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MESSAGE FROM THE DIRECTOR

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيم

By the grace of Allah S.W.T. the 3rd JKR Research Colloquium (JKRRC) was successfully organized by the Innovation, Engineering Research and Development Division, JKR Centre of Excellence for Engineering and Technology (CREaTE) from 23rd to 24th August 2021 via online platform during the COVID -19 movement control order. The theme chosen was '**Penyelidikan dan Inovasi Teras Pemerkasaan Kejuruteraan'** (Research and Innovation: the Core of Engineering Empowerment) which is in line with Theme 3 of JKR's Strategic Plan that is for JKR to become the Centre of Technical Excellence.

A total of 25 technical papers and 10 posters were presented covering diverse areas including Civil and Structural Engineering, Mechanical Engineering, Forensic Engineering, Electrical Engineering, Project Management, Construction and Infrastructure Engineering during the 3rd JKRRC. After a rigorous peer-review process by the Abstract and Manuscript Review Committee, 15 papers are published in this proceedings. This publication is extremely beneficial as it helps promote interdisciplinary development in engineering and disseminate knowledge derived from research findings which may subsequently contribute to the improvement of JKR's service delivery and to creating innovation which could potentially benefit the industry.

I sincerely offer my earnest gratitude to the entire organizing committee, presenters, participants and distinguished guests for making the 3rd JKRRC a grand success. Special thank you goes to all the authors, editorial committee and reviewers for their contributions and effort during the 3rd JKRRC and until the publication of the proceedings. I do hope that the content of the proceedings would entice readers into reading on until the end of the book.

Thank you.

ACKNOWLEDEGMENT

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 3rd. JKR Research Colloquium (JKRRC) 2021, including the authors, JKRRC delegates, staff members of the JKR Centre of Excellence for Engineering and Technology (CREaTE).

TABLE OF CONTENTS

Road Operation and Maintenance Carbon Footprint: Case Study of Malaysia Federal and State Road

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Abstract

The road infrastructure developed to comfort users and the surrounding neighborhood in ensuring the alignment while managing the operation and maintenance (O&M), corresponds to physical works such as asphalt production, construction, and road asset maintenance works. The road operation is executed to ensure satisfactory road functions while retaining the road performance. However, previous study reveals that the O&M activities impact the environment through road congestion, accidents, vehicle fuel costs, and excessive energy usage during operations which contribute to the greenhouse gas (GHG) generation which in turn leads to the phenomenon of climate change. Therefore, this study aims to identify the critical carbon emission, based on the O&M activities and sources, in addition to preparing the standard measurement in establishing the carbon footprint calculator. The study focuses on the Federal and State Roads during the O&M phase. The measurement of carbon emission was accomplished by compiling raw data from direct and indirect emissions focusing on Scope 1, 2 and 3 which were released from each activity. Data were collected from 11 road maintenance companies throughout Peninsular Malaysia, involving 74 districts in 10 states. Subsequently, the carbon emission was computed using carbon emission calculation measured as tons of carbon dioxide (tCO2) per activity. The overall study shows that O&M activities contributed 1.211 MtCO2, which represents 0.53% of the overall Malaysia's total emission of 226.8 MtCO2. The findings demonstrate that the significant O&M activities may impact the country's carbon emission thus, by determining the baseline it is possible to facilitate an overall GHG emission reduction, which is in line with the global carbon reduction goals of 45% reduction by 2030 and eventually reach net zero-emission in 2050.

Keywords: Sustainable road infrastructure; Operation and maintenance (O&M); Carbon emission; Routine maintenance; Malaysian road

Introduction

Sullivan et al. [1] define operations and maintenance (O&M) as the decisions and actions in controlling and upkeeping of property and equipment, which according to Akbiyikli and Eaton [2], the O&M phases of activities normally were extended between 30 to 40 years of the road lifecycle. The road operation is executed to ensure satisfactory road functions while maintenance is needed to retain road performance in its intended design [2, 3]. Previous studies identify that O&M's ability to contribute to sustainability of infrastructures, assets, and roads [4, 5] are significant. Proper and sufficient actions such as improving the road's service cycle,

reducing the maintenance works and extending the refurbishment cycle will elongate road service life [6].

Maintenance activities are programmed to ensure road functions and perform faultlessly during the service life tenures [8]. The road service standard is preserved by executing periodical preventive maintenance, treatment or corrective, and rehabilitation works [9–11]. Preventive maintenance comprises of scheduled and rigorous activities that require planning and precise execution [1, 2]. The maintenance activity should be applied when the pavement is still in decent condition to ensure road facilities are at their best performance [12, 13]. Corrective or responsive maintenance is initiated by a fault or trouble report, or when road performance tolerance is reached or violated [2, 14], while emergency maintenance starts when defects report, which requires immediate action, is received [2].

The commissioning of maintenance is commonly due when the performance of roads has deteriorated causing structure degradation which requires prompt actions that contribute to extra activities which create carbon emissions.[15, 16]. Preservation of ideal road performance is able to save the overall road life cycle cost [17–19]. A decent and appropriate maintenance treatment applied persistently contributes to road safety and ride comfort to the road users, ensures road performance is preserved throughout the service life cycle, improves road condition, and extends road lifespan before it reaches minimum acceptable performance [8], [14, 20]. Significantly, it is crucial to provide a proper channel to monitor the activities involved during O&M in order to manage the performance of carbon emissions based on the activities involved. Insufficient and non-consistent maintenance and rehabilitation works will lead to traffic congestion, accidents, time delays, and vehicle travel time [5, 21–23] and become a significant aspect of socio-economic and environmental impact hence contributing to carbon emissions increment.

