful occupants (Evans, G. W., & Johnson, D, 2000).

2. Acoustic in Green Buildings

Most of the literature reviews are the outcome of analysis, studies and surveys done on offices and educational buildings in the U.S. These buildings are rated as green building based on LEED (Leadership in Energy and Environmental Design) developed by U.S. Green Building Council (USGBC) in 1998.

Literature studies reviewed mainly focus on occupants' satisfaction in green buildings and comparing them to satisfaction from occupants in conventional buildings. The types of acoustical complaints were also being surveyed to determine the major acoustical problems occur. Rao, S.P. et al (2011) mentioned that only Hodgson (2008) reported the result of the acoustical measurement. Table 1 shows the measurement parameters and acceptability criteria used in Hodgson's study compared to ASHRAE Design Guideline for HVAC-Related Background Sound in Room. ACMV system noise always determined by NC curves which correlates well with occupant satisfaction in office buildings without excessive levels of low frequency noise or disturbing tonal noises. NC values are defined by a series of curves that give noise level limits in octave bands across the frequency range of human hearing.

Table 1. Measurement parameters and acceptability criteria (Hodgson's study)

Measurement Parameter	Acceptability Criteria (Hodgson)	ASHRAE
Background Noise-level, NC	NC 30-35 in meeting and conference rooms NC 35-40 in workspaces	NC 25-35 in meeting and conference rooms NC 30-40 in workspaces

Surveys by many researchers found huge occupant dissatisfaction on acoustic quality in green buildings compared to conventional buildings, especially in working spaces that utilizes the open plan office layout. The main acoustic problems established are the lack of speech privacy and the problem with intermittent noise. Major acoustic complaints made were people talking on the phone; people talking in neighbouring area, people overhearing their private conversation, getting caught up in others' conversation and telephone ringing. Other complaints were also received on noises projected by office equipment, mechanical system, office lighting, outdoor traffic and people in corridors.

It was found that there are four major green building design strategies that might contribute to the poor acoustical performance. They are natural ventilation, day lighting, reduced use of finishes and open plan office layout.

2.1 *Acoustic in Green Building Rating System*

The acoustic performance in Green building rating system generally considers the background noise in the space (Noise Criteria - NC, Preferred Noise Criterion - PNC, Room Criteria - RC), the noise isolation from adjacent spaces (Sound Transmission Class - STC, Noise Isolation Class - NIC) and from the exterior (Outdoor-Indoor Transmission Class - OITC), and the room acoustics (reverberation time, speech intelligibility). Providing sufficient attenuation to ACMV systems by designing appropriate room boundaries and by selecting suitable room finishes can control these acoustic parameters.

Acoustic comfort should be tackled in many ways in green building rating system as mentioned above but only contributes a low point in overall weightage. Table 2 shows the acoustic percentage rating system available in sustainable design.

Table 2. Acoustic credits of the overall credits available for sustainable design

Rating System	Total point	Acoustic Point	Acoustic Value
GBI (Malaysia)	100	1	1.0%
PH (Malaysia)	117	1	0.85%
BCA Green Mark (Singapore)	190	1	0.5%
LEED (USA)	100	1	1.0%

A low credit does not mean acoustic comfort shall be put aside but it needs to be tackled wisely or otherwise could create major problems, which had been proved in the ACMV noise and vibration forensic cases.

2.2 *Acoustic Issues in ACMV System*

Nowadays, building structures are designed with careful coordination in structural design and mechanical layout. Proper isolation for ACMV equipment located inside the mechanical room is necessary to avoid structure-borne noise phenomena. In other words, the ACMV system excessive noise appears to arise more from lack of proper design process than from inadequate technology that contributes to the noise. Typical ducted ACMV system acoustics problems arise from its main components, which are :

1. Equipment noise and vibration
    a. Location (radiated noise)
    b. Isolation

2. Duct system
    a. Duct borne noise
    b. Duct break-in and break-out noise
    c. Airflow-self generated noise (terminal noise)

Successful design of a ducted ACMV system must address two distinct points above to control the noise and vibration.

2.3 *Mechanical Equipment Noise and Vibration*

The rotating or motor-driven machinery, which is incorporated in ACMV system, will generate vibration energy that can travel through a building's structure and spread from the walls, floors and ceilings in the form of structure-borne noise and radiate noise into the receiver spaces. It is essential to control vibration at its source as once it is allowed to transmit into the building structure, vibration from building services equipment are widespread and extremely difficult to contain.

2.4 *Duct System (airflow)*

Duct borne noise propagates along the ductwork, follows all branches and bends and ultimately exits at the supply diffuser influencing the occupied space. The sound generated by the fan will travel along the ductwork both upstream and downstream of the Air Handling Unit (AHU) easily because the velocity of sound is much higher than the velocity of the air in the duct. The noise is generated aerodynamically by the flow of air through the duct system. This regenerated noise is very much dependent on the velocity of the air and smoothness of the flow. It increases very rapidly as the flow velocity is increased by changes in cross-sectional area of the duct. Airflow generated noise is proportional to the sixth power of velocity. In practice, for room not highly sensitive to noise, airflow generated noise can be ignored when velocities are below 8 m/s in the main duct and 3 m/s in branch duct. Duct break-in noise is radiated ACMV equipment noise that enters ductwork and propagates into rooms. A flexible duct is light in weight, flexible and ease for installation is commonly used in air conditioning systems. Noise can easily penetrate flexible duct because of its lightweight nature.

Duct breakout also propagates along ductwork and transmits through the wall of the duct affecting adjacent space. At frequencies above the transition between axial and multi-mode transmission of sound (*f > c/(2*duct width/height*)) in a duct, the sound field inside the duct may be considered as diffuse and the breakout of the noise from inside to the outside of the duct is protected by the sound reduction index or transmission loss of the duct wall. However, since the duct runs over a significant length inside the receiving room, the total amount of the noise breakout increases as the length increases. The final points in the ACMV air distribution system are the terminal air devices. There are “grilles”, “diffusers”, “register” and “vent cover” that go over duct opening in the room. Air noise from diffusers and from transitions can cause additional noise in the receiving room.

3. ACMV Basic Acoustic Design Techniques

Good space planning and location of mechanical room at early stage of design process is the best way to avoid noise and vibration problem in the office building. It is a good practice to position particularly noisy equipment in mechanical room or place where they are located away from critical area such as meeting or office room. Mechanical room shall be large enough to allow adequate turning before duct exit and defy any alleged floor space constraints if possible, avoid placing AMCV equipment enclosures close to walls or ceilings to avoid ‘close coupling effect’ where a small air space will conduct equipment vibratory motion to wall or ceiling. Airtight mechanical room construction is an advantage since sound can leak through as small as 1 mm opening. Alternatively, creating a buffer zone of less critical space such as storeroom between a mechanical room and noise-sensitive space allows simpler and less costly constructions to provide the desired isolation, and this minimizes the risk of noise leaks at penetrations.

Floating concrete floors, which are supported above the structure floor on resilient mounts are required to separate mechanical rooms from noise-sensitive spaces that are above or below the mechanical room. Floating floor is not generally designed as part of a vibration isolation alternative for mechanical equipment but their primary use is for airborne sound isolation. Addition to that, it is sometimes necessary to have special noise-isolation ceilings above and/or a buffer layer below mechanical rooms and ducts routes; an example of a good practice is shown in Fig. 1.

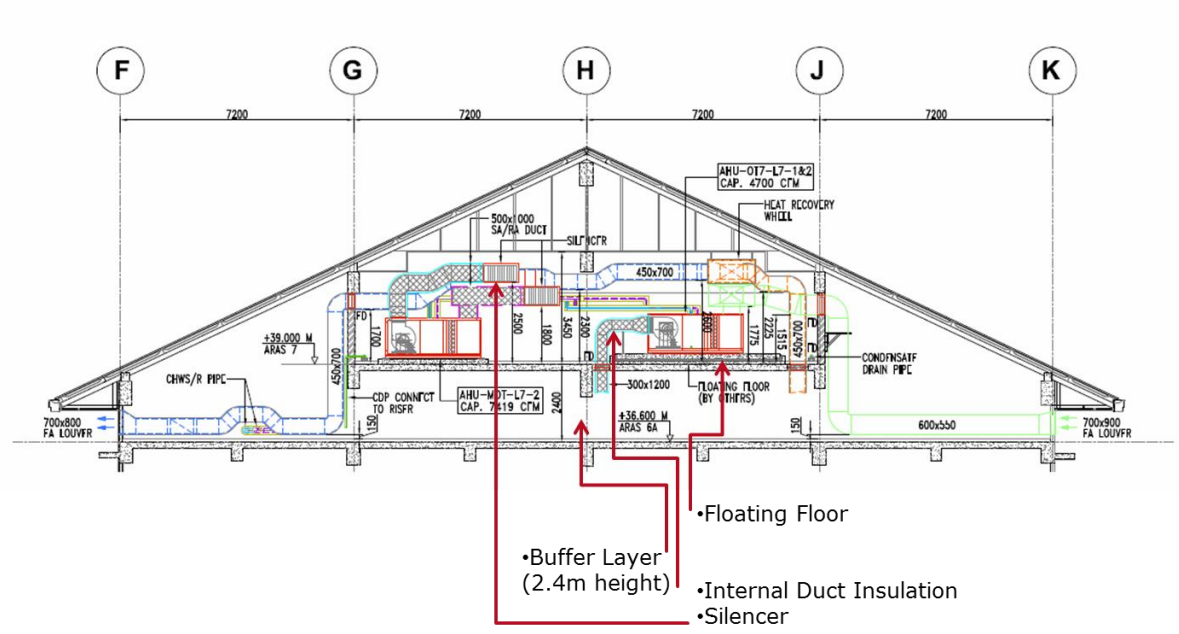
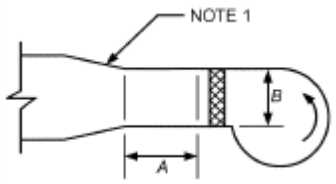
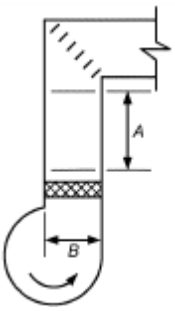
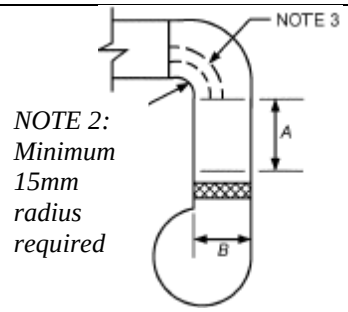
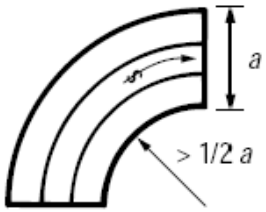
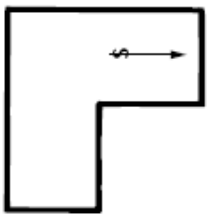
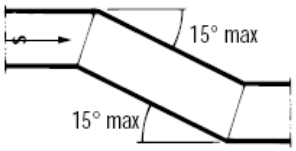
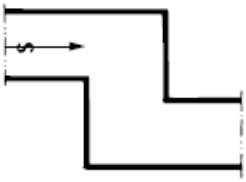
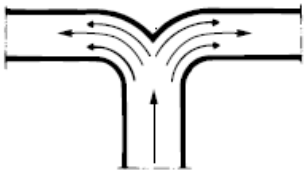
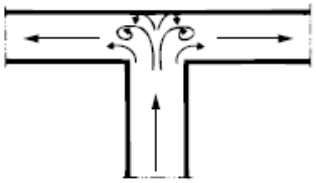


Fig. 1. AHU Room for Operation Theatre Room

Right sizing of ACMV equipment, distribution system and choosing the correct size (cooling capacity) is critical not only in getting the cooling comfort but also lowest maintenance and life cost cycle (LCC) of the system and the best acoustic efficiency. The basic duct design concepts to minimize ACMV system noise should not be ignored. Some types of solution are showed in Table 3 to minimize airflow noise

Table 3. Ductwork for the limitation of airflow noise

Strategy	Action	Sample of solution
Minimize rumble noise	Keep airflow velocity in the duct as low as possible (max. 7.5m/s) near critical noise areas.	 Optimum *NOTE 1: Slope 1 in 7 preferred for 10m/s above*  Bad

	Locate elbows or duct branch take-offs (A) at least 1.5 duct diameters apart (B).	 *NOTE 2: Minimum 15mm radius required* Good *NOTE 3: Rugged turning vanes should extend full radius elbow*	 Bad
Minimize flow resistance and turbulence	Use turning vanes in large 90° rectangular elbows and branch take-offs	 Long radius with vanes Quietest	 Square Noisier solution
	Duct expansion angle not more than 15°	 Quietest	 Noisier solution
	Proper duct tee design	 Quietest	 Noisier solution

4. Innovative Solution

One innovative product had been designed by PWD staff to overcome structure-borne noise transmission problem. This product has been registered for Intellectual Property (IP) and won medals in several international innovation competitions. This adjustable and moveable support system can be moved upward and downward enabling levelling of AHU and acts as absorber to building structure due to vibration while in operation. Measured data shows that the vibration effect (Peak RMS (V-mm/s)) of a running AHU has reduced up to 92% compared with concrete plinth as shown in Fig. 2. This moveable support system is also a good choice for AHU location arrangements in PWD projects implementation.

No	Point	Concrete	Adj. Support	Vibration Effect Reduction
		Peak RMS (V-mm/s)		
1	*Support*	0.000192340	0.000067217	65.05%
	Floor	0.000036477	0.000029290	19.70%
2	*Support*	0.000549970	0.000043291	92.13%
	Floor	0.000015871	0.000014312	9.82%
3	*Support*	0.000167093	0.000135961	18.63%
	Floor	0.000135961	0.000127081	6.53%
4	*Support*	0.000202578	0.000035029	82.71%
	Floor	0.000061970	0.000019286	68.88%

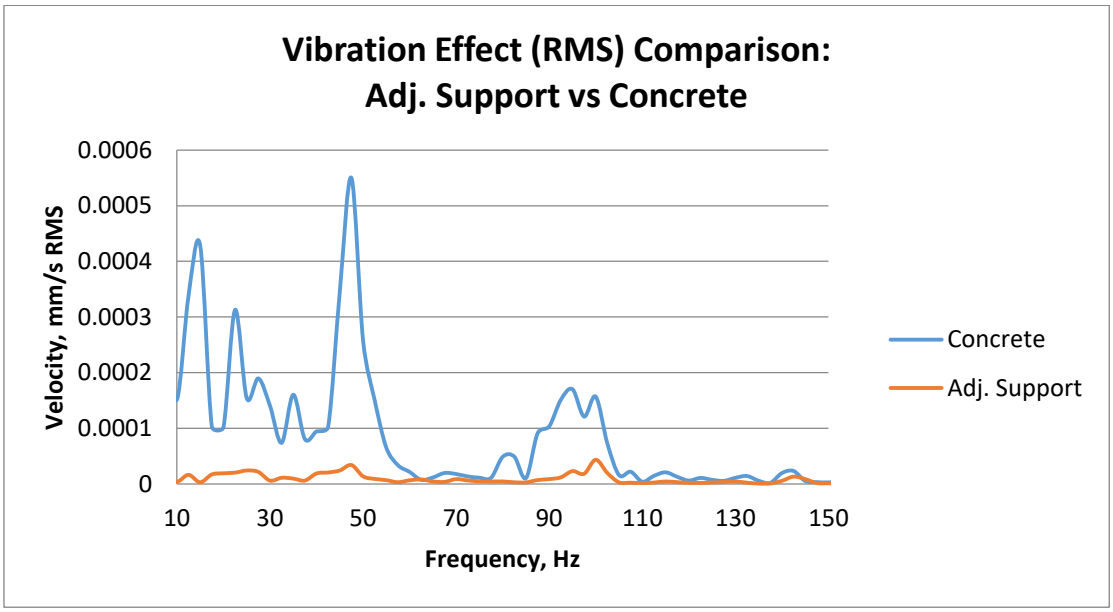


Fig. 2. Adjustable Support and Measured Vibration Data

5. Case Studies

Most acoustic problems appeared during pre-occupancy of the building or during defect and liability period. For each case, causes of the problem need to be investigated and analysed. A technical report consists of few alternative solutions that can be followed by the requester. Follow up inspection is also performed to verify the effectiveness of suggestion solution done by the requester or building owner. In this paper, three successful rectifications are presented as case studies. Most of the suggested retrofit works to suppress equipment's noise and vibration such as water and air cooled chillers usually need some consideration from building owner before proceeding to the retrofit work due to its cost and complexity.

5.1 *Equipment*

Hand held Sound Level Meter Type 2; SoundPro DL Data logging SLM 1/3 Octave with QuestSuite Professional II Software were used for noise level assessment and Photon Pro Analyzer; Single Axis Accelerometer (3056B2- 50g range, 100 mV/g, 10-32 top) with RT ProPhoton Software are used to measure vibration level for our forensic studies.

5.2 *Noise Descriptors*

Noise descriptors such as L_{eq}, L_{10}, L_{90}, L_{max} and NC were recorded. Usually in steady state noise condition the noise level measurement was carried out for 1-5 minutes using SLM data logger. Definition for the noise descriptors are presented as followed:

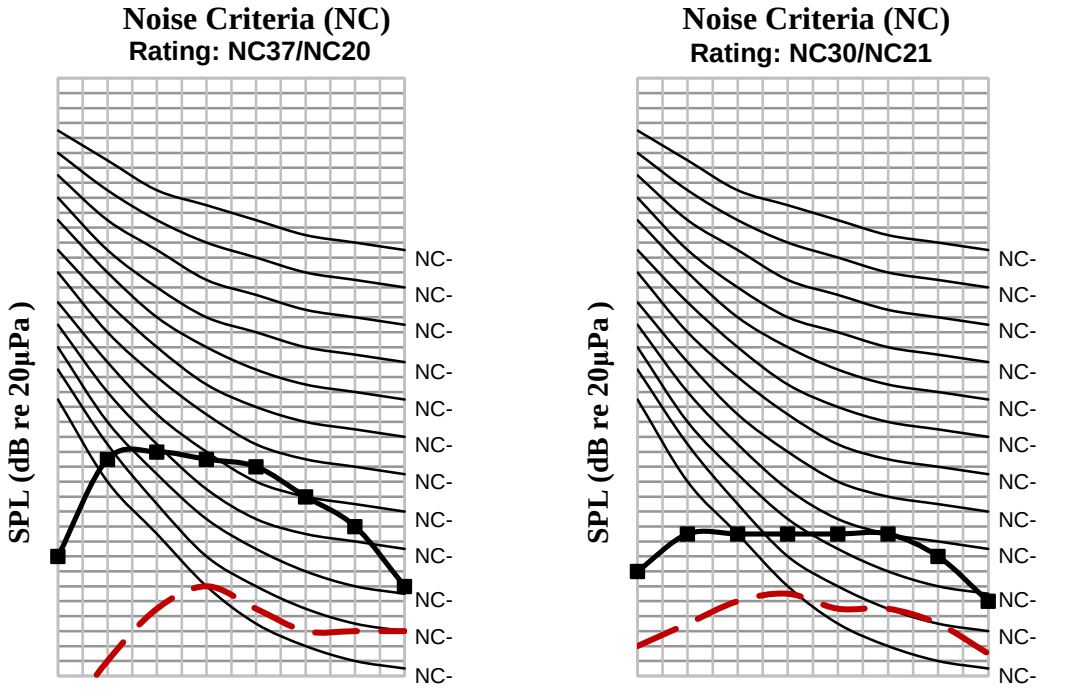
> L_{eq} : The equivalent continuous dBA level which has the same energy as original fluctuating noise for the same given period time.
> L_{10} : A specified dBA levels which exceeded ten percent of the time during the whole period of measurement.
> L_{90} : A specified dBA levels which exceeded ninety percent of the time during the whole period of measurement.
> L_{max} : The root means squared maximum level of a noise source or environment where peak is the maximum level of the raw noise source.
> NC : Noise Criteria curves define the limits that the octave band spectrum of a noise source must not exceed in order to achieve a level of occupant acceptance.

5.3 *Vibration Criteria*

Vibration criteria can be specified relatively to three areas, (1) human response to vibration, (2) vibration levels associated with potential damage to sensitive equipment in a building, and (3) vibration severity of a vibration machine. Equipment and structural vibration severity ratings are based on measured RMS velocity (mm/s).

Case Study 1: Noise From Duct Airborne

In this case, causes of the noise from air conditioning system that exceeded standard NC30 for Operation Theatre (OT) room during pre-occupancy stage were investigated. The main contributors to this noise were high velocity airflow and air turbulence in duct system serving to OT room. This duct-borne noise occurred because of existing supply duct size did not follow the design parameter causing airflow velocity inside supply duct slightly higher and created annoying noise.



a) Before Rectification Work
- Rating: NC37/ NC20 (ambient)
- L_{eq}: 46.4dBA/27.1dBA (ambient)
- Airflow velocity: 6.3 m/s

b) After Rectification Work
- Rating: NC30/ NC21 (ambient)
- L_{eq}: 38dBA/30.1dBA (ambient)
- Airflow velocity: 5.4 m/s

Fig. 3. Operation Theatre Room NC Curve

The airflow smoothness in duct could not be achieved due to air turbulence at the Air Handling Unit (AHU) outlet since the original design did not attach a turning vane at the first bend of the AHU outlet duct. With this finding, the authors suggested to project superintending officer to advice the responsible consultant to replace existing duct with a new one according to design parameter. It was also recommended to install turning vanes inside the AHU outlet duct to reduce air turbulence.

The retrofit works was done accordingly and as a result, OT room noise rating NC30 was achieved. Fig. 3 shows the comparison before and after retrofit works. Although this is just a simple fault in ACMV system and could be found anywhere but the annoying noises will give critical impact to the end user if not tackled wisely during early stage of construction especially for room that required low level background noise.

Case Study 2: Vibration Cause Condenser Water Pipe Leak

In this case, the cause of condenser water pipe leak while in operation was investigated. These piping systems are connected to a cooling tower and the pumps to circulate condenser water in the air conditioning system. Although this client has their own internal maintenance team, they still need technical advice to solve this problem since the authors are among the technical advisors to the Malaysian government.

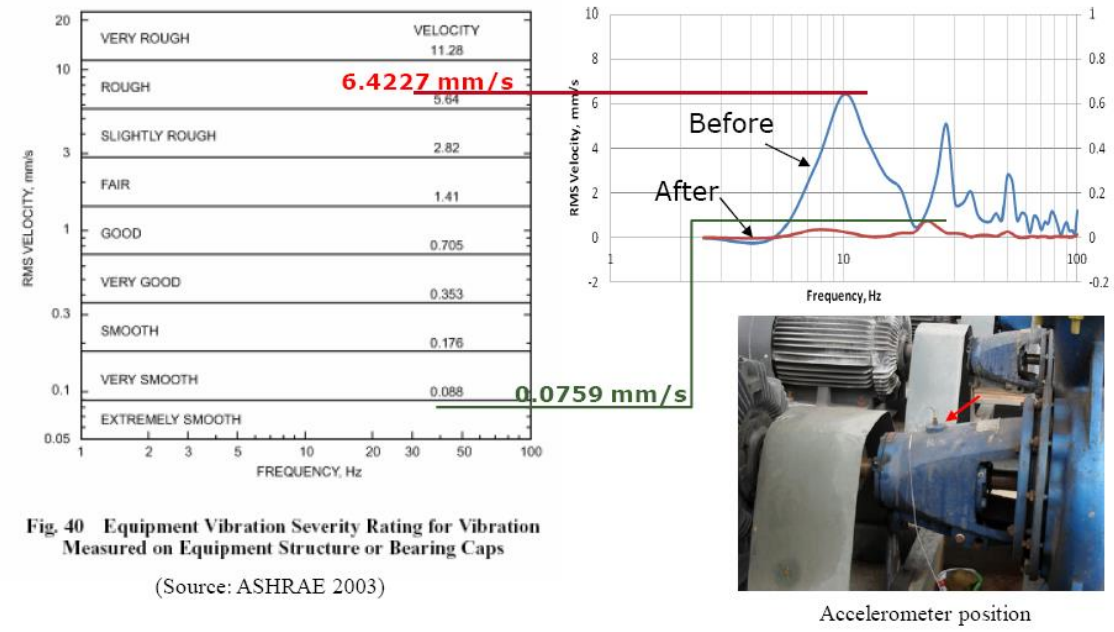


Fig. 40 Equipment Vibration Severity Rating for Vibration Measured on Equipment Structure or Bearing Caps

(Source: ASHRAE 2003)

Fig. 4. Vibration Measured on Pump Set

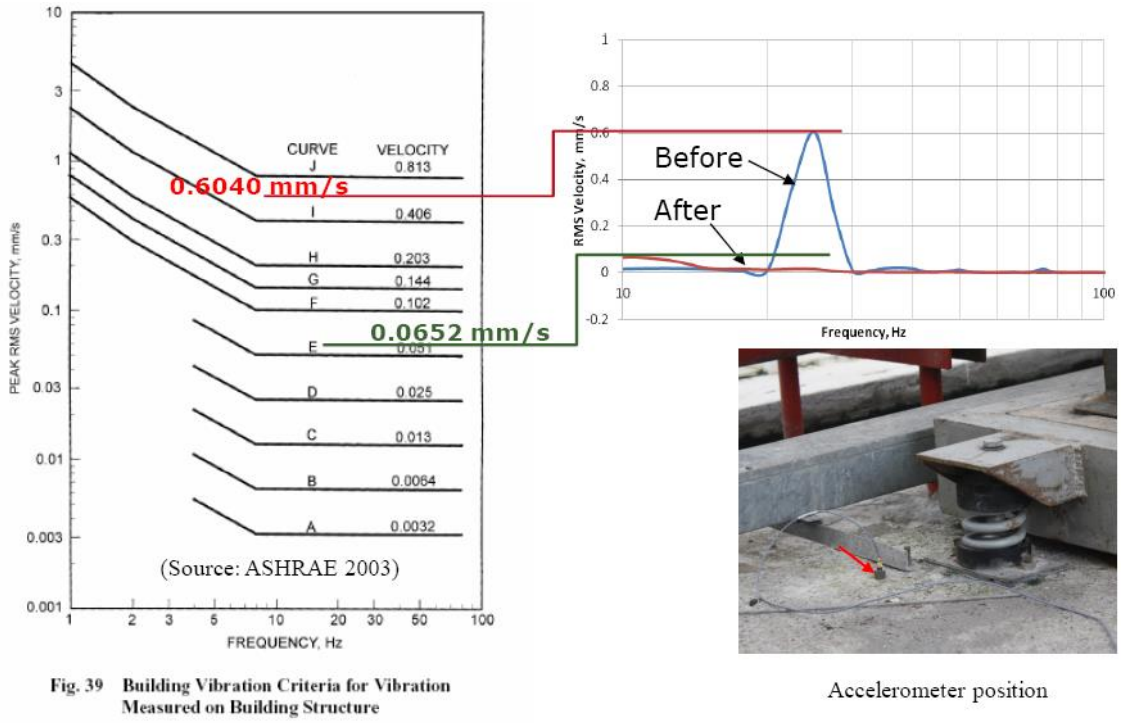


Fig. 39 Building Vibration Criteria for Vibration Measured on Building Structure

Fig. 5. Vibration Measured on Building Floor

Figs. 4 and 5 show the vibration level measured based on RMS velocity level for condenser water pump set and floor near to the condenser water pump set located on the rooftop. The peak RMS velocity for one of condenser water pump set was 6.4227 mm/s and RMS velocity of resonance interaction between pump sets and floor was 0.6047 mm/s, respectively. Both values exceeded the maximum allowable RMS Velocity Levels as recommended in ASHRAE Application Handbook. These situations occurred due to lack of maintenance causing excessive bearings wear that contributed to the condenser water pump sets being operated unbalanced. Assuming that impurity inclusion or defects existed inside pipe material and/or inside arc

welded portion, the severity pump vibration initiated fatigue crack, propagates and finally condenser water pipe leaked, spoiling the ACMV operation.

From these findings, suggestions were given to the building owner to perform major overhaul and re-alignment of the entire condenser water pump sets. As a result, after rectification works done, both situations show very low vibration effects and almost negligible; the peak RMS velocity for the same condenser water pump set is 0.0759 mm/s and RMS velocity for floor is 0.0652 mm/s.

Case Study 3: Excessive Exhaust Fan Noise

Investigation of this case was done in response to an official complaint received by building management from adjacent resident due to annoying noise released by the kitchen exhaust system. Neighbourhood apartments are located 10 meters away from the building perimeter fence or 40 meters from the exhaust fan outlet. The complainant would bring this matter to court and sue the building owner if this problem is not resolved. To avoid this matter being prolonged, building management has requested the State PWD Mechanical to solve this problem since their internal maintenance team does not have the expertise. Finally, the state counterpart has sought technical advice on these matters.

Based on the observation, although the location of this premise can be designated as mixed area development with high traffic movement, the noise from exhaust fan is obviously annoying residents nearby. Noise pressure level measured at affected apartment showed that it exceeded maximum permissible sound level (60 dBA) as specified in Department of Environment Malaysia (DOE) guidelines. As shown in Fig. 6 (a), the noise pressure level measured at balcony of affected apartment is L_{eq} = 66.3 dBA. The background noise at that time should be same as measured ambient noise, L_{eq} = 53.9 dBA. The kitchen exhaust duct was redesigned and changed the fan to a new one based on a backward design process since -built drawing or specification document of the existing system as a reference was not available. All needed measurements and raw data were taken based on actual site condition for calculation and analysis before preparing a complete specification and technical drawing of the kitchen exhaust system, enabling our PWD state counterpart to complete their procurement tendering process. Table 4 shows important data or parameters of existing and re-designed condition that most influences noise level of the kitchen exhaust system. Re-calculation has been made based on onsite measurement shows that the existing fan size is oversized, as a result the actual contaminated air volume to be exhaust out is slightly less, hence the new design needs a fan with much lower speed to lower the airflow speed and contributes in reducing airflow noise and more economical.

Table 4. Design Data and Parameter

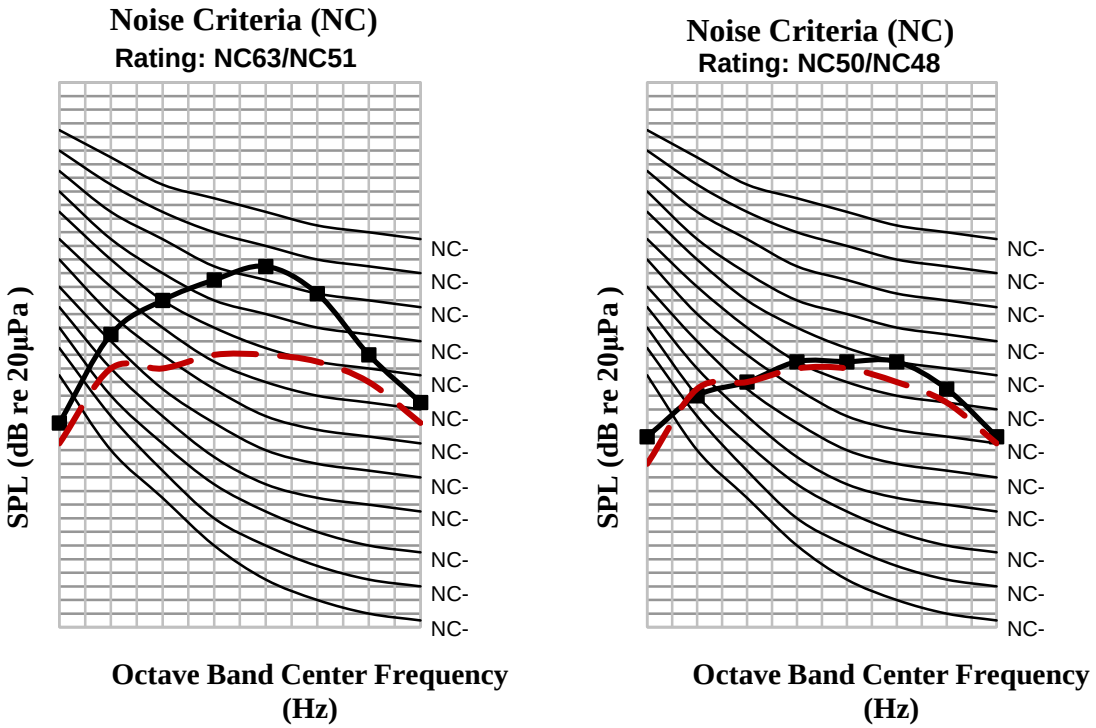
Factor	Existing Condition	Re-design Condition
Contaminated air volume	127,425 m^3/hr	95,144 m^3/hr
Fan Speed/Diameter	1,450 rpm/1,000 mm	960 rpm/1,400 mm
Motor Rating	40 kW	30 kW

Other improvements that have been made to assist the exhaust system as well as to reducing the background noise are introduced here of:

i) Acoustic wall barrier facing the affected apartment.
ii) Acoustic louvers facing exhaust fan outlet, so that exhaust air disperse and at the same time acts as a noise filter to the adjacent office room.
iii) Oversized duct to reduce contaminated airflow velocity complete with internal insulation and turning vanes inside duct bend.
iv) Introduced the plenum chamber concept to reduce air turbulent.

Fig. 6(b) shows the result after rectification works done. Noise pressure level tremendously fell to ambient level 55.5 dBA and noise criteria rating also show a lot of improvement from NC63 reduced to NC50, hence noise emission level diffused by kitchen exhaust fan system is lower than DOE maximum permissible sound level.