Problem statement

According to the World Bank, in 2005 the transport sector accounts for nearly 14% of global greenhouse gas (GHG) emissions, whereby 72% are caused by road construction rehabilitation, maintenance, and usage [24]. In contrast, roadworks account for around 28% of global energy consumption and approximately 22% of global CO2 emissions. The emissions are mainly produced by material usage from raw materials mining, materials processing and transportation from the manufacturing enterprises to the construction site, and fuel consumption from construction machinery such as asphalt concrete mixing equipment, motor graders, tire rollers, and dump trucks [25].

The pavement or asphalt surface layer is an essential element in transportation infrastructures, and it consumes energy, which leads to GHG emission during pavement construction and operation [26, 27]. Although energy consumption is mainly associated with fossil fuel vehicles, pavement conditions, construction, and maintenance contribute as much carbon from emission materials consumption, equipment utilization, and traffic disruption [26]. Zainab et al. [28] summarize the uppermost carbon emissions from road pavement rehabilitation due to the material used for pavement and milling machines with high engine capacity. While according to Lizasoain-Arteaga, E. et al. [29], the result from the study on traffic delay from maintenance activities shows an 85% increment in carbon emissions that arises under heavily congested maintenance work zones.

As discussed earlier, the increase in road maintenance is partly due to the poor road condition, and in the study by Ruiz and Guevara [15], the generated CO_2 emissions and preservation of the road network are directly related to the road network condition. Chong and Wang [26] concur these in a study on the pavement lifecycle where factors affecting energy consumption and GHG emissions are attributed to a vehicle travelling on a rough pavement condition. Another study conducted by Schweikert et al. [30] focused on GHG emission increment due to increased road maintenance has confirmed the amplified GHG emissions.

Therefore, to ensure that road functions as it intended aims in providing satisfactory services to road users without compromising environmental effects, sustainable maintenance and rehabilitation policies are vital for promoting CO_2 emission reduction strategy [15]. Carbon emissions reduction is achieved by having exceptional commitments from the government, transport department, vehicle companies, and road users [31].

Purpose of the study

This study aims to determine the data availability for carbon sources and carbon emission measurement for non-tolled roads in the O&M phase. The study focuses on the carbon footprint measurements from routine maintenance activities of Federal and State roads from which an estimated reporting, based on activities, can be identified and a set of baselines can be achieved. The following are the objectives outlined to achieve the goal of this research:

1. To identify the sources of carbon emission during the road O&M activities;
2. To measure the performance of carbon emission from road O&M activities; and
3. To develop a carbon emission baseline based on maintenance works.

Research scope

This study focuses on operational non-tolled for Federal and State roads connecting states and districts maintained by the Public Works Department of Malaysia (PWD). The data were gathered from road maintenance concession companies responsible for maintaining roads in Northern, Central, Eastern, and Southern Peninsular Malaysia regions.

Methodology

Carbon capture survey

A carbon capture was based on the availability of survey which was gathered during the road maintenance activities. For this purpose, data were collected from 10 states involving 74 districts all over Peninsular Malaysia. Furthermore, 11 road maintenance companies were approached for the data capture and reporting. The companies represent the four regional areas assigned for Federal and State Road maintenance, including the Northern region, Central region, Southern region, and Eastern region. The survey was conducted by using the semi-structured interview. Selected respondents, based on the expertise and experience, were interviewed based on questionnaire survey form and routine maintenance activities involved. The survey was later analyzed using SPSS Statistics software to determine the average index value for overall data availability. For this study, if the average value is lower than 50%, the carbon source data can be neglected and removed from further analysis. In contrast, data with an average index value of more than 50% is considered significant [32] and employed for the subsequent procedure, focusing on the carbon emission measurement.

Carbon emission measurement

Table 1 Emission source from routine maintenance discovered from data availability survey

R01-Pothole Patching	Material - pavement production
	Fuel Usage – material delivery, types of machinery & equipment for patching works & waste disposal's transport
R02-Maintenance of Road Shoulder	Material - production
	Fuel Usage - types of machinery & equipment for works
R03-Grass Cutting	Fuel Usage - machinery for grass cutting work
R04-Maintenance of Road Furniture	Material - cleaning agent & water usage
	Fuel Usage - machinery & equipment for cleaning/repair works
R05-Maintenance of Bridges and Culverts	Fuel Usage - machinery & equipment for cleaning/repair works
R07-Drainage	Fuel Usage - types of machinery & equipment for cleaning/repair works
RI-Routine Inspection for Roads	Fuel Usage - the vehicle for inspections
Street Lighting/traffic lights *(data from PWD)*	Electrical usage - kWh consumed *(data from PWD)*
Office-Staff	Electrical usage - kWh Water - M^3 or gal. Paper/ - sheets or rim Fuel Usage - the vehicle for staff commuting
Overall	Carbon Emission Calculation & Reporting

Once, the activities were recorded, a standard measure of carbon emissions from routine maintenance activities were identified. Table 1 indicates the carbon sources identified from the survey, which include embodied carbon from material consumed, fuel consumption from material and waste transportation, fuel usage from machinery employed in maintenance works, vehicle fuel usage from routine inspection and staff commuting, energy usage from electricity, water, and paper usage in the office, and street lighting/traffic lights electricity consumption. The observation and recorded were then being reviewed. Later the emissions were calculated based on direct and indirect emissions from maintenance activities which were collected from previous survey.

Besides routine maintenance activities, the data captured were also based on the contribution of street lighting and traffic light. The total electricity in (kWh) were then computed based on total light's quantity multiplied by its power and total hours in operation per day as reflected in equation 1. For this study, all streetlights are assumed to have operated 12 hours per day while operations of traffic lights are 24 hours per day. The quantity and power of lights contribute to carbon emission computed by total tCO_2/kWh of electricity energy usage.