Although the new installed exhaust fan outlet facing only 15 meters away from the adjacent office room, noise pressure level and noise criteria inside that office room remain at a comfort level, where L_{eq} = 43.5 dBA and NC33 respectively.



a) Before Rectification Works
- Rating: NC63/NC51 (ambient)
- L_{eq}: 66.3dBA/53.9dBA (ambient)

b) After Rectification Works
- Rating: NC50/NC48 (ambient)
- L_{eq}: 55.5dBA/55.7dBA (ambient)

Fig. 6. Noise Data Measured at Affected Apartment's Balcony

6. Conclusion

It can be concluded that without careful implementation in overall ACMV system design strategies, acoustic quality is easily compromised. The designers should not overlook this influence as it could jeopardize the acoustical environment. It is hoped that this article demonstrates a simple guide in predicting the potential acoustical problems that might occur in office building. The selected three case studies of noise and vibration problems in office building claim the immediate countermeasure action i.e. minimizing error is necessary. There

should not be any compromise to occurrence of mistakes during the initial stage of design processes such as ACMV equipment sizing, suitable location or positioning to avoid any noise and vibration effects from ACMV system especially to sensitive rooms. Full attention on supervisory work during ACMV system installation promises high quality products in the sense of human comfort. Performing scheduled predictive maintenance on ACMV equipment is very important to eliminate system failure creating problem such as tendency of crack initiation on floor structure due to excessive equipment vibration while in operation. Besides that, for long term corrective measure, new specifications and technical drawing for noise and vibration control details have been incorporated into documents known as i) Standard Technical Specification for Air conditioning and Mechanical Ventilation System and ii) Standard Mechanical Design Detail Drawing For Designers/Contractors. With these documents, noise and vibration control designs can be implemented in new projects and retrofits installation to meet the JKR standard of requirements.

7. References

[1.] Istvan L.Ver and Leo L.Branek. 2006. Noise and Vibration Control Engineering, Principles and Applications: John Wiley and Sons.

[2.] N.Y. Gergeo, G.A. Sehrndt and W.Parthey. 1992. Noise Sources. *Proceedings 6th International FASE-Congress, Zurich*. 104-124

[3.] 2001 ASHRAE Fundamentals Handbook (SI). Chapter 7, 7.1-7.18,

[4.] 2003 ASHRAE Application Handbook (SI). Chapter 47, 47.1-47.50

[5.] A.R. Ismail, M.J.M. Nor, M.F.M. Tahir, H.Mohamad, R.A.Bakar, R. Zulkifli, 2010 Environmental Noise Impact To Urban Area In Malaysia: A Case Study Due To Aircraft Noise. *3rd Regional Conference on Noise, Vibration and Comfort (NVC)*, pp. 443-451

[6.] The Planning Guideline, *Environmental Noise Limits and Control*, 2007. DOE of Malaysia pp 10

[7.] B.Atzori, P.Lazzrin and G.Meneghetti. 2005. A unified treatment of the mode I fatigue limit of components containing notches or defects. International Journal of Fracture, 133:61-87

[8.] Sreenivasaiah Purushothama Rao1, Asrul Mahjuddin Ressang Aminuddin, Hong Wan Thing, Nurul Amira Abd Jalil, Nazli Bin Che Din and Nila Inangda Manyam Keumala Daud, Thermal and acoustic environmental requirements for green building in Malaysia, *Journal of Design and Built Environment Vol.11, Dec 2011.*

Experimental Investigation of a Thermochemical Adsorption Cooling System

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Abstract

In this paper, a novel thermochemical energy storage/cooling system, utilizing Vermiculite and Calcium Chloride composite adsorbent material is experimentally investigated. A laboratory test unit consisting of two pipe sections namely; adsorption and evaporation/condensation sections, separated by a valve was designed and constructed. The system was experimentally tested and the temperature across the cooling side of the test rig was observed to have dropped to a low temperature of around 2.5°C from an initial temperature of 18°C. The experimental results also revealed that the system could utilise relatively low temperature, around 60°C for charging/adsorbent regeneration, which could be realized using low grade thermal energy and renewable energy sources. The results also showed that the system has potential for high performance thermochemical adsorption cooling and could be up-scaled and utilised for building application.

Keywords: Thermochemical energy storage; thermochemical materials; adsorption cooling

1. Introduction

There is a growing concern about fossil fuel energy use and its negative impacts to the environment. Buildings (residential and commercial) are responsible for between 20% and 40% of the global energy consumption [1, 2] and contribute to over 30% of the CO_2 emissions [3]. A large proportion of this energy is fossil fuel based and is utilised for thermal comfort in buildings [2, 3].

Thermal energy storage (TES) systems could vitally help in reducing global building energy consumption and also contribute to a more efficient and environmentally benign energy use[4, 5]. These systems are employed when intermittent energy sources are used, or when there is a mismatch between thermal energy supply and demand. TES can be achieved using sensible heat storage, latent heat storage, physical sorption heat storage or chemical heat storage. Chemical energy storage, through the use of thermochemical materials (TCMs) has the highest potential for long-term energy storage and this is depicted in Fig. 1(a). TCMs can operate within a wide range of working temperatures and have high storage density with some materials having storage densities close to the properties of biomass, as explained by Hastings and Wall [6]. TCMs have repetitive storage property, and there is no heat loss to the environment during storage since it is done at ambient temperature. Due to their higher energy density property, thermochemical TES systems can provide more compact energy storage relative to latent and sensible TES systems. A recent and comprehensive review on thermochemical TES systems have been given by Ding and Riffat [7].

This paper presents results of experiments conducted to investigate the performance of a novel thermochemical energy storage/cooling prototype system. The prototype utilizes a new form of composite adsorbent; Vermiculite + $CaCl_2$, which possess better adsorption and desorption properties, compared to other traditional adsorbents such as silica gel, activated carbon and zeolites. Composite adsorbent materials often referred to in literature as 'salt inside porous matrix' (CSPM) or 'selective water sorbents' (SWS) are two-component systems: one component is a host matrix and the other one is an inorganic salt placed inside the matrix pores. Recently, composite adsorbents have been recognized as promising materials for adsorption heating/cooling systems due to their enhanced sorption capacity to common working fluids including water [8].

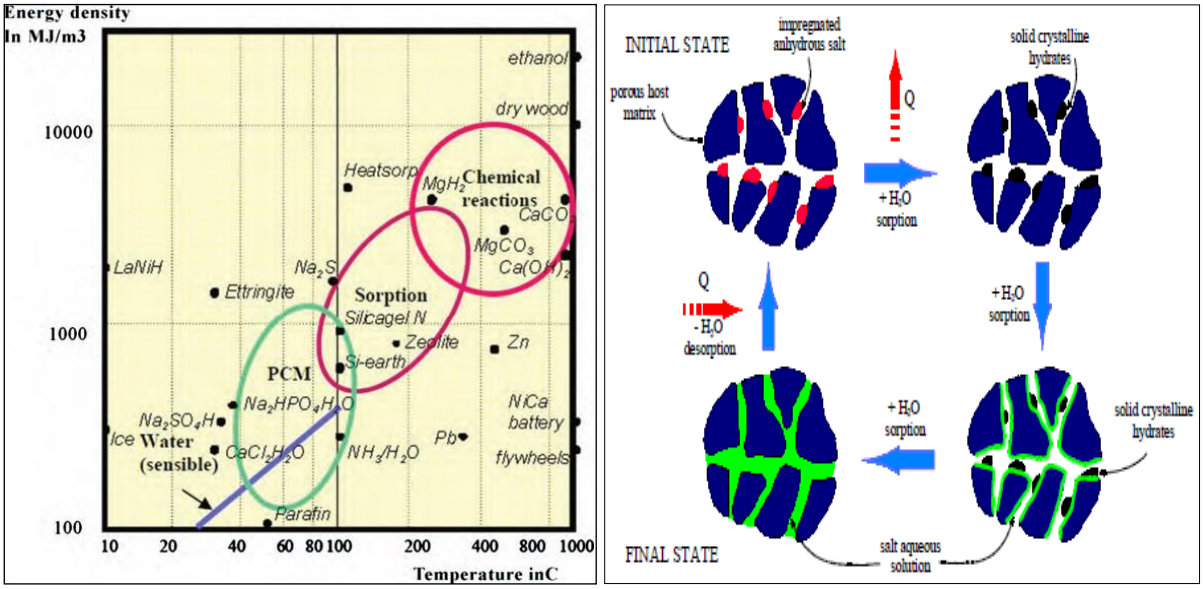
Principle of the Thermochemical Energy Storage / Cooling System

The novel thermochemical energy storage/cooling system is based on the application of a unique adsorption heat pipe that incorporates a reactor section (adsorbent bed) and evaporator/condenser refrigerant section. The system is operated under vacuum conditions, and may utilise a range of adsorbent materials including silica gel, activated carbon, zeolites and composite adsorbents (e.g. Vermiculite + $CaCl_2$), and could utilise water as working media. The scheme of water interaction with the Vermiculite + $CaCl_2$ adsorbent (and similar composites) is depicted in Figure 1(b), indicating the two main mechanisms of water sorption occurring on a composite sorbent. These are (1) solid absorption (or chemical reaction), which is responsible for about 10-15% of the total sorption, and (2) liquid absorption, responsible for approximately 80% of total sorption. In addition, heterogeneous adsorption on surface of matrix is responsible for 3-5% and can be neglected [9].

The system operation under vacuum conditions allows water evaporation at a low temperature level and water vapour transport without the need for a pump or fan, but just as a result of difference in pressure. The adsorbent material could be placed in the upper section, while the water/wick structure is positioned at the lower section of the vertically oriented energy storage pipe system. This configuration would improve the heat transfer and enhance the overall performance of the energy storage system, compared with bulky heat exchanger with packed adsorbent. The basic operation principle of the thermochemical energy storage system, involving several phases is illustrated in Fig. 2 [10] and described below;

Charging phase (desorption/regeneration of adsorbent): The charging phase involves an endothermic process. Thermal energy is absorbed from an energy source, such as heat from solar energy, off-peak power, or heat generated from low grade thermal energy sources such as efficient heat pumps, and fed to the energy storage system. The heat energy is supplied to the adsorbent pipe section, heating the adsorbent and thereby driving off the water moisture in the adsorbent material and storing up heat during the charging phase. The desorbed water vapour is led and condensed to the lower temperature evaporation/condensation pipe section of the test rig.

Storage phase (separation of adsorption and evaporation sections): During the storage phase, the charged/dry adsorbent contained in the adsorption pipe section is separated from the liquid working fluid (water) contained in the evaporation /condensation section, by closing the inter-connecting valve. Heat storage with no losses is possible (neglecting sensible heat) if these two pipe sections remain separated.



(a) (b)

Fig. 1. (a) Energy storage density of different materials, Adapted from [7]; (b) Scheme of water sorption on composite sorbent, Adapted from [9]

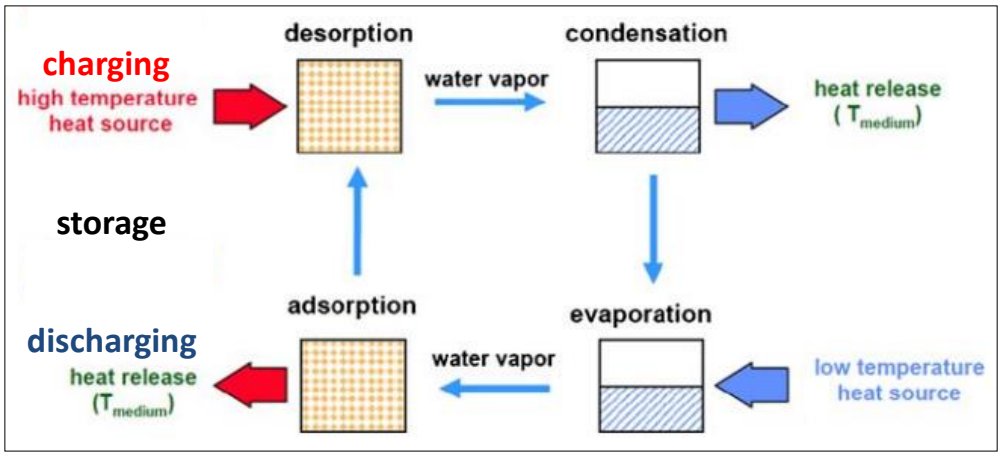
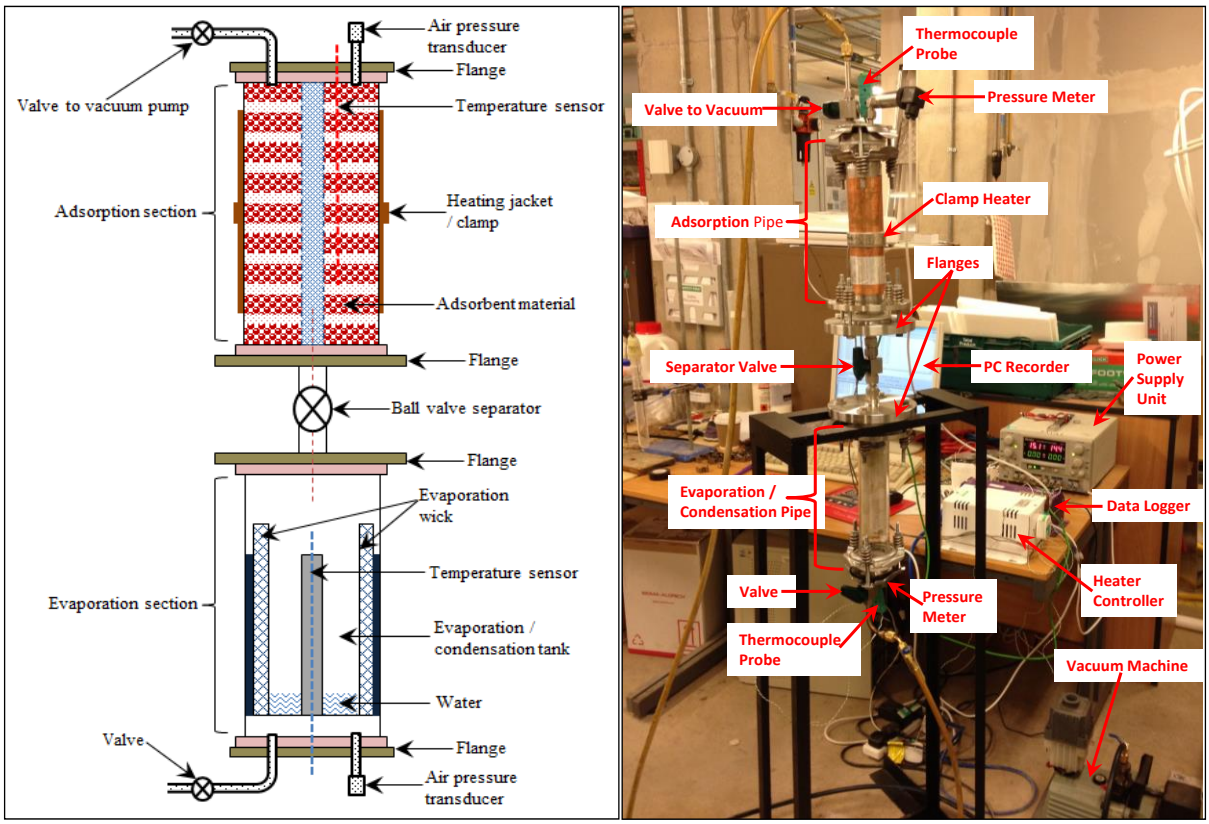


Fig. 2. Working principle of the proposed energy storage/cooling system, partly extracted from [10]

2. System Design and Experimental Rig Set-Up

The thermochemical energy storage/cooling test rig system, based on adsorption pumping pipe was designed, tested at the Sustainable Research Building laboratory, University of Nottingham. The test rig has two main sections, namely; adsorption and evaporation/condensation sections, consisting of two QVF-DN50 (300 x 33mm) glass pipes, which were connected and held together vertically by steel pipe assembly and DN50 flanges. The glass pipes are separated by a Swagelok ball valve through the aforementioned steel pipe assembly. Labelled schematic and photographic views of the full glass pipes test rig are shown in Fig. 3(a) and 3(b), respectively. A perforated multi chambered adsorbent cartridge, made of aluminium mesh and copper wire was utilised for the containment of adsorbent material inside

the adsorption pipe section of the rig. The cartridge allowed for the storage of multiple layers of adsorbent and provided a large surface area for moisture adsorption. A cylindrical water container with cotton wick material was used for the storage of water, inside the evaporation pipe section of the rig. The wick material allowed for mass water evaporation when the pipe section was evacuated. The adsorbent cartridge and cylindrical water/wick container, in both pipe sections are shown in Fig. 4(a) to 4(d). Pipe sections of the rig were fully insulated to reduce energy loss during discharging phase. Furthermore, the adsorption glass pipe section of the rig was equipped with a copper jacket electric heating clamp system, which provided a heating temperature of 60°C through a programmable temperature controller, for adsorbent desorption/regeneration (charging). An ice jacket was wrapped around the evaporator pipe in order to create a temperature difference between the two pipes sections, aiding moisture condensation at the evaporator/condensation pipe section, during adsorbent desorption/charging. The test rig was fitted with digital pressure meters and thermocouple probes at both pipes sections, for the measurement of air pressure and temperature, respectively. The test rig was also equipped with a data logger, for the recording of experimental data on a computer. The tested laboratory rig energy storage/cooling unit contained approximately 49 grams of Vermiculite + $CaCl_2$ composite adsorbent material.



(a) (b)

Fig. 3. Schematic (a) and photographic (b) views of the adsorption energy storage/cooling test rig system

(a) (b) (c) (d*)*

Fig. 4. Adsorption pipe showing adsorbent cartridge: (a) without adsorbent (b) with adsorbent; and Evaporation pipe showing water container: (c) without wick material (d) with wick material/water

3. Results and Discussion

The experimental data for discharging/adsorption and charging/desorption tests using Vermiculite + $CaCl_2$ adsorbent, conducted using the energy storage/cooling test rig assembly, described in section 2 was analysed and the results are presented in this section of the paper. The test rig cooling system was initially tested for air leaks before subsequent experiments were conducted. The air leakage tests results showed that the test rig is capable of sustaining a good vacuum pressure of approximately -1 bar over long periods.

3.1 *Discharging (adsorption)*

Adsorption test was initially carried out, using the Vermiculite + $CaCl_2$ adsorbent and the results of temperature variations at the adsorption and evaporation/condensation pipe sections of the rig have been shown in Fig. 5. A low temperature of around 2.5°C was recorded from an initial temperature of 18°C, corresponding to a temperature drop of 15.5°C across the evaporation/condensation pipe section of the adsorption cooling test rig, when only 100 millilitres of water and 49 grams of charged/dry Vermiculite + $CaCl_2$ adsorbent were used. Both the adsorption and evaporation/condensation pipe sections of the test rig were fully insulated with insulation material to minimise energy loss, as described in section 2, and the temperature variations in the test rig were monitored. Overall, a low temperature of between 2.5°C to 10°C across the evaporation/condensation pipe section of the system was observed to have been maintained over a period of beyond 5 hours, as shown in Fig. 6.

The total mass of Vermiculite + $CaCl_2$ adsorbent material in the adsorption pipe section was weighed before and after the discharging test. The total mass of adsorbent was noticed to have increased to 89 grams from an initial 49 grams mass of dry adsorbent, corresponding to a total moisture adsorption capacity of 0.55 grams of water per gram of adsorbent (0.55g H_2O/g). By measuring the amount of water loss in the evaporation pipe section after the adsorption test reconfirmed the results. The mass of water loss in the evaporation pipe section was measured, and observed to be equal to the mass gained by the Vermiculite + $CaCl_2$ adsorbent, after discharging/adsorption.

3.2 *Charging (desorption)*

It is necessary for the adsorbent material of choice used in the prototype adsorption cooling system to be re-generable at a relatively low desorption temperature, in order for low thermal energy sources to be used during the charging of the system. As described earlier in section 2, an electric clamp heating source was employed, and a heating temperature around 60°C was used for desorption of water moisture in the hydrated/moist Vermiculite + $CaCl_2$ adsorbent in the adsorption pipe section of the rig. The adsorbent was desorbed at a regeneration temperature of around 60°C for over 4 hours, under good vacuum condition of -1 bar, as shown in Fig. 7. The final mass of adsorbent after desorption test was recorded and the total amount of moisture desorbed from the adsorbent was measured to be 0.26 g H_2O/g of adsorbent. This verified through the amount of desorbed water moisture that had been condensed in the evaporation/condensation pipe section of the rig during charging.

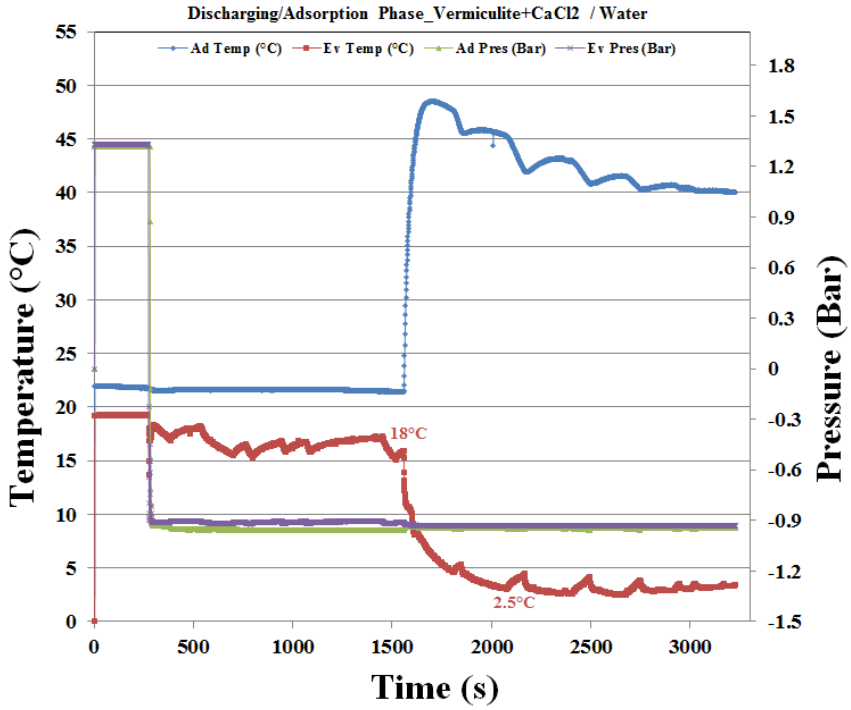


Fig. 5. Temperature variations at adsorption and evaporation rig pipe sections during discharging (adsorption) phase

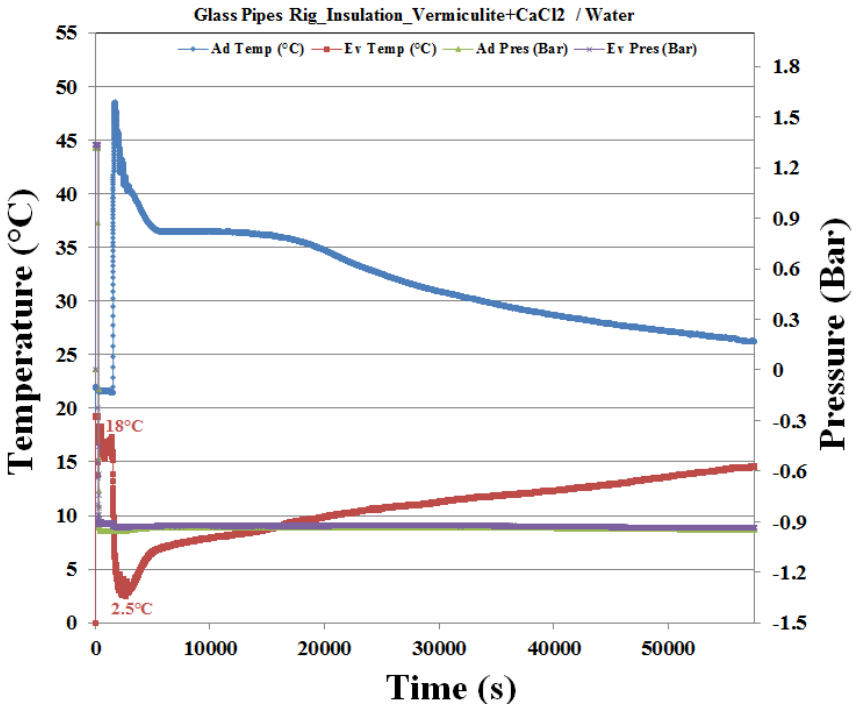


Fig. 6. Adsorbent material temperature drop during discharging phase, with test rig fully insulated

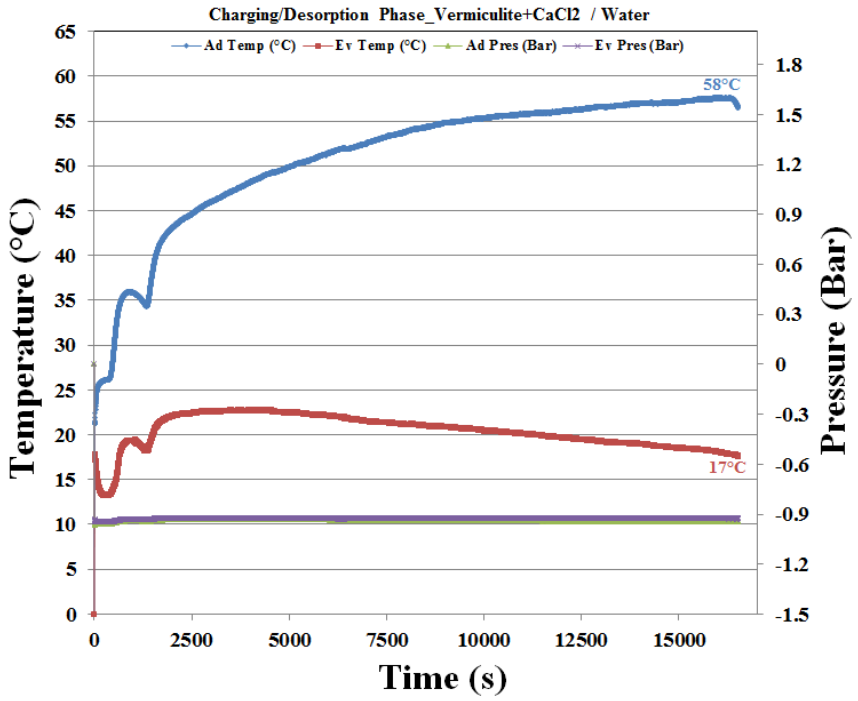


Fig. 7. Temperature and air pressure profiles of adsorption and evaporation pipe sections during charging (desorption) phase

1. Conclusions

The results of experimental investigations on a novel thermochemical energy storage/cooling prototype system based on adsorption cycle, utilising Vermiculite + $CaCl_2$ composite adsorbent and water as working pairs have been reported in this paper. Fully saturated solution of $CaCl_2$ hygroscopic salt component was confined in the micro-porous structure of the Expanded

Vermiculite granules host matrix, using dry impregnation method of synthesis. The prototype system could be utilised as a thermal energy store for domestic building/industrial cooling applications.

Discharging/adsorption and charging/desorption experimental tests have been carried out in the course of this investigation. During the discharging/adsorption phase, a low temperature drop of 2.5°C was observed from an initial temperature of 18°C, corresponding to a temperature drop of 15.5°C across the evaporation/condensation pipe section of the adsorption cooling test rig, when only 100 ml of water and 49 g of dry Vermiculite + $CaCl_2$ adsorbent were used. The adsorption test results also confirmed that Vermiculite + $CaCl_2$ composite adsorbent is capable of adsorbing large amount of water vapour under vacuum condition, 0.55 g of H_2O/g of adsorbent.

Charging/desorption test results showed that the majority of the adsorbed water moisture could be desorbed from the Vermiculite + $CaCl_2$ adsorbent at a low desorption temperature of 60°C and the desorbed water moisture could be condensed at the lower temperature evaporation/condensation pipe section of the rig.

Based on the obtained results, further research work is currently ongoing to develop a large-scale demonstration system in order to verify the viability and performance of the thermochemical energy storage/cooling system.

5. Acknowledgments

The author wishes to express acknowledgements to Public Works Departments (PWD) and Public Services Departments of Malaysia (PSD) for their scholarship support associated with this study and Department of Architecture and Built Environment, University of Nottingham UK for the support of research equipment.

6. References

[1.] L. Pérez-Lombard, J. Ortiz, and C. Pout, "A review on buildings energy consumption information," *Energy and Buildings,* vol. 40, pp. 394-398, 2008.

[2.] L. Pérez-Lombard, J. Ortiz, J. F. Coronel, and I. R. Maestre, "A review of HVAC systems requirements in building energy regulations," *Energy and Buildings,* vol. 43, pp. 255-268, 2011.

[3.] L. Yang, H. Yan, and J. C. Lam, "Thermal comfort and building energy consumption implications – A review," *Applied Energy,* vol. 115, pp. 164-173, 2014.

[4.] I. Dincer and M. A. Rosen, *Thermal Energy Storage Systems and Applications.*: John Wiley & Sons, Ltd, 2011.

[5.] S. Hongois, F. Kuznik, P. Stevens, and J.-J. Roux, "Development and characterisation of a new MgSO4−zeolite composite for long-term thermal energy storage," *Solar Energy Materials and Solar Cells,* vol. 95, pp. 1831-1837, 2011.

[6.] R. Hastings and M. Wall, *Sustainable Solar Housing Strategies and Solutions: Stratergies and Solutions* vol. 1. London, UK: Earthscan, 2007.

[7.] Y. Ding and S. B. Riffat, "Thermochemical energy storage technologies for building applications: a state-of-the-art review," *International Journal of Low-Carbon Technologies,* vol. 8, pp. 106-116, 2013.

[8.] L. G. Gordeeva and Y. I. Aristov, "Composites 'salt inside porous matrix' for adsorption heat transformation: a current state-of-the-art and new trends," *International Journal of Low-Carbon Technologies,* vol. 7, pp. 288-302, 2012.

[9.] Y. I. Aristov, "Selective Water Sorbents, A new Family of Materials for Adsorption CoolingHeating State -Of -The -Art," presented at the V Minsk International Seminar “Heat Pipes, Heat Pumps, Refrigerators”, Minsk, Belarus, 2003.
[10.] K. E. N’Tsoukpoe, H. Liu, N. Le Pierrès, and L. Luo, "A review on long-term sorption solar energy storage," *Renewable and Sustainable Energy Reviews,* vol. 13, pp. 2385-2396, 2009.

Enhanced Energy Efficiency Technology for a Large Scale Building

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Abstract

This paper discusses on the Particle Swarm Optimization (PSO) technique used to determine the optimal location and sizing of voltage regulators and capacitors for attaining the optimal solution of energy saving, total power loss reduction and total cost investment for an unbalanced electrical system in a large-scale building. The results show that the proposed method provides an auspicious amount of energy saving as well as improvement in power loss with minimal investment cost whilst maintaining the power factor, voltage magnitude as well as total harmonic distortion within specified limit prescribed by the utility. Further comparison in terms of energy saving is performed with the base case condition of an unbalanced electrical system for a large-scale building.

Keywords: Large scale building, Energy efficiency; Particle Swarm Optimization (PSO), Capacitors; Voltage regulators;

1. Introduction

Most developing countries are not able to implement a large number of alternative energy resources because it involves a large amount of capital costs for the installation of this technology [1]. Nonetheless, the more affordable yet effective energy efficiency technologies have been discussed and analysed by scholars as well as practitioners to solve the energy related problems [2]. Advanced techniques utilizing the concept of voltage and reactive power (Volt-VAR) optimization also known as VVO are often employed to improve the energy efficiency of a distribution system [3]. The energy efficiency improvisation based VVO customarily optimizes the network using Volt–VAR control assets such as the On-Load Tap Changing transformer (OLTC), voltage regulators (VR), capacitor banks (CB) and other Volt–VAR control components (VVCC).

In recent years, various studies have been performed to develop new energy optimization solutions for a distribution system [4-8]. Yong et al., [4] presents a Honey-Bees Mating Optimization (HBMO) algorithm to perform the multi-objective function of Volt-VAR control in a distribution system considering Distributed Generators (DGs) and it is merely focused on a daily scenario rather than a quasi-real-time manner. In another study, a fuzzy adaptive Particle Swarm Optimization has been used to perform the VVO of a distribution system taking into account the DGs under the daily scenario [5]. This signifies that all of the studies recently implement the VVO technologies in a distribution system rendered by the utility and on the other leaf, it has not been implemented in an unbalanced electrical system of a large scale building which will be introduced as well as discussed in this paper.

In order to deal with the aforementioned problems of energy efficiency in an unbalanced electrical system of a large-scale building, several studies on capacitor installation has been carried out to improve the voltage profiles and total power losses [8]. However, the side-effect is often overlooked in which a small increment of total real power (kW) drawn by the system leads to a higher electricity bill as well as deficiencies in power factor and total power losses. Hence, the issue of energy efficiency improvement inflicting to an energy saving can be solved by implementing the finest amalgamation between voltage regulators and capacitors. In particular, it can be done by utilizing the proposed technique of optimal placement and sizing of voltage regulators (OVRPS) as well as optimal placement and sizing of capacitors (OCPS).

This paper presents the optimal placement and sizing of voltage regulators and capacitors using the Particle Swarm Optimization (PSO) in which it is performed to determine the energy efficiency of an unbalanced electrical system of a large-scale building. The objective function of PSO is referred to the total energy saving gained per year embodied with the total amount of energy consumption, energy losses and the investment cost of voltage regulators and capacitors. The optimization is performed by the PSO while maintaining the power factor, voltage magnitude and total harmonic distortion within a limit specified by the utility.

2. Methodology

Two main problems need to be solved for an energy efficiency problem in an unbalanced electrical system involves energy saving inclusive with system stability and security mainly focusing on total power loss improvement. Conventionally, the main purpose of installing the voltage regulators in an unbalanced electrical system of a large-scale building is to regulate the voltage at risers in turn reducing the total incoming power or power consumption. Whereas, the conventional aspect of capacitors installation is to reduce total power losses in an unbalanced electrical system of a large scale building. Nevertheless, in order to further improve the energy efficiency in a building, technology improvement involving voltage regulators and capacitors is introduced wherein its location for installation and sizing are optimally determined with the aid of Particle Swarm Optimization (PSO).

2.1 Procedure of Optimal Voltage Regulators and Capacitors Placement and Sizing using Particle Swarm Optimization (PSO)

PSO was originally developed for nonlinear optimization problems with continues variables [6]. However, it can be easily expanded to treat problems with discrete variables. Hence, it is applicable to optimize the placement and sizing of voltage regulators and capacitors with discrete variables. In this study, a three-phase unbalanced electrical system of a large scale building has been designed taking into account several important electrical parameters such as the three phase load, distribution line, buses, incoming source and measurement blocks. The load flow simulation performed will provide the electrical measurement in a time domain response during steady state condition.

a. Set the parameters of unbalanced electrical distribution systems and PSO technique.
b. Perform an unbalanced load flow solution for the original system in order to obtain base case value of total active power and total active power losses.
c. Initialize every n_p^{th} particle that holds multidimensional values of position, *x*, and of velocity, *v*.
d. Update the particles of velocity, *v*. The selection of particle position for *pbest* and *gbest* is basically based on the objective function, *OF*.
e. Update the particles position, *x*, associated with the new velocity, *v*.
f. Determine a voltage regulator size at the chosen locations based on particles movement dependent on the position, *x*, and velocity, *v*.
g. Determine a capacitor size at the chosen locations based on particles movement dependent on the position, *x*, and velocity, *v*.
h. Calculate the objective function of the proposed PSO technique.
i. Select the particle of position, and particle of voltage regulator's size and capacitor's size, allocated at a particular n_p^{th} particle having the maximum objective function.
j. Select the particle of position to represents as the *pbest* and *gbest* at the current iteration *k*.
k. Repeat steps (g) to (m) for the next iteration, *k*.