Following this, the measurement of carbon emission was accomplished by compiling data from all the emission sources before these data are analyzed using the formula specified by MyCarbon. The carbon measurement objective is to collect direct and indirect emissions (Scope 1, 2 & 3) released from routine maintenance activities, identify type and quantity of works, determine the type of equipment and machinery, and administer office's energy usage in everyday operations. The stages and steps involved in evaluating carbon emissions are listed below.

i. Define the assessment boundary - *Scope 1, 2 & 3;*
ii. Identify the emission source – *refer to Table 1 - Emission source from routine maintenance*;
iii. Data collection from the emission source;
iv. Selection of emission factor for different emissions source – *refer to Table 2;*
v. Calculation of carbon emission; and
vi. The general equation used in the emissions calculation, according to Olaguer [33] and MYCarbon [34], is as shown in Equation 1.

Actual or Estimated Activity Data	X	Emissions Factor	=	Total Carbon Emissions	(Equation 1)

The emission factor for the purpose of emission calculation is commonly influenced by local emission factors, whereas for this study, the emission factor published by MYCarbon [34] was utilized. However, customized emission factors from third-party emission factors and other published emission factors were manipulated to substitute default emission factors.

Table 2 Carbon emissions factor for total emission analysis

Scope	Activity	Emission Factors	Unit	Sources
Scope 1				
Oil Products	Motor Gasoline	0.002272	tCO_2/ litre	(MYCarbon,2014)
	Gas/Diesel Oil	0.002677	tCO_2/ litre	(MyCarbon,2014)
Fleet Vehicles	Medium Gasoline Automobiles	0.002328	tCO_2/ litre	(MyCarbon,2014)
	Diesel Automobiles	0.002682	tCO_2/ litre	(MyCarbon,2014)
	Gasoline Light Truck	0.002328	tCO_2/ litre	(MyCarbon,2014)
	Gasoline Heavy Truck	0.002328	tCO_2/ litre	(MyCarbon,2014)
	Diesel Light Truck	2.002682	tCO_2/ litre	(MyCarbon,2014)
	Diesel Heavy Truck	0.002682	tCO_2/ litre	(MyCarbon,2014)
	Light Motorcycle	9.34E-05	tCO_2/km	(MyCarbon,2014)
Scope 2				
Electricity Usage (Purchased Electricity)	Electricity	0.741	tCO_2/MWh	(MyCarbon,2014)
Scope 3				
Water Usage	Water	0.201	$kgCO_2/m^3$	(Shimizu, Dejima & Toyosada, 2012)
Stationeries	Paper	0.15	$kgCO_2$/kg	(ICE, 2008)
Embodied carbon	asphalt (road &pavement)	0.14	$kgCO_2$/kg	(ICE, 2008)
	soil	0.023	$kgCO_2$/kg	(ICE, 2008)
	stone gravel	0.017	$kgCO_2$/kg	(ICE, 2008)
Staff Commuting	Small Gasoline Automobiles	0.000189	tCO_2/km	(MyCarbon,2014)
	Light Motorcycle	9.34E-05	tCO_2/km	(MyCarbon,2014)
	Diesel Automobiles	0.002682	tCO_2/litre	(MyCarbon,2014)

Results and discussion

Carbon capture and measurement survey analysis

The carbon capture and measurement were identified through the road maintenance routine activities. The routine maintenance activities were based on pre-determined schedule, type of work, and consistent work procedure, which provide a consistency of works and the data collection time frame. The routine maintenance activities include Pavement, Maintenance of Road Shoulder, Grass Cutting, Maintenance of Road Furniture, Maintenance of Bridges and Culverts, Drainage, Landscaping, and Routine Inspection for Roads. Periodical and Preventive Maintenance (PPM), and Emergency Works were excluded in the study due to the inconsistency of data availability and unscheduled works during the study.

The survey results were analyzed using SPSS Statistics software to determine the average index value for overall data availability. For this study, data collected from the survey was analyzed by type of machinery or equipment, type of material and quantity, fuel consumption, and other energy usages from routine maintenance scope. Referring to Figure 1, carbon source data with an average index value of more than 0.50 is employed for the subsequent carbon emission measurement procedure. This shows that the practicality of the activities were significant for the purpose of data analysis. Based on the overall analysis, ten (10) carbon source data from Table 3 with an average value lower than 0.50 are neglected and removed from further analysis.

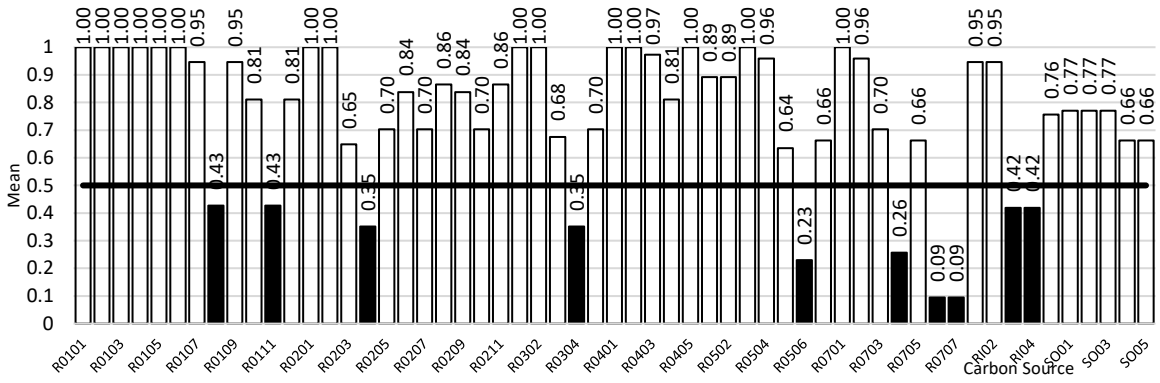

Fig. 1. Carbon source data availability analysis result by the mean score based on the federal and state road activities