3. Results and Discussion

In this case study, an unbalanced distribution system of a building was considered as a test system for analysis of optimal voltage regulators and capacitors placement as well as sizing determined by using the proposed PSO method. The electrical distribution system is operating in a nominal secondary voltage magnitude of 433*V* where the voltage is stepped down by the five incoming transformers that fed from the utility substation operating at 11 *kV*. Each secondary side of incoming transformer is connected to the main switchboard (MSB) and from the MSB there are several risers wherein each riser is specifically connected to a respective load.

Table 1 shows the comparison of results extracted from the unbalanced load flow simulation. As depicted in Table 1, it can be observed that the best solution in terms of energy efficiency through implementation of voltage regulators and capacitors placement and sizing via PSO have shown that the system draws a real and reactive power of 2387.88 kW and 1350.59 kVar for the power consumption with the total real and reactive power losses of 2.05 kW and 1.16 kVar, respectively. The power consumption has been reduced by 562.13 kW compared to the base case that represents 19% of total real power saving. Other than that, OVRPS and OCPS with PSO algorithm shows a significant reduction of total real and reactive power losses incurred in the system with about 58% and 53% reduction, respectively.

The total cost of energy consumption and energy losses with OVRPS with amalgamation of OCPS via PSO is RM 1,380,573.84 per year and RM 1,183.85 per year, respectively. This results elucidates that savings obtained from OVRPS with amalgamation of OCPS via PSO compared to base case condition is significant at RM 296,558.19 total saving per year. The maximum and minimum operating voltage magnitudes are 240.99 $V_{p\text{-}n}$ and 238.49 $V_{p\text{-}n}$, respectively, which comply with the tolerance prescribed by the Energy Commission of Malaysia. The power factor during OVRPS with amalgamation of OCPS via PSO load flow condition is 0.87 *p.f* has improved as compared to base case of 0.84 p.f. The power factor also complies with the minimum value of power factor at 0.85 p.f. The total harmonic distortion of voltage magnitude (*THDv*) of 3% is obtained from the OVRPS with amalgamation of OCPS

via PSO load flow solution comply with the *THDv* regulation below the limit of 5%. The implementation of voltage regulators with capacitors have succeeded to secure energy efficiency in a building with improvement regarding incoming power factor value, power losses and total energy consumption in the system compared to previous method with total saving of RM 296,558.19.

Table 1. Energy Efficiency Results of Voltage Regulator and Capacitor Placement and Sizing using PSO on SSAAS Building.

System parameters	Base case	OCPS and OVRPS via PSO
Objective Function (RM/year)	-	296,558.19
Total cost of energy consumption (RM/year)	1,705,578.63	1,380,573.84
Total cost of energy losses (RM/year)	2,812.25	1,183.85
Total cost of voltage regulators (RM)	-	13,275.00
Total cost of capacitors (RM)	-	16,800.00
Total real power consumption (*kW*)	2950.01	2387.88
Total reactive power consumption (*kVar*)	1696.27	1350.59
Total real power loss (*kW*)	4.86	2.05
Total reactive power loss (*kVar*)	2.47	1.16
Total current flow through incoming secondary side of transformer (*kA*)	5.22	4.19
Total voltage regulators size (*kVA*)	-	50.00
Total capacitors size (*kVar*)	-	292.50
Maximum voltage magnitude ($V_{p\text{-}n}$)	253.44	244.30
Minimum voltages magnitude ($V_{p\text{-}n}$)	250.12	238.49
Average power factor (*p.f*)	0.84	0.87
Maximum *THDv* (%)	3%	2%

4. Conclusion

This paper has presented the Particle Swarm Optimization (PSO) technique used to solve the problem of optimal voltage regulators and capacitors placement and sizing in a large scale building. The results have shown that the optimal capacitors placement and sizing improves energy efficiency performance of the unbalanced electrical distribution system in terms total real power losses with minimum cost of installation whilst satisfying all system constraints such as limitations of *THDv*, voltage magnitude and power factor.

5. References

[1.] G. Ahmadi, and S. M. Shahrtash, "Neutral to earth voltage analysis in harmonic polluted distribution networks with multi-grounded neutrals," *Int. J. Electr. Electron. Eng.*, vol. 3, no. 12, pp. 741–745, 2009.

[2.] J. D. Bouford, D. J. Hurley, S. S. Member, D. J. Hurley, and S. S. Member, "A recommended standard for voltages appearing across publicly accessible surfaces," *IEEE Trans. Power Deliv.*, vol. 29, no. 1, pp. 48–51, Feb. 2014.

[3.] N. Abed, S. Member, S. Salem, and J. Burke, "Evaluation of induced stray voltages from transmission lines using EMTP," in *IEEE PES General Meeting*, Providence, RI, USA, 2010, pp. 1–5.

[4.] J. Yong, C. Zhou, B. Yang, and X. Wang, “A harmonic-based approach for open-neutral fault detection in low voltage systems,” in *Proc. Int. Conf. Harmon. Qual. Power, ICHQP*, Hong Kong, China, 2012, pp. 53–58.
[5.] X. Xie, Y. Sun, X. Long, and B. Zhang, “A new method to monitor the primary neutral integrity in multi-grounded neutral systems,” *energies*, vol. 10, no. 3, pp. 380, 2017.
[6.] Z. A. Abu Zarim, A. B. Abd Ghani, and S. K. Tiong, “The measurement and temperature profile of cable insulation failure due to loose connection at the cable termination,” *Proc. Int. Symp. Electr. Insul. Mater.*, Mie, Japan, 2008, pp. 570–572.
[7.] “IEEE Guide to Understanding, Diagnosing, and Mitigating Stray and Contact Voltage,” 2016.
[8.] X. Su, M. A. S. Masoum, and P. J. Wolfs, “PSO and improved BSFS based sequential comprehensive placement and real-time multi-objective control of delta-connected switched capacitors in unbalanced radial MV distribution networks,” *IEEE Transactions on Power Systems*, vol. 31, no. 1, pp. 612-622, 2015.

Energy Consumption Coefficient (ECC) for Optimum Solar PV-diesel Hybrid System Design

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Abstract

Alternative energy technology has been widely used in Rural Electrification Programs (REPs) all over the world for many years now. Renewable energy sources, such as solar, wind and biomass, are the preferred choices given the abundant resources available on site and the sophistication of the technologies involved. Combination of two or more of the resources, together with an energy storage system and occasionally a conventional energy generator, creates a hybrid system, which is reliable and durable. In Malaysia, solar photovoltaic (PV) based systems, implemented on a large scale, can provide round-the-clock electricity services for areas that are inaccessible by electricity grid network. One of Malaysia's REP initiatives is a solar PV-diesel hybrid system for 160 schools in rural Sabah. An optimum system capacity is always a need so that the system can be fully utilized once operated. This paper determines the Energy Consumption Coefficient (ECC) in optimizing the design of solar PV diesel hybrid system. For this analytical approach, eleven schools with the installed solar PV-diesel hybrid system were selected. The study shows that the actual energy consumption is correlated with the Total Connected Load (TCL). For Malaysia's rural school, the ECC was found to be in the range of 3.0 – 3.2 hours.

Keywords: *Solar PV-diesel; hybrid system; Energy Consumption Coefficient; Total Connected Load*

1. Introduction

Renewable energy technology has long been used as an alternative stand-alone electricity power supply for rural and remote areas that are not connected to an electricity grid network. More than 1.4 billion people still live in areas without electricity, mostly in South Asia and Sub-Saharan Africa [1]. Meanwhile, almost 1.2 billion will still be without electricity by 2030 [2]. It is unlikely that an area without electricity can be developed economically, as it is an important factor in modernization. Geographical conditions, the smallness of village sizes and the remoteness of the locations mean that the extension of an electricity grid network is expensive, uneconomical and not attractive as an investment, by either the government or the private sector.

Rural Electrification Programs (REPs) is the process, plans, programs and initiatives by government, private sectors, institution or organization to fight poverty, enhance the economic growth and to balance the development between urban and rural areas. The REPs bring electricity services to rural and remote areas, which includes electricity grid network extension as well as off-grid power supply systems. People and communities can move towards modern civilization if electricity is made available as it benefits their lifestyle by improving the level of health, education, economy and technology [3]. Among all the renewable energy resources that are available, solar photovoltaic (PV) system is a popular option in off grid rural areas [4].

Most studies use approximation in selecting data and parameters to model a solar PV system's sizing capacity. In determining the daily energy consumption of the load demand, engineers would normally put assumption on numbers of hours for each electrical appliance (switch socket outlet, fan, and lighting) to calculate the solar PV system capacity. This had sometimes led to system capacity inaccuracy once implemented on-site and had caused difficulties to the system engineer in foreseeing the actual performance of the system [5]. The engineer has to estimate the energy demand, which is difficult and complex and for areas that have never been supplied with electricity; this information can be inaccurate [6]. It is important to analyse the system's operation using long term recorded data, which could describe the changes if any, in energy demand, system degradation due to aging factor, and the influence of each component towards energy balance and supply [7]. However, the main problem remains that the availability of long-term recorded data is usually incomplete or unavailable.

This paper describes the actual energy demand profile of eleven rural schools in Malaysia that uses solar PV-diesel hybrid system. The relation of the daily energy consumption and the Total Connected Load (TCL) is explained, which emphasis on the use of Energy Consumption Coefficient (ECC) in designing a solar PV-diesel hybrid system for optimum and highly reliable system.

2. Methodology

Scope of Study

Eleven solar PV-diesel hybrid systems that were installed at Sabah rural school were selected and categorized into system capacity, geographical condition and year of operation to ensure the subgroups homogeneity as shown in Table 1. The daily energy consumption of each school was recorded using Sunny Webbox data logger. Measured energy consumption of the schools was compared against the design energy consumption to seek the differences, if any. It is very critical that the availability of information was high in monitoring the system operation in long period. For this study, the data for each system was recorded for a period of two to three years. Another important parameter was the Total Connected Load (TCL), which was obtained from the system design documents.

Correlation of Energy Consumption and TCL

The actual energy consumption and the TCL were analysed statistically to inform the relation of both parameters. Pearson Correlation Coefficient, which is the measurement of linear relationship of two variables, was used in order to test and analyse the relation of the actual energy consumption and the TCL [8]. The range of correlation coefficient (r) is between -1 and +1 and describes the direction and strength of the linear association between two variables. The sign of the correlation indicates its direction and r-value closer to -1 or +1 indicates a strong relation between the variables and vice versa. The variable would be considered as no relation if the value was 0. A strong relation of both parameters would give indication that the ratio of the actual energy consumption and the TCL, namely the Energy Consumption Coefficient (ECC) can be developed and then be used in any solar PV system design process, as shown in Equation [1].

The use of ECC would ease the design process in calculating the energy consumption that would give more accurate energy consumption and solar PV system capacity values.

$$Energy\ Counsumption\ Coefficient\ (ECC) = \frac{Daily\ energy\ consumption\ (kWh)}{Total\ COnnected\ Load\ (TCL)(kW)} \quad [1]$$

3. Result and Analysis

Energy Demand and Load Profile

The actual daily energy consumption of each school shows less energy usage than the expected values (Fig. 1). All of them have enough margins in terms of energy capacity for future demand growth. Three of the systems (SK Golong, SK Litang and SMK Timbua) almost reached the expected value of 92.8%, 87.8% and 81.7% respectively. The remaining systems used between 50% and 80% of the actual and expected energy consumption ratio. The types of teachers' residencies, the number of occupancies and the location of the schools, as shown in Table 2, determine the level of daily energy consumption by each school.

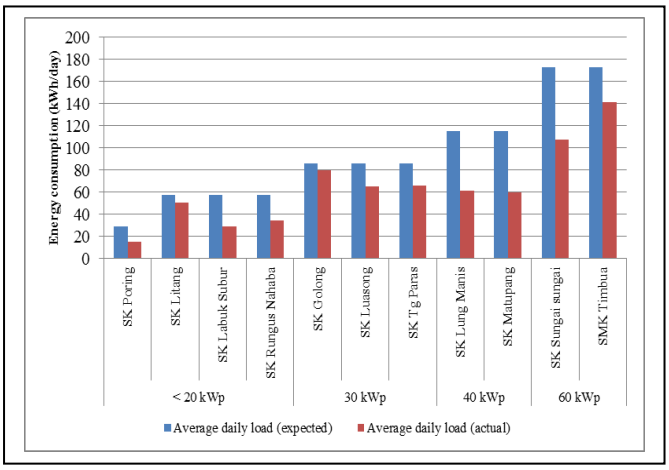

Fig. 1. Comparison between expected and actual daily energy consumption

The type of load at each school in general consists of Compact Fluorescent Lights (CFL) of 24 W each, compound/street light using CFL for the walkway and school road access, ceiling fans of 70 W each and power sockets. The compound/street lights were in operation for 12 hours daily at night (6 pm to 6 am). The power sockets were used for electrical appliances like computers, laptop, printer, photocopy machine, projector and air-conditioning unit for school building, while quarters would normally use television set, radio, refrigerator, rice cooker and hair dryer. Mobile phone charger might also be used in areas within mobile network coverage. However, it was difficult to determine the exact type of electrical appliance since some of them belong to the users for personal use.

Fig. 2 shows the relation between levels of daily irradiation and the daily energy consumption in each school. The correlation suggests a weak association between the two variables where the value of the correlation coefficients (r) at SK Poring, SK Litang, SK Labuk Subur and SK Rungus Nahaba were 0.194, 0.07, 0.28 and 0.34 respectively. Hence, the level of the irradiation intensity at each school has less effect on the school's daily energy consumption. The correlation in other schools shows similar result.

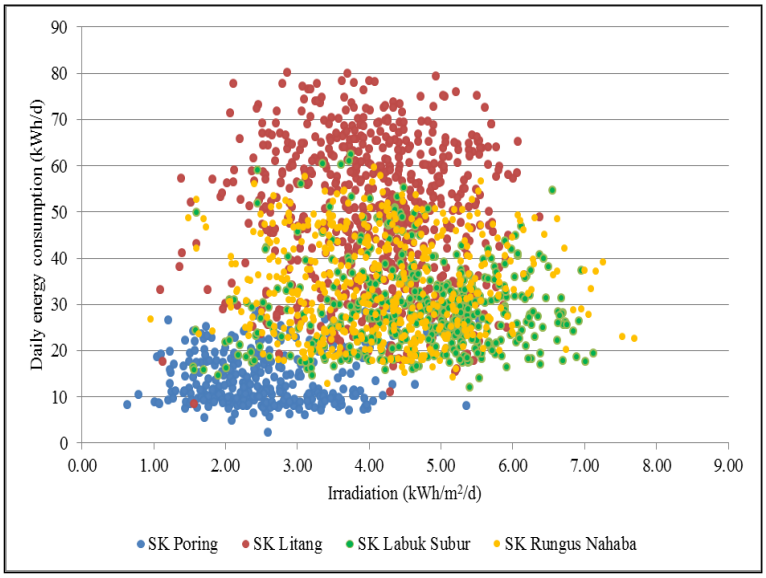

Fig. 2. Correlation between daily energy consumption and irradiation at schools with system capacity 20 kWp.

Energy Consumption Coefficient (ECC)

The results as described in Part III (A) above gives evidence on the variation of the actual energy consumption to the expected value. Therefore, load consumption estimation method can no longer be the accurate approach to determine the daily energy demand as well as solar PV system capacity. Site characteristics need to be considered in the design stage. In this study, type of buildings and teachers' residence, number of occupancies and seasonal energy demand, i.e.; school days and school holidays influenced the load demand.

Depending on the capacity of the schools, the daily energy consumption varies from 31.2 kWh to 192.75 kWh. The maximum energy consumption during the measurement period was considered for it would describe the most energy requirement of the school. The Energy Consumption Coefficient (ECC) ranges from 3.0 to 3.22 hours with average of 3.08 hours. Figure 3 shows the linear relation of energy consumption and the TCL of each school, which suggest a strong positive relation of both variables where the (r) value was 0.902 at 99% confidence level. Thus, the ECC is practical in future design process to determine the daily energy demand.

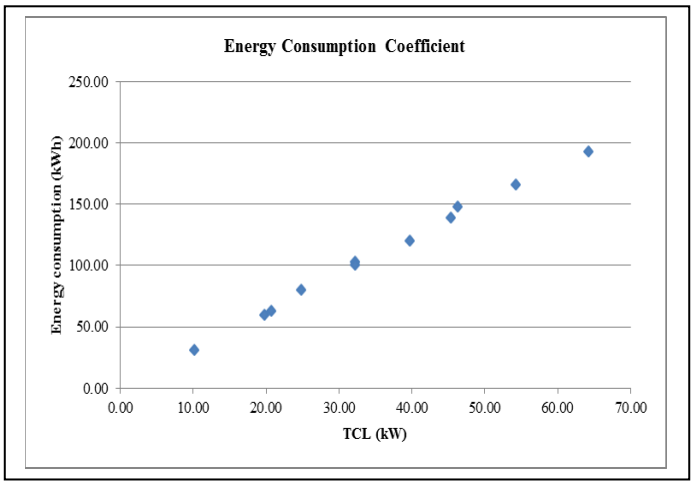

Fig. 3. Relation of energy consumption and the Total Connected Load (TCL).