Table 3 Carbon source data excluded from data collection

Routine Maintenance Scope	Code	Carbon sources	Mean	Remarks
R01 - Pothole Patching	R0108	Asphalt Waste-Type material & Quantity	.43	The possibilities of carbon emission data available for measurement are below average.
	R0111	Sealing-Type material	.43	
RO2 - Maintenance of Road Shoulder	R0204	Vegetation Waste-Type material & Quantity	.35	
RO3 - Grass Cutting	R0304	Grass Waste -Type material & Quantity	.35	
RO5 - Maintenance of Bridges & Culverts	R0506	Bridge Veg. Waste-Type material & Quantity	.23	
RO7 - Drainage	R0704	Drain Waste-Type material & Quantity	.26	
	R0706	Drain Repair-Type of machinery	.09	
	R0707	Drain Repair--Average Fuel	.09	
RI - Routine Inspection for Roads	RI03	Report submission-Type of machinery	.42	
	RI04	Report submission--Average Fuel	.42	

Carbon emission measurement for Federal and State Road activities

The data collected from 74 districts and total emissions for the full routine maintenance cycle in a year from every district are reflected in Figure 2. Considering the data are based on raw data collected from road maintenance companies and computed using carbon emission calculation, the reliability of data is subject to the data integrity obtained from the companies. As stated in Figure 2, the top four highest annual carbon emissions originated from Pahang districts with 3391 tCO_2, 3686 tCO_2, 2917 tCO_2, and 3869 tCO_2 for Jerantut, Kuantan, Lipis, and Maran district, respectively, whereas the lowest emission are contributed by Sabak Bernam district (142 tCO_2), Timur Laut district (135 tCO_2), Alor Setar district (90 tCO_2), and Marang district (9 tCO_2).

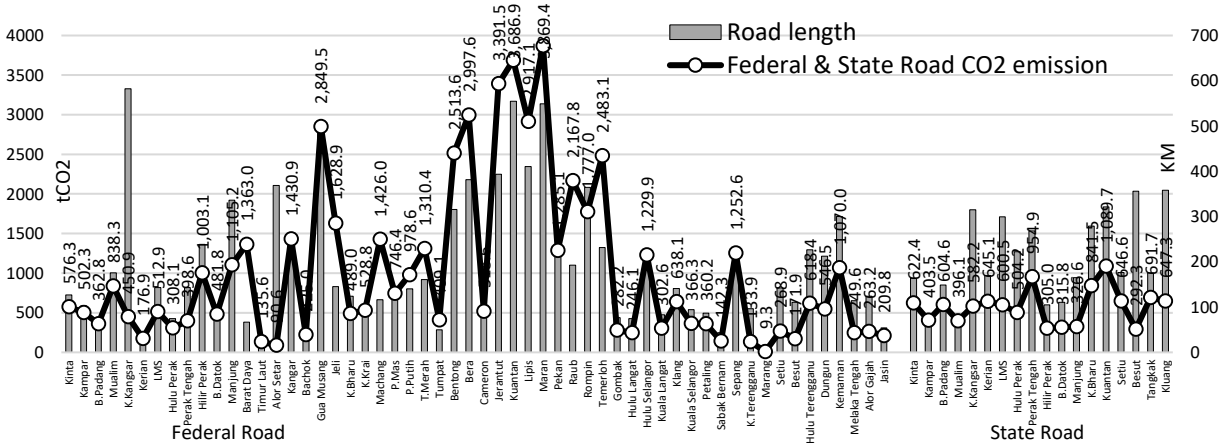

Fig. 2. Total CO_2 emission from Federal and State Road by districts vs. road length

Figure 3 shows the total CO_2 emission and total road length. The annual emissions for Pahang districts show the highest carbon emitter with a total of 27,607 tCO_2 in the year 2019. It is to be noted that the O&M were maintained by Roadcare Pahang, and the contributions of the emission were the longest among other road maintenance companies. Kuala Kangsar and Alor Setar have insignificant CO_2 emissions due to the O&M having the least activities.

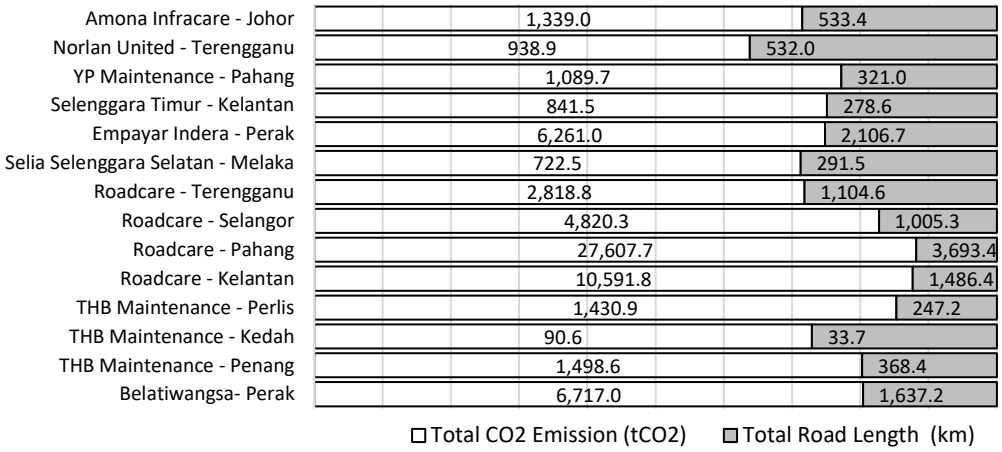

Fig. 3. Total CO_2 emission and total road length by road maintenance companies

The average carbon emission measured from seven (7) routine maintenance activities, including energy used by the administration office and staff per day, is reflected in Figure 4, where carbon emission was calculated from a single day's work. As for Office and Staff, the monthly emission data collected are divided by monthly working days for an average daily emission. Figure 5 depicts the average carbon emission from a full routine maintenance cycle in a year. The analysis is essential to demarcate emissions from routine maintenance with different cycles per year. For example, in Figure 4, RO2-Maintenance of road shoulder shows a significant amount of carbon emission for a single day's work; however, the work only occurred at one cycle/year. The annual emission is among the lowest from that of other works. On the contrary, RO3-Grass cutting works contribute a lower daily carbon emission; however, due to its 12 cycle/year or monthly recurrence, the annual emission is the highest with an average of 571.892 tCO_2/year for Federal roads and 162.761 tCO_2/year for State roads (2nd highest).

This study aims to observe and determine the amount of emission from the road maintenance in various states with different road categories and lengths. Therefore, to enhance carbon emission measurement data accuracy, average carbon emission per kilometer road length is analyzed as stipulated in Figure 6. According to federal and state roads category, these average emission values were employed for computation of carbon emission, which eventually accounted for the total carbon emission for road O&M.

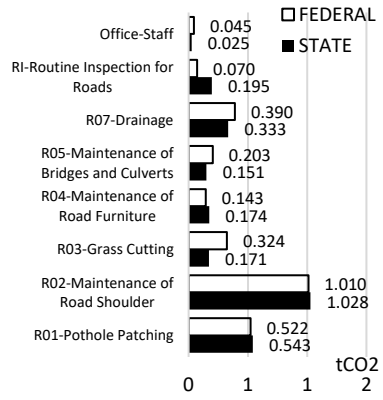

Fig. 4. Average CO_2 emission (tCO_2) per day by works

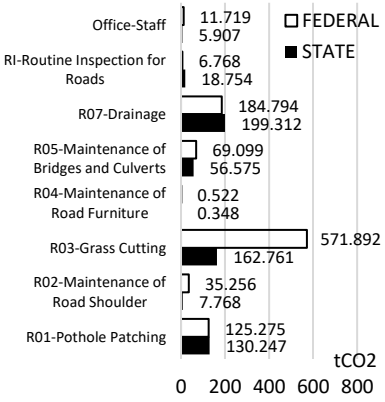

Fig. 5. Average CO_2 emission (tCO_2) per year by works

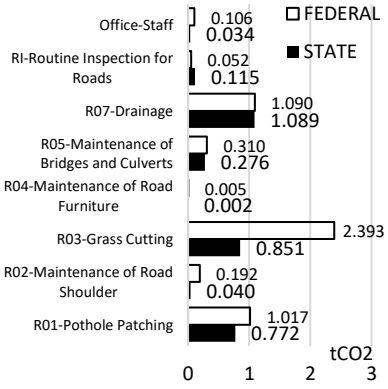

Fig. 6. Average CO_2 emission (tCO_2) per year per km by works

From the electricity consumption of Scope 2, as reflected in Figure 7 and Figure 8 the contribution of carbon emissions were also based on street lighting and traffic light. Figure 8 shows the overall quantity of lights according to lights power (watts) (data for Federal Road only), indicating 250W light as the most common streetlights and the type utilized in the country, while for the traffic light, the 18W LED lights are commonly utilized. Except for traffic lights, LED usage for street lighting is still minimal, where the usage is merely 2.7% from overall lights type. In addition, Melaka has the most streetlights with an average of 142 lights/km of road, while Terengganu has the lowest lights per km of road with 38 lights/km. The quantity and power of lights contribute to carbon emission computed by total tCO_2/KWh of electricity energy usage.

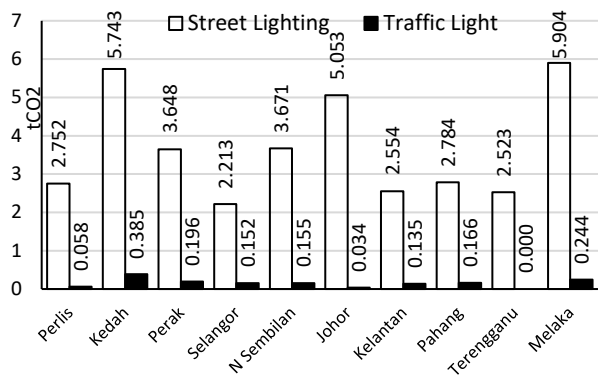

Fig. 7. Total CO_2 emission (tCO_2) per month per km by States

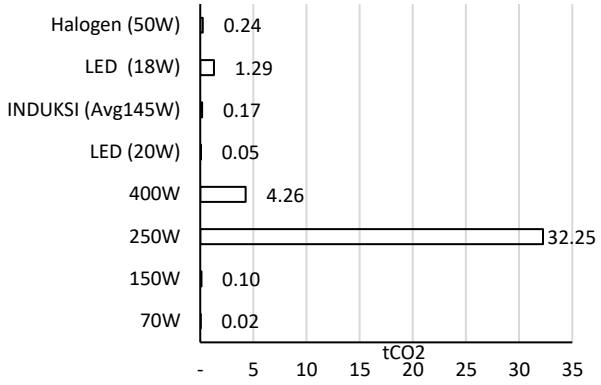

Fig. 8. Total CO_2 emission (tCO_2) per month per km by lighting power

Conclusions

The findings suggested that the total carbon emission identified for each carbon source is essential in promoting future carbon emission reduction strategies from road O&M activities, in turn support the climate change reduction efforts. The average carbon emission per km of road length from O&M, streetlights, and traffic lights were compiled and consolidated as baseline tCO_2/km values for Federal and State Road according to states in Malaysia.