4. Discussion

The findings on energy demand rate at each school showed that the end users never exceeded the allocated daily electricity energy usage that the system was able to provide. The usage rate provides sufficient energy capacity margin for future demand growth. Thus, for a stand-alone power supply system, the accuracy of the actual load pattern against the expected load as calculated from the system design was unpredictable. This was due to unavailability of energy usage history and therefore the system load profile was determined by the designer's assumption that has become a common method in designing a stand-alone power supply system. In this context, the introduction of the ECC is beneficial to assist engineers to design an optimum solar PV system.

Additionally, when it comes to real time operation, the trend in load profile and the total daily energy used were differentiated by several factors which were school holidays and weekend, number of occupants who used the electricity services daily (teachers/staff stayed or did not stayed at school), accessibility to the school from nearby city (teachers stayed in the city or spend their weekend in the city if less travelling time and cheaper transportation cost) and type of electrical appliances used. There was no evidence on the effect of seasonal weather on the energy demand of the schools.

5. Conclusion

The study has provided understanding of actual electrical energy preferences and profile for schools in rural areas in Sabah in terms of energy demand, daily load pattern and preferences in electrical appliances; all of which are important in REP implementation and development whether for current initiatives or future plans. The characteristic of the electrical energy profile is essential to be used in REP planning.

The relation of daily energy consumption and the Total Connected Load (TCL) proves that the ratio of both variables can be utilized to determine the daily energy consumption during the design process. Thus, it can eliminate the normal method base on assumption on hourly load use. For this study, it was found that the Energy Consumption Coefficient (ECC) for rural school in Malaysia was in the range of 3.0 – 3.22.

6. Acknowledgment

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7. References

[1.] P. Cook, "Infrastructure, rural electrification and development," *Energy Sustain. Dev.*, vol. 15, no. 3, pp. 304–313, Sep. 2011.

[2.] B. K. Sovacool and A. L. D'Agostino, "A comparative analysis of solar home system programmes in China, Laos, Mongolia and Papua New Guinea," *Prog. Dev. Stud.*, vol. 12, no. 4, pp. 315–335, Oct. 2012.

[3.] F. S. Javadi, B. Rismanchi, M. Sarraf, O. Afshar, R. Saidur, H. W. Ping, and N. a. Rahim, "Global policy of rural electrification," *Renew. Sustain. Energy Rev.*, vol. 19, pp. 402–416, Mar. 2013.

[4.] S. A. Chowdhury, M. Mourshed, S. M. R. Kabir, M. Islam, T. Morshed, M. R. Khan, and M. N. Patwary, "Technical appraisal of solar home systems in Bangladesh: A field investigation," *Renew. Energy*, vol. 36, no. 2, pp. 772–778, Feb. 2011.

[5.] H. Jacobus, B. Lin, D. H. Jimmy, R. Ansumana, A. P. Malanoski, and D. Stenger, "Evaluating the impact of adding energy storage on the performance of a hybrid power system," *Energy Convers. Manag.*, vol. 52, no. 7, pp. 2604–2610, Jul. 2011.

[6.] P. Díaz, C. A. Arias, R. Peña, and D. Sandoval, "FAR from the grid: A rural electrification field study," *Renew. Energy*, vol. 35, no. 12, pp. 2829–2834, Dec. 2010.

[7.] P. Díaz, R. Peña, J. Muñoz, C. A. Arias, and D. Sandoval, "Field analysis of solar PV-based collective systems for rural electrification," *Energy*, vol. 36, no. 5, pp. 2509–2516, May 2011.

[8.] M. K. W. Trochim, "Research Methods Knowledge Base," *Statistic's Solution Consulting*. [Online]. Available: http://socialresearchmethods.net. [Accessed: 15-Feb-2015].

[9.] A. M. Mahmud and R. E. Blanchard, "Assessing a rural electrification program in Malaysia: system performance analysis on 11 solar PV-diesel hybrid systems," in *4th International conference on the developments in renewable energy technology (ICDRET 2016)*, 2016.

TABLE I. LIST OF THE 11 SCHOOLS AND THE SOLAR PV-DIESEL HYBRID SYSTEMS CAPACITY. (SK MEANS PRIMARY SCHOOL AND SMK MEANS SECONDARY SCHOOL) [9].

School name	District	Geographical (*elevation from sea level)	Year operation	Capacity			
				Solar PV (kWp)	Grid Inverter / Bidirectional inverter (kW)	Battery (Ah)	Genset (kVA)
SK LUASONG	TAWAU	LAND (62 m)	2011	30	32 / 20	4500	24
SK LABUK SUBUR	SANDAKAN	LAND (4 m)	2011	20	20 /15	3000	13
SK LITANG	KINABATANGAN	LAND (13 m)	2011	20	20 /15	3000	13
SK GOLONG	BELURAN	LAND (11 m)	2011	30	32 / 20	4500	24
SK LUNG MANIS	SANDAKAN	LAND (51 m)	2011	40	44 / 30	6000	30
SK MATUPANG	RANAU	LAND (216 m)	2011	40	44 / 30	6000	27
SK PORING	TUARAN	LAND (836 m)	2009	15	13.7 / 10	1500	12
SK TANJUNG PARAS	LAHAD DATU	ISLAND (10 m)	2011	30	32 / 20	4500	24
SMK TIMBUA	RANAU	LAND (38 m)	2011	60	64 / 45	9000	33
SK SUNGAI SUNGAI	BELURAN	LAND (17 m)	2014	60	60 / 45	9000	30
SK RUNGUS NAHABA	RANAU	LAND (614 m)	2011	20	20 /15	3000	13

TABLE II. INFORMATION OF THE ELEVEN SCHOOLS.

Schools	Occupants		Residence	Distance to nearest town	Access
	Teachers	Students			
SK Sungai sungai	24	280	Quarters	148 km	Asphalt road
SK Golong	16	95	Quarters	107 km	Gravel road for 10 km
SK Litang	17	64	Quarters	73 km	Gravel road for 50 km
SK Matupang	22	144	Town/village nearby	41 km	Asphalt road
SK Long Manis	18	185	Town nearby	67 km	Gravel road for 5 km
SK Labuk Subur	14	111	Village nearby	85 km	Gravel road for 6 km
SK Luasong	24	269	Quarters	98 km	Gravel road for 22 km
SK Poring	12	9	Quarters	40 km	Asphalt road
SMK Timbua	52	534	Quarters	61 km	Gravel road for 8 km
SK Rungus Nahaba	12	26	Quarters	31 km	Gravel road for 11 km
SK Tg Paras	17	235	Town nearby	5 km	Boat

Applicability of Islamic Leadership Principles in Construction Project Management with Specific Reference to JKR Malaysia - The Use of Delphi Method & Expert Validation

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Abstract

Project management continuously faces challenges in an increasingly dynamic and competitive environment. This demands strong leadership by project manager in order to achieve project success. Previous empirical studies have indicated the positive impact of Islamic leadership on organisational performance and outcome in various sectors such as businesses, banking, etc; however, no similar studies have been conducted in construction field. Delphi method is an option to the traditional and popular methods used for data collection in research such as interview and questionnaire survey. It is increasingly adopted in various areas of research including in project management as well as Islamic studies that aims to reach consensus and decisive opinions on topics that are being researched by involving a group of panel or experts. Subsequently, the outcome of the Delphi survey was validated with experts. This paper presents the adoption of this method in a postgraduate research and the findings on the applicability of Islamic leadership principles (ILP) in project management with specific reference to JKR Malaysia (Public Works Department of Malaysia). Acceptable level of consensus from the Delphi survey were achieved in all constructs attributing to the Islamic leadership principles and its strategies. The findings indicated that Islamic leadership principles were highly applicable and it could enhance the likelihood of achieving project success in JKR project management.

Keywords: Project Management; Project Success; Islamic Leadership Principles; Delphi Method

1. Introduction

The positive impact of Islamic leadership in various organisational types and settings has been proven empirically in previous research, that it is positively related to and it can increase organisational performance [1]-[53]-[67]-[30]-[31]-[36]-[97]-[51]. However, there is lack of evidence to support that the same research has been conducted in construction projects environment or in project management [57]-[58]-[59]-[60]-[61]-[62].

Islam is not merely a religion but a way of life and the divine revealed and sources of the Qur'an, the Sunnah Prophet S.A.W. and other non-revealed sources of Islamic teachings are the complete and comprehensive guidance for mankind covering all aspects of human life including business

transactions and project management which is part of muamalat (transactions or dealings according to Islam) [4]-[49]. The completeness and comprehensiveness of Islam provides the best guidance and as a way of life, to regulate the whole life of mankind and to resolve and fulfill all the needs of men and women, as stated in the following verses of the Qur'an:

"This day, I have perfected to you your religion, completed My Favour upon you, and have chosen for you Islam as your religion" [90]. In another verse, Allah Says: "And there is no creature on [or within] the earth or bird that flies with its wings except [that they are] communities like you. We have not neglected in the Register (Book) a thing. Then unto their Lord they will be gathered" [90]. Infact, Muslims are obliged to follow Islamic teachings that are also clearly mentioned in the Qur'an as follows: "To each among you, We have prescribed a law and a clear way" [90].

This commandment is all encompassing all human affairs and not to exclude matters pertaining to leadership in project management. In fact it is obligatory (for Muslims) as part of obligations towards Allah to identify the lawful (halal) and otherwise those prohibited in our daily dealings [83]-[84]-[12]- [49]. For non-Muslims, although it is not obligatory, Islamic system, values and principles, as such, Islamic leadership will provide one best alternative to practice, since Islam will bring benefits to the whole ummah and it is not only meant for Muslims, and one best example of this is the great success of Islamic banking system. Allah says in the following verse of the Qur'an: "And We have not sent you, [O Muhammad], except as a mercy to the worlds" [90]. In this regard, the success of Islamic finance and banking system as well as Islamic insurance (Takaful) have provided sufficient proof that Islam benefits all and the brings the best to mankind as stated in surah al-Anbya.

Despite this development, as stated earlier and the potential of Islamic leadership, and the fact that there is no evidence and none of its kind of initiatives have been introduced into construction project management in particular the public sector projects until recently, some early indications inclined towards this direction is seen. An acknowledgement of Islamic principles is stated in project management guidance for public projects that project manager imbued with faith (iman), taqwa, trustworthy, high quality, etc would have better control on projects and therefore can manoeuvre their project to success [5]. They have internal control mechanism that can influence their ways and behaviour towards their projects and the people involved that is often neglected in the vast majority of project management literature. Nevertheless, there is still no evidence of empirical studies conducted with respect to imbue Islamic leadership principles into the practice of project management.

Project success is commonly viewed as successful achievement of completing a project within the agreed budget, within the specified time, expected quality and satisfy the client [78]-[47]-[96]-[72]. Successful projects demand strong leadership capability by the project manager [92]. Thus, improving their leadership can influence the project outcome and increasing the chances of meeting project success.

This research was undertaken in project management of PWD (Public Works Department), Malaysia. PWD Malaysia is also known as JKR (Jabatan Kerja Raya).

2. Project Management and Project Success

Project management for public projects in Malaysia is best represented by JKR as the main technical department for implementing physical and infrastructure projects [46]-[40]-[38]-[48]. In this respect, JKR has long been leading other government agencies on technical guidelines for building, road, and maintenance projects, construction contracts and project management. Project management in JKR is divided into five (5) project phases ie; planning, design, procurement, construction and handing over [40]-[38]-[48].

As the premier technical agency, it has all the in-house technical expertise comprising of all main disciplines that makes the department capable of handling a project from sketches to until it is ready to be handed over to client and users. Planning is project initiation, that the need for having a project is established by the client with preliminary indications on budget, time and expectation of end products. Project manager and initial team members are appointed to define and obtain the client's ideas in his mind to technical documentation.

Planning is crucial to decide whether to 'go or not' with a project. In design phase, details design will be prepared taking the inputs from planning as the client's needs and wants. Revisions will be done for example if there is a constraint with regards to technical guidelines, as more information is revealed at this stage. Procurement phase is to prepare documentations for the project to be procured and the best contractor that meets various evaluation criteria can be selected. Construction is the implementation phase to transform the paper on planning and design to reality.

This is the real test for the project manager, his team and stakeholders involved in any project as full team comes into and interfacing project activities running concurrently. Project fate mostly is determined in this phase. Handover is closing phase that physical components are approaching completion and testing and commissioning of deliverable items are performed. This phase is to ensure that a project accomplishes its missions, meets its main objectives and fits for purpose to the client and satisfy him.

Project management literature has evolved on the meaning of project success from the 'Iron Triangle' of Cost, Time and Quality [10]-[22]. To include more recent criteria that reflects the increasing in clients' requirements and demand and project complexity ie; client's satisfaction and stakeholder's satisfaction or requirement [78]-[47]-[72]. Nonetheless, JKR project management is still basically focusing towards achieving and fulfilling the three (3) traditional and commonly accepted criteria of project success which are Time, Cost and Quality.

One of the reasons is that these criteria's are quantifiable leading to direct evaluation on its achievement and progress. On the contrary, client's satisfaction is not directly observable and interpreted that is also known as latent variable, although scale can be suggested to represent it. These three (3) criteria's are the traditional success criteria widely used and accepted in literature thus being the norms of measuring project success or failure in construction industry. The essence of the project success in terms of time, cost and quality is to meet the needs and satisfy the client on which projects are constructed for.

3. Islamic Leadership Principles

Islamic leadership principles (ILP) are discussed in literature of Islamic studies for example in [42]-[43]- [3]-[2]-[88]-[50] –[56]. There are six (6) ILP that has been appraised and identified by the author; leadership is a manifestation of human role as His Khalifah; leadership is knowledge acquisition and translation leading with knowledge; leadership is a responsibility; leadership is teamwork; leadership by example and leadership is vision and the will to achieve the vision.
Al-Qur'an and al-Sunnah form a principal source of deriving ILP (as it is mentioned in verses Al-Ahzab:72, Al-An'am:165 and Al-Zukhruf:32), followed by practices of companions that immediately upon their appointment would address clearly the followers and stating what leadership principles in Islam are.

Upon the occasion of his first speech once appointed, as first Caliph, Abu Bakr (ra) stated: O people! I have been selected as your trustee although I am not better than anyone of you. If I am right, obey me. If I am misguided, set me right". Similarly, 'Umar (ra) was quoted as saying to the people: I have appointed over you governors and agents not to beat your bodies, but rather to teach you and serve you [44]. The six (6) ILP will be discussed in the following paragraphs.
Firstly, the purpose of creation of men by Allah as His Khalifah (Vicegerent) or leaders on earth is repeated in the Qur'an such as in al-Baqarah, 2.143, al-Baqarah, 2:30; al-Hajj, 22.041; al-Anaam, 6.165; az-Zukhruf, 43:32; al-Maida, 5:8; al-Yusuf, 12:55; al-Yusuf, 12:56, In one verse Allah Says: "And (remember), when your Lord said to the angels, "I am about to place a vicegerent on the earth…" [90].

This indicates that leadership principles are already embedded in us and came from the very first moment men was created. Being Khalifah is to live by upholding the divine guidance of the Qur'an and Sunnah ie. performing good deeds and preventing from wrongdoings (amal maaruf wahna anil munkar) among fellow men, taking care of other creations, in all aspects of life including matters relating to work and in this regards, project management. Realising this principle, all activities are actions of ibadah with the inner admission as servant to Him that counted for in the Hereafter, thus men will always strive for optimisation and there is no room even as small as seed, for corrupted doings in all dealings.

Secondly, being a knowledgeable person is very demanded in Islam. Many verses in the Qur'an shows how important Islam views the seeking of knowledge on individual Muslim and what more important to lead and to become leaders. The first verse of the Qur'an is talking about reading in verse al-'Alaq, and in al-Zumar:09, Allah SWT asks "…Are those who know equal to those who know not?"… ([90]. Infact, seeking knowledge and acting with knowledge is synonymous to religious duty (obligatory) as it is repeated so many times in the Qu'ran and in the hadith of the Prophet S.A.W. For example, when Mu'awiyah (ra) reported the Prophet SAW as saying, "When Allah wishes good for someone, He bestows upon him the understanding of Deen."[20]. Understanding of Deen as stated, reflects the call for knowledge acquisition.

Thirdly, leadership in Islam is a divine trust (*amanah*), not an honour or privilege, neither for self-fulfilment and thus it becomes a religious duty to accomplish in the best manner and in full commitment. The principle that leadership is a trust comes at the highest rank above all other reasoning. In the same notion, a leader is accountable for all his actions and endeavours towards God more than people who have vested interest in project ie. the stakeholders. Allah Says in surah

al-An'am of the Qur'an that some of us will be appointed to be leaders to lead the others and in the verse of Al-Hajj, leaders are to lead himself and to serve and guide followers to do good deeds and prevent committing those that are prohibited. Allah Says: "It is He Who hath made you (His) agents, inheritors of the earth: He hath raised you in ranks, some above others: that He may try you in the gifts He hath given you: for thy Lord is quick in punishment: yet He is indeed Oft-forgiving, Most Merciful. ([90]. Being trustworthy and responsible is also to be just ie. to practice justice (*ad'l*). Justice is a fundamental principle in Islamic religion that Islam promotes just society and against any actions of oppression and manipulation of rights (haq) and that justice ensures properity and peace of ummah (society) [44[-[66]-[49]-[7]- [70].