Referring to the emission values, the estimated total carbon emission from road O&M contributed to 1.211 $MtCO_2$, which is 0.53% of the overall Malaysia's total emission of 226.8 $MtCO_2$ (data for 2018), while for total emission per capita, road O&M contributed 0.038 tCO_2/capita from a total of 7.2 tCO_2/capita (data for 2018). The knowledge on emission source and its contribution to the country's total carbon emission is essential in promoting carbon emission reduction strategy, aligned with the global carbon reduction goals of 45% reduction by 2030 and eventually reaching the net zero-emission in 2050. The findings highlight the impact that carbon emission from road O&M activities has on the national carbon footprint. The sources of carbon emission identified in this study can be useful in formulating strategies for future GHG emission reduction.

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A Case Study for the Implementation of Material Test Plan for Assessment of Concrete Structure Defects

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Abstract

The steel reinforcement in concrete is protected from corrosion by thin passive film which is automatically formed on the surface of reinforcement due to high alkalinity in concrete. Corrosion will initiate when the passive film is destroyed and subsequently causing delamination and spalling to the concrete cover. This paper presents the implementation of Material Test Plan (MTP) for assessment of school buildings in Sabah which was reported to have experienced structural damage. From the visual inspection, most of the structures are suffering from some material degradation as a result of delamination and spalling of the concrete. No sign of structural distress was found at the main structural elements such as beams, columns and slabs. MTP is a test plan to investigate the characteristics and to ascertain the condition of the reported damaged structures. The tests that have been done for the MTP of those buildings are Covermeter Survey, Concrete Coring Test, In-Situ Carbonation Test, Chloride Content Test, Half-Cell Potential Measurement, Concrete Hacking and Petrography Examination. The defects observed are general material deterioration from corrosion. Concrete deterioration of structure in this exercise is due to the high free water cement ratio which allows the ingress of carbon dioxide into the concrete structure and neutralized the highly alkaline condition of the concrete cover which protects the reinforcement. Furthermore, seashells were observed in some concrete structure elements showing that chloride ion has likely induced the steel corrosions but not extensive. The MTP provides the factual evidence for formulating repairs of the damaged reinforced concrete.

Keywords: Concrete spalling; Delamination; Concrete deterioration; Chloride induced corrosion; Concrete coring; Carbonation; Chloride content; half-cell potential; Petrography; Seashells in concrete

Introduction

This paper presents a case study of material testing on deteriorated building due to reinforcement corrosion resulting in delamination and spalling of concrete. In this study, the causes of defects were presented based on Material Test Plan that were carried out. The purpose of the assessment of Material Test Plan is to collect testing results of existing structural members including result analysis and subsequently to propose suitable repair method and strategies for extending the service life for those building.

Reinforced concrete has been widely used as the main material in construction and the major reason is because of the exceptional durability of the material. Deterioration in concrete can be caused by many reasons such as material limitations, design and construction practices, and

severe exposure conditions. The concrete deterioration may also result in aesthetic, functional, or structural problems.

Generally, concrete provides an ideal protective environment to reinforcement from corrosion. Thin passive film of ferric-oxide (**Fe2O3**) is automatically formed on the surface of reinforcement due to high alkalinity in concrete. This layer, though is thin, effectively protects the reinforcement from corrosion. But unfortunately, this layer is effective only if the surrounding remains alkaline. Therefore, if we can manage to keep the alkaline environment, the corrosion of reinforcement can be prevented effectively, and the durability of the structure can be ensured. The alkaline medium can be maintained for a longer period by making the concrete impermeable [1]. Corrosion of embedded metals in concrete can be greatly reduced by placing crack-free concrete with low permeability and sufficient concrete cover [2]. According to clause 3.11.2 in CP110-1:1972, cover to reinforcement should be determined by considerations of fire resistance and durability under the envisaged conditions of exposure. The lowest nominal concrete cover for mild condition of exposure is 15 mm for concrete grade 30 and above as set by CP110-1:1972 [3]. To compare with BS 8110-1: 1985, the lowest nominal concrete cover for mild condition of exposure is 20 mm for concrete grade C35 and above [4].

Structure Description

The building is approximately a kilometer distance from the sea. The building has been used for school usage. It consists of two (2) blocks of two (2)-storey building. The building structure is a typical reinforced concrete (RC) frame. The roof consisted of roof truss and covered with metal roofing sheet. The building was completed in 1994 and although BS8110 replaced CP110 in 1985, it was assumed that this building was designed using CP110 Part 1 which was produced in 1972 taking into account of late adoption of BS8110 at that time.

Visual Inspection

Based on the visual inspection, the school building has shown severe indication of material deterioration on concrete structures. No sign of structural distress was found at the main structural elements such as beams, columns and slabs. There was a pattern of delamination and spalling on concrete which is normally caused by corrosion of reinforcement. The defects were identified at several locations of reinforced concrete members and the worse affected area was at 2nd floor columns of the building. During several detailed inspections on the structural elements, it was observed that there were seashells in the concrete as shown in Figure 1. Preliminary assumption was that the school building structure might have used sea sand in the concrete mixture during construction phase. Besides that, the overall of the building was also exposed to the sea environment which may contribute to the defects of the building.