Fourthly, leadership is indeed by all perspectives about establishing and maintaining teamwork because leaders cannot accomplish anything alone without teamwork and their followers and the very fundamental fact of the meaning of leadership itself refers to a concerted group effort between leaders and their followers energised by influence to achieve a desired goal [97]-[26]-[52]-[23]. This means, leadership fails without teamwork or the result of good leadership is the existence of teamwork. In Islamic teaching, the six pillars of *iman* and the five pillars of Islam form a catalyst of unity. Everybody is heading towards one direction under the notion of religiosity. Islam is very much synonymous with team working ie. the principle of collective efforts rather than individualism that is manifested for example in the performance of daily prayer in congregation (*jemaah*) and the striving for social justice and sharing the burden of those less fortunate people in the community through the giving of charity (sedekah) and zakat. In this respect, Islam instills the practice of mutual consultation or shura for maintaining teamwork and cohesiveness in solving problems or facing challenges. It is also a famous tradition of the Prophet S.A.W. as well as it is a fundamental construct of leadership [34]-[49]- [37].

Fifth, being at the front line of the people, leaders must be an exemplary icon ethically, morally and charismatically and free from all degradations, and live with what they preach to followers or in modern terms, 'walk the talk' as Allah clearly Reminds this Surah as-Saff, "O believers! Why do you say what you never do?"[90]. Islam has bestowed upon the believers, the best leadership role model in the leadership of Prophet S.A.W., followed by the subsequent Caliphs of Abu Bakar, Uthman and Ali. Allah Testifies in the Qur'an on the Prophet S.A.W. as the noblest example of leadership; "Indeed in the Messenger of Allah, you have a good example, for anyone who looks forward to (please) Allah and the (reward of the) Last Day and remembers Allah much (whether in times of hardship or comfort" [90].

Finally, leaders articulating visions for the people and organisation they lead and make them achieve it and this distinguishes a leader with a routine manager or even a normal person [52]-[23]-[72]. Although, leaders set visions for followers and organisation they lead, in both conventional and Islamic leadership, however, Islam sets a far wider dimension of visions that is comprehensive and all-encompassing ie. To include spiritual visions [44]-[6]-[87]-[88]-[89]-[93]. The Prophet S.A.W. had exemplified that leadership in Islam is farsighted and encompasses the visions of both worlds ie. not only to succeed in this world but to achieve the real and utmost level of success (al-Falah) in the Hereafter.

The leadership principles from Islamic perspective that have been discussed are divinely sourced leadership guidance that is for mankind in all walks of life including project management as stated

earlier in this paper. It is anticipated that the principles that bring elements of faith and religion of Islam would have positive impact because it strives for true purpose of life and so be it in projects, correctness of behaviours, strong internal control and inner feelings that guide such correct actions, culture of transparency, perfection and excellence as well as putting justice at the right place, to the leaders and followers will have positive impacts on projects as it has demonstrated in other areas 1]-[53]-[67]-[30]-[31]-[36]-[97]-[51]-[11].

4. Methodology

The objective of this paper is to present the methodology, data collections, results and findings of a postgraduate research on ILP and its applicability in JKR project management. The following are the key activities involved:

i. Conducting literature review for obtaining adequate information on ILP and availability of well-established instrument that can be used for this research;
ii. The design of instrument based on the information from literature and to best tailor to the project management practice in JKR;
iii. The designed instrument is validated by experts;
iv. Selection of panellist for the Delphi interview;
v. Face to face structured interview with the Delphi panellist;
vi. Experts Interview for validation
vii. Results and findings

4.1. *The Use of Delphi Method and Advantages*

Delphi technique, that was developed by Dalkey and Helmer (1963) at the Rand Corporation in the 1950s in a US Air Force project, is particularly a good research method and is widely adopted for deriving consensus among a group of individuals having expertise on a particular topic. The information sought is subjective opinions, complex issues, exploratory and literature proves it as a reliable scientific method for empirically consensus-reaching in various field of researches [77]-[17]-[18]-[25]-[75] as well as in project management and construction related studies involving project managers [35] [32]-71]-[55]-[76].

In brief, Delphi method is a group decision making process that consist panel of experts aiming to reach consensus and since experts opinion is sought, a purposive sample is employed whereby Delphi participants (the experts) are selected not to represent the general population (as the case in quantitative research) but rather their expert's ability to answer the research questions and objectives ([85] Delphi method can also be considered as survey but it is conducted among the panel of experts or panellist as participants that is the same as respondents in typical survey [39]-[18]-[68]-[95]. In terms of data collection approach to respondents (experts) can be done through ethnographic interview or via questionnaire [79].

There is no "typical" or standard Delphi; that the method is always and can be modified to suit the circumstances and research questions that many authors view the commonly applied in research is modified Delphi [85]-[41]. However, original or classical Delphi according to characteristics as defined by [77] must have these four characteristics; anonymity allows participants to express their choices freely without pressure to conform the others in the group, iteration by allowing participants

to refine their answers, controlled feedback that participants can change their earlier views and the use of quantitative data analysis. By this definition given by [77], the method that is employed in this research conforms to all four (4) Delphi characteristics.

This method is applicable in the context of this research because it involves opinions that are subjective, subtle and qualitative in nature that a robust and reliable consensus outcome is sought as whether the Islamic leadership principles are applicable or not. A consensus opinion is derived from experts individuals involved in the area when large scale of quantitative statistical data fails to discover and provide such good insights [68]-[32]. In fact, Delphi method allows researchers to obtain highly reliable data from experts using strategically designed surveys, in circumstances whereby traditional methods such as surveys, interviews etc. fail or are not appropriate [35].

Secondly, the iterative process Delphi method is conducted in a few series; involving a few rounds normally between two (2) to four (4) and the number of participants varies depending on who the selected experts are and whether the sample is heterogeneous or homogenous. Normally, although varies depending on the type of research, most studies employ between 10 to 15 or 15 to 35 people and although in some cases it can reach hundreds [28]-[68] –[85]-[32]. The respondents for Delphi were project managers in JKR, 43 respondents and this number is within the numbers as defined in the literature. They are at senior grade, with over 25 years of project management experience as shown in the profile data of the respondents and they are expert project managers that represented different categories of specialisation of project types in JKR project management structured in different Branches. A person with twenty-five (25) years project management experience is considered an expert project manager (Berggreen Ramsing, 2013). This number (ie. 41) is an appropriate size number for a Delphi method. In fact, project managers have previously participated in Delphi survey [35] [32]-[71]-[55]-[63]-[75]-[76].

Thirdly, this method is well suited for research instrument when the research is new and there is incomplete knowledge and information available about a problem or phenomenon that is being studied, and it focuses to improve understanding of problems, solutions or developing forecasts [68]-[85]. This is also relevant in this research because the applicability of Islamic leadership principles in project management is new and novel, previous data in similar context is not available and the instrument that has been developed is new, thus, a breakthrough of its kind in the given scenario ie. project management in JKR.

Furthermore, due to these predetermined goals for employing a Delphi method, the key to a successful Delphi study lies in the selection of participants since their experts opinions, judgments and their ability to reach saturated level or consensus will be the core of this method and this is absent in typical interview or survey [28]-[85]. This is one of the strengths of Delphi that is not available and cannot be obtained from normal interview either by structured, semi-structured or unstructured interview.

4.2. *Design of the Questionnaire and Piloting*

The objective of the questionnaire is to assess the applicability of ILP in JKR project management.

The six (6) ILP that have been identified from the literature will form the first part of the instrument. Respondents will be given the opportunity to indicate their opinion on the applicability of the Islamic leadership principles by using Likert scale 1-5 (1-strongly not applicable to 5- strongly

applicable) based on the statement of indicators supporting under each the six leadership principles. The original Likert scale that was invented by Likert (1932) used five responses of scale and it is still commonly used in research [45]-[16]-[21].

The second part is to assess on applicability of ILP that can be best applied in JKR project phase ie. planning, design, procurement, construction and handover. Respondents are given a nominal scale (1- planning, 2- design, 3- procurement, 4- construction, 5- handover) to choose from, to further assess the Islamic leadership principles in terms of where do these principles can be most appropriately or best applied among the five (5) project phases.

The draft instrument that was prepared by the author was piloted with academic experts in the field of project management leadership and Islamic studies at the Kuliyyah and from within the university. There were five experts involved and their feedbacks and comments were taken as inputs for further improvement of the instrument. The objectives of conducting pilot study are to refine the instrument and to ensure that the instrument (questionnaire) is appropriate to be answered by respondents and it is free from ambiguities or errors, enabling respondents to give easy answer as well as providing opportunity for improvement [64]-[65]-[85]-[26]. In addition, several rounds of discussions with supervisors are also very useful and were part of piloting process ([64]-[65]-[26].

The outcome is a total of six (6) ILP and twenty five (25) indicators being identified for assessment of applicability in the five (5) phases of project in JKR project management. The third part is to assess whether applying ILP will have impact on the project outcome ie. increase the chances of project success in terms of time, cost and quality.

4.3. *Selection of Panellists and Data Collection*

The selection of panellists to participate in the Delphi survey was determined as the project managers that were involved in ongoing projects. This is due to the reasons as has been defined in literature that a project manager in any given project is the person responsible for managing the project and accomplishing the project objectives. The project manager becomes the man in the central point of every project organisation by providing technical, managerial and leadership expertise and he or she is engaged and needed to be present in all stages from inception and planning to project completion [8]-[92]-[98]-[91]-[38]- [19]-[100].

The full list of project managers that met the criteria to be the respondents involved in project implementation were obtained, making the total number of 43 respondents for Delphi survey Round 1 and Delphi survey Round 2.

Results from Delphi survey Round 1 became the questionnaire for the subsequent stage. Internal validity was addressed by having each stage instrument piloted and validated initially by academic faculty members (lecturers), colleagues that were PhD students, followed by academic experts in the field of project management leadership and Islamic studies[64]-[65]-[26].

Experts' interview on the results of Delphi after the completion of Round 2 was conducted to address any shortcomings or flaws in the data that are obtained from the survey [74]. The experts consisted of five (5) highly positioned officers in the Department (JKR).

Level of consensus in Delphi can be determined by achieving the SD (Standard Deviation) score of less than 1.5 [55]-[74]. In terms of reliability, it was addressed by the score of Cronbach's alpha value above 0.7 and 0.8 in Round 1 and Round 2. It is a value for internal reliability that is essential to be calculated when using Likert-type scale for measurement [21]. It refers to the internal consistency reliability that shows the extent to which items in an instrument are consistent among themselves and which the overall instrument as a group, that it is measure of scale reliability [21]-[104]. Low Cronbach's alpha value indicates items are heterogeneous which perform poorly in representing the dimensions being measured [54]. Thus, high value indicates good representation.

5. Results and Findings

The data from Delphi Round 1 and Delphi Round 2 were analysed and an acceptable level of consensus were achieved in all six (6) ILP after the Delphi Survey Round 2. Level of consensus is determined by achieving SD (Standard Deviation) score of less than 1.5. Subsequently, it was validated in interview with experts. The main findings are as follows:

i. Finding 1: ILP are applicable in JKR project management ie. Leadership is a Manifestation of Human Role as Khalifah; Leadership is a Knowledge Acquisition and Translation-leading with Knowledge; Leadership is a Responsibility; Leadership is Team Working; Leadership By Example and Leadership is Vision and The Will to Achieve the Vision;

ii. Finding 2: ILP are best applicable in relation to enhancing the chances of project success, firstly; in Construction phase and secondly; Planning phase in overall five (5) project phases in JKR project management;

iii. Finding 3: ILP can enhance the chances of project success in JKR project management.

6. Conclusions

This research has empirically proven and expands further previous researches on Islamic studies that Islamic principles are not merely religious scripts and ritual practices but they are meant to shed lights on the practical side of human activities and modern life affairs in this regards, project management. It gives evidence that divine doctrine is applicable, practical and relevant in contemporary settings. It also provides the basis with empirical evidence for applying Islamic leadership principles to enhancing the chances of project success in the field of project management. It is evident that Islamic principles are universal and therefore are applicable in all spheres and activities of life, and not limited only for religious and ritual purposes. As such, the outcome of this research can be viewed as an introductory initiative or starting point for the applicability of ILP in project management.

7. Contributions and Recommendations

This research is significant, as it has conducted an empirical research on ILP in the field of project management or construction-related type of organisation that is lacking in previous studies. It contributes to the body and knowledge of academia as well as to the industry in several ways. Firstly, developing and proposing a research instrument on ILP and its applicability in context of project management, since the vast majority of leadership studies previously were Western and Christian dominant due to its theoretical origin from those part of the world. Secondly, the findings

of this research strongly supports and has extended the previous studies on the positive impact of Islamic leadership would have on organisational performance and outcome. Thirdly, the use of Delphi method that is rare in both project management and Islamic leadership studies is another contribution that provides the support of the advantages of this method. Further research can be conducted in other organisations that implement public or private projects in larger scale within the construction industry.

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9. References

[1.] Abbasi, A.S., Ur Rehman, K, Abbasi, O.H., (2010b), Role of Islamic Leadership in Value Based Corporate Management : The Case of Pakistan, African Journal of Business Management Vol. 4(18), pp. 4003-4020.

[2.] Adalat. K. (2007), Islamic Leadership Principles (A Success Model for Everyone and AllTimes),http://www.irfi.org/articles/articles_1401_1450/islamic_leadership_principles.htm.accessed.11.03.2014.

[3.] Adnan, A. (2006), A Study of Islamic Leadership Theory and Practice in K-12 Islamic Schools in Michigan, Ph.D Thesis, Brigham Young University.

[4.] Akram Laldin, M. (2006), Introduction to Shari'ah and Islamic Jurisprudence, Kuala Lumpur: CERT Publications.

[5.] Ali Hamsa, Tan Sri Dr. Ketua Setiausaha Negara, Civil Servants Carry Out Government Development Projects without Misconducts, News on 2, RTM 2, 3 December 2016.

[6.] Ali Jubran Salleh (2007), Leadership: An Islamic Perspective, paper presented at International Conference, Management from Islamic Perspective at Hilton Kuala Lumpur, 15-16 May 2007, Organised by International Islamic University Malaysia (IIUM).

[7.] Amrozi, S. R. (2014), The Power of Rasulullah's Leadership - Hebatnya Kepimpinan Rasulullah S.A.W. dan Pengaruhnya Sehingga Abad Ini, Al Hidayah House of Publishers Sdn. Bhd.

[8.] Anantatmula, V.S. (2010), Project Manager Leadership Role in Improving Project Performance, Engineering Management Journal, Vol. 22 No. 1.

[9.] Anuar, N. (2011), Redefining Roles and Responsibilities of Project Team Member in JKR Matrix Organisation, Master Capstone Project Report, Universiti Teknologi Malaysia (UTM).

[10.] Atkinson, R. (1999), Project management: cost, time and quality, two best guesses and a phenomenon, its time to accept other success criteria, Int. Journal of Project Mgmt, 17, pp. 337-342.

[11.] Azila, A. S., Khairuddin, A. R., Srazali, A., Sharina Farihah, H., Puteri Nur Naadia, A. F., Muhamad Rosdi, S. (2016), Identification of Islamic Leadership Principles and Their

Applicability in Construction Project Management, Journal of Scientific Research and Development, Vol. 3(4), pp. 66-70.
[12.] Bilal,K., Ayesha Farooq, Zareen Hussain (2010), Human Resource Management: an Islamic Perspective, Asia Pacific Journal of Business Administration, Vol. 2, No. 1, pp. 17-34.
[13.] Beekun, R.I., Badawi, J. (1999), Leadership: an Islamic Perspective, Amana Publications, Maryland.
[14.] Beekun, R.I. (2012a), Character Centered Leadership: Muhammad (p) as an Ethical Role Model for CEOs, Journal of Management Development, Vol. 31 No. 10, 2012, pp. 1003-1020.
[15.] Berggreen Ramsing, L. (2013), Unpacking Project Management Communication – A Relational Approach to Strategy, PhD Dissertation, Aahus University.
[16.] Bertram, D. (2007), Likert Scale – Are The Meaning of Life, CPSC 681 Topic Report, http://poincare.matf.bg.ac.rs/~kristina/topic-dane-likert.pdf. accessed.8.5.2017.
[17.] Boone, H. N., Boone, D. A. (2012), Analyzing Likert Data, Journal of Extention, Vol. 50, No. 2. https://joe.org/joe/2012april/pdf/JOE_v50_2tt2.pdf.
[18.] Chia-Chien, H., Sandford, B. A. (2007), The Delphi Technique - Making Sense of Consensus, Practical Assessment, Research and Evalution, Vol. 12, No.10, pp. 1-10.
[19.] Cuhls, C. (2003), Delphi Method, pp. 93 – 113.
[20.] Cleland, D. I., Ireland, L. R. (2002), Project Management – Strategic Design and Implementation, Fourth edition, McGraw-Hill Companies.
[21.] Collection of Hadiths from Riyad-us-Saliheen Compiled by Al-Imam Abu Zakariya Yahya bin Sharaf An-Nawawi Ad-Dimashqi (2002), Selected and Collected by Sheikh Safi-ur-Rahman Mubarakpuri, Translated by Dr. Muhammad Amin and Abu Usamah Al-Arabi bin Razduq, Darussalam, Riyadh, Saudi Arabia.
[22.] Croasmun, J. T., Ostrum, L. (2011), Using Likert-Type Scales in the Social Sciences, Journal of Adult Education, Vol. 40, Number 1, pp. 19-22.
[23.] De Witt, A. (1988), Measurement of project success, Int. Journal of Project Mgmt., Vol. 6 (1988), pp. 164-170.
[24.] Dubrin, A. (2012), Leadership: Research Findings, Practice and Skills, 7th edition, Houghton Mifflin, Boston, MA.
[25.] Dyett, V. (2011), Roles and Characteristics of the Project Manager in Achieving Success across the Project Life Cycle, Ph.D Thesis, Lynn University.
[26.] Faucher, J.B. P. L. (2010), Reconceptualising Knowledge Management: Knowledge, Social Energy, and Emergent Leadership in Social Complex Adaptive Systems, phD Thesis, University of Otago.
[27.] Fellows, R. A., Liu, A. (2003), Research Methods for Construction, Wiley & Sons, Inc., John.
[28.] Goel, R., Gupta, N. (2014), Survey on Acceptance Testing Technique, International Journal of Software and Web Sciences (IJSWS), Vol. 8(1), pp. 20-23.
[29.] Gordon, T. Fletcher, A. J., Marchildon, G. P. (2014), Using the Delphi Method for Qualitative, Participatory Action Research in Health Leadership, International Journal of Qualitative Researchs, pp. 12 – 18.

[30.] J., The Delphi Method (2009), The Millineum Project, Futures Research Methodology—V3.0, pp. 1-29.
[31.] Gholamreza, Z., Mohamed, S., Babak, N., Nayal Rashed M. M. (2013a), The Relationship between Spirituality and Leader's Effectiveness: A Perspective from the Holy Qur'an, Caspian Journal of Applied Sciences Research, 2(4), pp. 08-16.
[32.] Gholamreza, Z., Mohamed, S., Babak, N., Nayal Rashed M. M. (2013b), The Relationship between Responsibility and Leader's Effectiveness: A Perspective from the Holy Qur'an, World Applied Sciences Journal 24 (4): pp. 550-555.
[33.] Grisham, T. (2009), The Delphi technique: a method for testing complex and multifaceted topics, International Journal of Managing Projects in Business, Vol. 2, Issue 1, pp.112 – 130.
[34.] Groves, K.S., La Rocca. M.S. (2011), Responsible Leadership Outcomes via Stakeholder CSR Values: Testing a Value-centered Model of Transformational Leadership, Journal of Business Ethics, Vol. 98, pp. 37-55.
[35.] Haddara, M, Enanny, F. (2009), Leadership: An Islamic Perspective, Feb. 2009.
[36.] Hallowell, M., Gambatese, J. (2010), Qualitative Research: Application of the Delphi Method to CEM Research, Journal of Engineering and Management, Vol. 136, Special Issue, pp. 99-107.
[37.] Hakim. A. (2012), The Implementation of Islamic Leadership and Islamic Organisational Culture and Its Influence on Islamic Working Motivation and Islamic Performance PT Bank Mu'amalat Indonesia Tbk. Employee in the Central Java, Asia Pacific Management Review 17(1) (2012), pp. 77-90.
[38.] Handoko, L. H., Kayadibi, S. (2013), The Implementation of Good Governance in the Era of Caliphate Omar Ibn Abd al-aziz (61H-101H/717-720M), Global Review of Islamic Economics and Business, Vol. 1, No. 2 (2013), pp. 133-149.
[39.] Hannerita, M. Z. (2012), Maintaining Project Alignment: A Grounded Theory Study of Project Managers in the Public Works Department of Malaysia (PWDM), PhD thesis, Curtin University, Australia.
[40.] Hasson, F., Keeney, S., McKenna, H. (2000), Research Guidelines for the Delphi Survey Technique, Journal of Advanced Nursing, Vol. 32, Issue 4, pp. 1008–1015.
[41.] Hazimul-Din, A. R. (2010), Establishing Project Management Office for a More Effective and Efficient Implementation of Projects in JKR, Master Thesis UTM.
[42.] Irdayanti, M. N., Ramlee, M., Abdullah, Y. (2015), Delphi Technique – Enhancing Research in Technical and Vocational Educational, Journal of Technical Education and Training, Vol. 7, No. 2, pp. 12-23.
[43.] Ismail, N. (2000), Kepimpinan Nabi Muhammad S.A.W. – Pengurusan Altruistik Model Ikutan Sepanjang Masa, Utusan Publications & Distributors Sdn. Bhd.
[44.] Ismail, N. (2002), Prophet Muhammad's Leadership, The Paragon of Excellence - Altrusitic Management, A Cross-Application to Modern Management and Leadership Practice, Utusan Publications & Distributors Sdn. Bhd.
[45.] Jabnoun, N. (2005), Islam and Management, International Islamic Publishing House, Riyadh, Saudi Arabia.
[46.] Jamieson, S.(2004), Likert Scale: How to (Ab)use Them, Medical Education, Blackwell Publishing Ltd.

[47.] Judin, A. K. (2010), The National Landmarks, Ibu Pejabat JKR.
[48.] Jugdev, K., Muller, R. (2005), A Retrospective Look at Our Evolving Understanding of Project Success, Project Management Journal, Vol. 36, 19-31.
[49.] Ketua Pengarah Kerja Raya (2010), JKR Strategic Framework (2012-2015) Pejabat Ketua Pengarah Kerja Raya, Kuala Lumpur.
[50.] Khaliq Ahmad, Fontaine, R. (2011), Management from Islamic Perspective, International Islamic University Malaysia, Kuala Lumpur.
[51.] Khanittha, S. (2015), Leadership Competency Model for Islamic School Leaders, International Journal of Humanities and Management Sciences (IJHMS) Vol. 3, Issue 2, pp. 86-88.
[52.] Kriger, M., Seng, Y. (2005), Leadership with Inner Meaning: A Contingency Theory of Leadership based on the Worldviews of Five Religions, The Leadership Quarterly, Vol. 16, pp. 771-806.
[53.] Lussier, R. N., Achua, C. F. (2007), Leadership - Theory, Application and Skill Development, Third edition, Thomson South-Western.
[54.] Majeed, Y., Khalid, Z., Khan, M.A. (2011), The impact of Islamic leadership on organizational Objectives, Far East Journal of Marketing and Management, Vol. 1, NO. 1, pp. 54-65.
[55.] Megat Zuhairi, M. T. (2012), Leadership Style in the Malaysian Construction Industry, DBA Thesis, Universiti Teknologi MARA (UiTM).
[56.] Mohd. Fairullazi, M. A. (2014), Cost Data Inputs in Life Cycle Cost Analysis in Malaysia – Assessment of Data and Development of Proposed Strategies and Protocol to Enhance Data Quality, unpublished PhD Thesis, International Islamic University Malaysia (IIUM).
[57.] Mohd. Sani, B., Nor Hartini, S. (2016), Kepimpinan dan Amanat Peradaban, Penerbit IKIM.
[58.] Muhamad Rosdi, S., Khairuddin, A. R., Azila, A. S. (2013a), Islamic Perspective of Leadership for Construction Project Manager, International Conference on Architecture and Built Environment 2013 (ICABE2013), International Islamic University Malaysia (IIUM), Kuala Lumpur, 7-8 Nov. 2013.
[59.] Muhamad Rosdi, S., Khairuddin, A. R., Azila, A. S., Rapiah, M. Z. (2013b), Islamic Perspective of Leadership for Construction Project Manager, 12th. Management in Construction Research Association (MiCRA 2013) Conference and Annual General Meeting, 8 Dec. 2013.
[60.] Muhamad Rosdi, S., Khairuddin, A. R., Azila, A. S., Rapiah, M. Z. (2014a), Construction Project Leadership from the Perspective of Islam, International Journal of Islamic Thought (IJIT), Vol. 6, Dec. 2014.
[61.] Muhamad Rosdi, S., Khairuddin, A. R., Azila, A. S., Rapiah, M. Z. (2014b), Project Leadership from the Perspective of Islam - A Model, 13th. Management in Construction Research Association (MiCRA 2014) Conference and Annual General Meeting, 6 Nov. 2014.
[62.] Muhamad Rosdi, S., Khairuddin, A. R., Azila, A. S., Rapiah, M. Z. (2014c), A Research Agenda for Islamic Perspective of Leadership in Project Management, 2nd. AICIF (Asian International Conference on Islamic Finance) 2014, Yogyakarta, 13-14 Nov. 2014.

[63.] Muhamad Rosdi, S., Khairuddin, A. R., Azila, A. S., Rapiah, M. Z. (2015a), West Meets Islam in Contemporary World – Construction Project Leadership Perspective, Journal of Islamic Studies and Culture, June 2015, Vol. 3, No.1, pp. 1-5.Naji, Z. A., Lailawati, M. S., Mohamed Z. A., Amini, A. A. (2014), The West and Islam Perspective of Leadership, International Affairs and Global Strategy, Vol. 18, 2014.
[64.] Muir, R. (2012) in IPMA Research Awards: Press release 2012, IPMA (International Project Management Association) World Congress in Greece, 2012.
[65.] Naoum, S. G. (2007), Dissertation Research and Writing For Construction Students, Butterworth-Heinemann.
[66.] Naoum, S. G. (2013), Dissertation Research and Writing For Construction Students, Third Edition, Routledge, Taylor and Francis Group.
[67.] Norfazila, I. (2012), Sistem Pengurusan Islam Alternatif Terbaik – Budaya Kerja Berlandas Paradigma Tauhid Menjadilkan Organisasi Cekap, Capai Al-falah, Berita Harian, Artikel Agama, 5 June 2012.
[68.] Nayal Rashed, M. M. (2007), Leadership from the Qur'an Relationship between Taqwa, Trust and Business Leadership Effectiveness, PhD Thesis, Universiti Sains Malaysia (USM).
[69.] Okoli, C., Pawlowski, S. D. (2004), The Delphi Method as a Research Tool: An Example, Design Considerations and Applications, Information & Management, Vol. 42, Issue 1, December 2004, pp. 15–29.
[70.] O'Donnell, J. G., (2012, A Study of The Relationship Among Project Managers' Leadership Practices, Project Complexity, And Project Success, DBA Dissertation, University Seattle College of Business.
[71.] Pahrol Md. Joi, IKIM, Slot Islam Itu Indah, 26 December 2015.
[72.] Pejman Ghasemi, P. S., Reza, A., Ali Bagheri, F., Hamid, A., Kiyanoosh Golchin, R. (2013), Necessary Competencies of Construction Managers in Iran as a Developing Country, Research Journal of Applied Sciences, Engineering and Technology, Vol. 7, No. 10, pp. 2162-2171.
[73.] Pinto, J.K. (2010), Project Management – Achieving Competitive Advantage, Second Edition, Prentice Hall.
[74.] PROKOM (Cawangan Pengurusan Projek Kompleks) (2008), The Roles of HOPT, HODT and SO, Ibu Pejabat JKR Malaysia.
[75.] Puteri Nur Farah Naadia, M. F. (2015), A Proposed Framework Construction Works Loss and Damage Claim Under The Insurance of Works in Contractor's All Risks (CAR) Takaful, Ph.D Thesis, International Islamic University Malaysia.
[76.] Reza Afshari, A., Rosnah Mohd Yusuff (2012), Developing a Structural Method for Eliciting Criteria in Project Manager Selection, Proceedings of the 2012 International Conference on Industrial Engineering and Operations Management, Istanbul, Turkey, July 3 – 6, 2012.
[77.] Reza Afshari, A. (2015), Selection of construction project manager by using Delphi and fuzzy linguistic decision making, Journal of Intelligent & Fuzzy Systems, Vol. 28, no. 6, pp. 2827-2838.
[78.] Rowe, G., Wright, G. (1999), The Delphi Technique as a Forecasting Tool: Issues and Analysis, International Journal of Forecasting, Vol. 15, pp. 353–375.

[79.] Samiaah M., Hassen M. Al-Tmeemy, Hamzah A. R., Zakaria, H. (2011), Future Criteria for Success of Building Projects in Malaysia, Int. Journal of Project Mgmt, Vol. 29, No. 3, pp. 337-348.
[80.] Sarantakos, S. (1998), Social Research, Second edition, MacMillan Press Limited.
[81.] Sarantakos, S. (2005), Social Research, Third edition, Palgrave MacMillan.
[82.] Sekaran, U. (2000), Research Methods for Business - A Skill-building Approach, Third edition, John Wiley & Son, Inc..
[83.] Sekaran, U., Bougie, R. (2010), Research Methods for Business – A Skilled Building Approach, Fifth Edition, John Wiley and Sons Ltd..
[84.] Setter, M. (2013), User Acceptance Testing – How To Do It Right!, http://usersnap.com/blog/user-acceptance-testing-right/8.11.2016.
[85.] Siti Nora Haryati Abdullah Habib, Khairuddin Abdul Rashid (2008a), Shari'ah Compliant Construction Contract: A Proposed Methodolgy, A Paper presented in Shari'ah Compliant Construction Contract Conference, Kuala Lumpur, 16 April 2008.
[86.] Siti Nora Haryati Abdullah Habib, Khairuddin Abdul Rashid (2008b), Survey on the Understanding of Quantity Surveyors on Shari'ah Compliant in the Formation of Construction Contract, A Paper presented in Shari'ah Compliant Construction Contract Conference, Kuala Lumpur, 16 April 2008.
[87.] Skulmoski, G. J., Hartman, F. T., Krahn, J. (2007), The Delphi Method for Graduate Research, Journal of Information Technology Education, Vol. 6, pp. 1-11.
[88.] Steckler, A., McLeroy, K. M. (2008), The Importance of External Validity, American Journal of Public Health. 2008 January, 98(1), pp. 9–10.
[89.] Syed Fayyaz, A. (2007), Ethical Basis of Organisational Perspective: An Islamic Perspective, paper presented at International Conference, Management from Islamic Perspective at Hilton Kuala Lumpur, 15-16 May 2007, Organised by IIUM.
[90.] Syed Omar, S.A., Djasriza, J., Fatimah, P. (2007), Nine Islamic Management Practices and Habits in Islamic History: Lessons for Managers and Leaders, UNITAR E-Journal, Vol. 3, No. 2, pp. 42-59.
[91.] Syed Othman al-Habshi (2007), Leadership Personality in an Era of Empirism, paper presented at International Conference, Management from Islamic Perspective at Hilton Kuala Lumpur, 15-16 May 2007, Organised by IIUM.
[92.] Tafsir Ar-Rahman (2007), Interpretation of the Meaning of the Qur'an, Department of Islamic Development Malaysia (JAKIM).
[93.] Tan, A. A. L. (2005), The Top-Flight 'Ideal' Project Manager, Venton Publishing(M) Sdn. Bhd.
[94.] The Project Management Body of Knowledge (PMBoK), Project Management Institute (PMI), 2013 edition.
[95.] Toor, S.R. (2008), Merging Spirituality and Religion: Developing An Islamic Leadership Theory, International Islamic University Malaysia (IIUM) Journal of Economics and Accounting, 16, No. 1 (2008), pp. 15-46.
[96.] Toth, P. A. (2011), Project Leadership and the PMBOK Guide, DBA Project Dissertation, Jones International University.

[97.] Wakhid Slamet, C. (2005), Application of Analytic Hierarchy Process in Prioritization of Critical Success Factors of TQM, ©2005 Wakhid Slamet Ciptono. All rights reserved.
[98.] Wan Maimun, W. A., Ahmad, R. (2006), Does Successful Project Management Equates to Project Success, ICCI 2006, Kuala Lumpur.
[99.] Wan Norhayate, Wan. D., Marlisa, A. R., Aizzat, M. N. (2014), Quality of Islamic Leadership and Organisational Performance within the Takaful Industry in Malaysia: A Conceptual Study, Asian Social Science, Vol. 10, No. 21: 2014.
[100.]Verma, V. K. (1995), Organising Projects for Success, The Human Aspects of Project Management, Vol. 1, Project Management Insitute (PMI).
[101.]Villanova University, The Purpose of User Acceptance Testing,https:// www. villanovau. com/ resources/software-testing/user-acceptance-testing/#.WCF7FCuV0dU.8.11,2016.
[102.]Zarina, A., Zarita. A., Muhammad, F. M. I. (2012), Project Management towards Best Practice, ASIA Pacific International Conference on Environment-Behaviour Studies, Mercure Le Sphinx Cairo Hotel, Giza, Egypt, 31 Oct-2Nov. 2012.
[103.]http://guide.agilealliance.org/guide/acceptance.html.31.3.2016.
[104.]Tutorial points, What is User Acceptance Testing? https://www.tutorialspoint.com/software_testing_dictionary/use_acceptance_testing.htm.8.11.2016.
[105.]Institute for Digital Research and Education, UCLA (2016), http://www.ats.ucla.edu/ stat/ spss/faq/alpha.html.accessed.27.4.2016

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