Fig. 1. Spalling and delamination at the 2nd Floor columns. Seashell was observed in the concrete.

Subsequently from the visual inspections, further tests have been identified and implemented to confirm the cause of corrosion of the steel reinforcement in the school building. From the test results and based on the BS EN 1504-9, rectification works can be recommended [5]. Based on the assessment and condition of the structure, a few recommendations, which refer to BS EN 1504 – 9:2008, shall be considered.

Material Test Plan

Material Test Plan (MTP) is a test plan to investigate the characteristics and to ascertain the condition of the reported damaged structures. The test for reinforced concrete can be carried out by two (2) methods: destructive test (DT) and non-destructive test (NDT). In this context, the crushing of the samples is the usual DT to determine the RC properties. On the other hand, NDT can be defined as a test method used to determine the properties of concrete used in the actual structures [6]. For this study, tests that have been conducted for the building are Covermeter Survey, Concrete Coring Test, In-Situ Carbonation Test, Chloride Content Test, Half-Cell Potential Measurement, Concrete Hacking and Petrography Examination.

Covermeter Survey

The Covermeter uses electromagnetic field generated by the battery-powered search head to detect the location and size of reinforcement embedded in the concrete. When a reinforcing bar lies within the generated electromagnetic field, the lines of force become distorted. The disturbance caused by the presence of the metal in turn produces a local change in field strength as detected by the search head and indicated by the meter.

Concrete Coring Test

Basically, concrete coring test is a process of extracting concrete core sample for compression testing. The test was carried out by cutting cylindrical core from the concrete slab, beam and column by using 100 mm diameter diamond-tipped drill. The extracted core samples are then photographed, sketched and recorded. The presence of reinforcement bar, voids, seashells and thickness are recorded and marked on the drawing reference. The core was tested in compression to obtain the core compressive strength.

In-Situ Carbonation Test

Carbonation test is conducted by using the acid/base indicator phenolphthalein. The phenolpthalein indicator solution method is the basis of almost all carbonation studies,

especially due to its usefulness in field tests [7]. The purpose of the carbonation test is to determine the depth of carbonated concrete that has a pH value of approximately below 9. As a result of the penetration of atmospheric carbon dioxide into the concrete, carbon dioxide dissolve in concrete pore water and starts to neutralize the natural alkalinity of the concrete. Once the pH value of the concrete around the steel bar falls below 9, the concrete layer wrapping around the steel bars loses its protective ability against corrosion. The sound concrete will make the solution turns into purple color when sprayed with the phenolphthalein solution. However, the solution will remain colorless if the concrete is carbonated. The carbonation test is often carried out on fresh concrete-cores or on the concrete substrate exposed by hacking or drilling as shown in Figure 2. This is a qualitative test for concrete and not a quantitative test therefore, only the depth of carbonation can be determined but not the degree of carbonation.

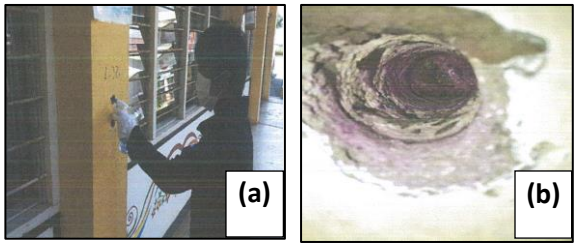

Fig. 2. Drilled hole in a column (a) is sprayed with phenolphthalein (b) for in situ Carbonation Test.

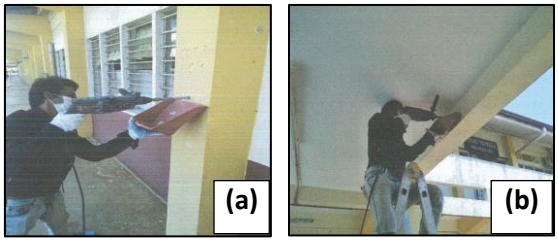

Fig. 3. Concrete dust sampling by drilling concrete column (a) and beam (b) to a certain depth for Chloride Content Test.

Chloride Content Test

Whenever there is chloride in the concrete there is an increased risk in corrosion of the embedded reinforcement. Chlorides promote the corrosion process by forming alternative anodic and cathodic region within the reinforcements. Chloride may also adversely affect the sulphate resistance of concrete. Constituents of concrete may be contaminated with chloride salts, e.g., in the aggregate or admixture. For this case, it was assumed that in the past, sea sand was used in the mixing of concrete and therefore, the chloride content of the concrete should be investigated to ascertain its influence on the deterioration process. Sampling for chloride content is conducted by taking dust sample from concrete specimen by drilling to a certain depth as shown in Figure 3. These concrete dust sample is then tested in the laboratory to determine the chloride content. Looking back into CP110-1:1972, the limit of chloride content in reinforced concrete as expressed in percentage relationship between chloride ion and weight of cement in the mix is 0.35%. As for comparison to MS EN 206: 2016 which adopts the BS EN 206, the chloride content of a concrete, expressed in percentage of chloride ions by mass of cement, shall not exceed the value for the selected class given, which is 0.4% [8].

Half-Cell Potential Measurement

The Half-Cell Potential test was carried out to identify the probability of reinforcement bar corrosion in reinforced concrete. This test is used when visual inspection is unable to justify the condition of the embedded steel reinforcement and hacking is to be avoided. For this test to be carried out, a small hole is required to be hacked or drilled in the concrete to expose a small section of the reinforcement bar that provides a physical connection between the reinforcement bar which forms part of the grid intended for the testing and one terminal of the half-cell. The other terminal, which constitute a wetted sponge, will come into contact with the concrete surface. Concrete which is porous material will absorb the moisture from the sponge

hence providing a path for electrical conductivity. The test is conducted by measuring the concrete surface electrical potentials relative to a standard reference electrode on a pre-determined grid. Figure 4 shows marked grid on a concrete surface and positioning of terminal which is wetted with sponge. Its principal of the Copper/ Copper Sulphate Electrode (CSE) measurement technique is described in ASTM C876-15 [9]. Table 1 gives the interpretation of the half-cell readings to the possible conditions of the reinforcement bar.

Fig. 4. The potential readings is recorded at every location on marked grid on (a) the sides of column and (b) on the sides of beam.

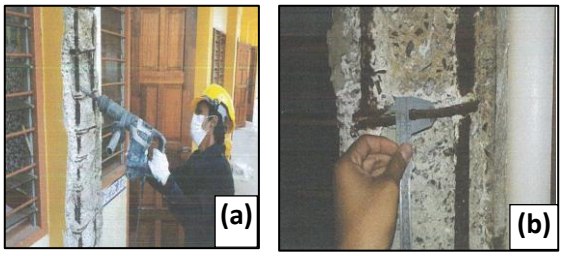

Fig. 5. Concrete column is being hacked (a) to expose reinforcement bar for measurement (b).

According to The Concrete Society [10], corrosion can only be identified with a 95% certainty at potentials less than -350mV. It is recommended that this test be used in conjunction with results from chloride content test, Covermeter survey and carbonation test. Reinforcement in concrete is generally protected from corrosion by the development of a stable oxide film on its surface. This film is formed by the chemical reaction between highly alkaline concrete pore water and the reinforcement. Corrosion is negligible until the protective layer is attacked by chloride ions. Corrosion of reinforcement bar is an electrolytic process, which needs moisture and oxygen in the concrete. Corrosion stops when the concrete does not contain enough moisture or oxygen. Corrosion damage is primarily confined to areas suffered from moisture intrusion into the concrete elements. In areas that are dry, or the concrete is of less porous or protected by painting, there will be little or no sign of corrosion damage.

Concrete hacking

Some area of the RC structural elements was broken up/hacked to expose the rebar for inspection. Sometimes this method is also called verification of reinforcement bar. This is carried out by measuring the actual reinforcement size together with its quantity and condition (Figure 5). The information gathered may be used for confirmation matching to the existing drawing details and/or for further design capacity checking. The hacked area is then patched back using shrinkage compensated repair mortar.

Petrographic Examination

The major applications of petrography are in characterization, quality assurance, evaluation and failure investigation of construction materials. Since proper diagnosis drawing up to proper repair plan, petrography is gaining a noteworthy recognition in the concrete repair industry. The petrography examination was carried out on samples in accordance with ASTM C856-14 which includes the type and general properties of raw material such as cement and aggregate used, homogeneity of mixing, micro structure and potential durability of the concrete samples [11]. Concrete samples are obtained by drilling cores from concrete under investigation (see Figure 6).

a. Visual Inspection

This was performed to obtain a first impression of the homogeneity of the concrete samples and its constituents to look for symptoms of damage and secondary reaction and to select an area on the sample for preparation of ground and polished thin section.

b. Microscopic analysis

The microscopic analysis was performed on a ground section using a stereo microscope and on a thin section with a Polarizing and Fluorescent Microscope (PFM) under transmitted and reflected light. For preparation of a thin section, a small block of the sample was cut and ground to attain a smooth finish. The preparation of a thin section, a small concrete block was sawn from the core sample, glued to an object glass and impregnated with an epoxy resin containing a fluorescent dye. After hardening of the epoxy, a thin section with a surface area of approximately 33 x 63mm and a thickness of 20-30 µm was prepared for PFM analysis. Through examination of the ground section, assessment was made on the homogeneity of the concrete, compaction and types and distribution of large particles. Under transmitted light, the various components (type of cement and aggregate), air voids content, compaction pores and damage phenomena in the samples were identified. Under reflected light, the fluorescent microscopy made it possible to study the homogeneity of the mix and the cement paste, capillary porosity, micro-cracks and other defects in the samples. It is also possible to estimate the water cement ratio from the capillary pores using standard reference thin sections based on Nordtest method NT Build 361 [12].

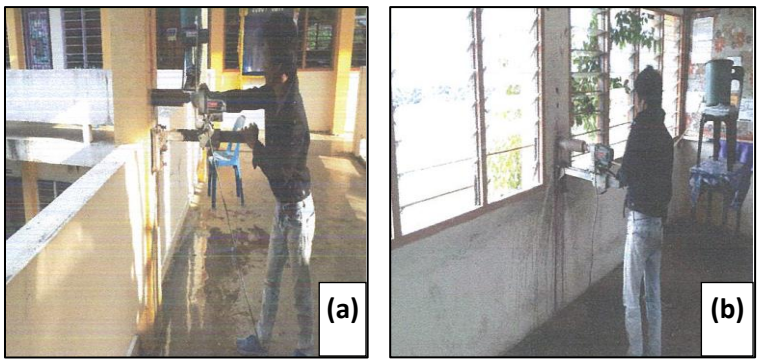

Fig. 6. Obtaining concrete cored sample by core drilling on column at corridor (a) and at classroom (b).

Results and Discussion

Covermeter survey was conducted on eight (8) locations throughout the building to check the rebar spacing and concrete cover and results are summarized in Table 1. The Covermeter survey results yielded that most of the concrete covers are with sufficient thickness except for certain soffits of the slab and beams. Covermeter and hacking survey indicates that concrete maximum cover does have significance in preventing the structures from being defective. Insufficient concrete cover can lead to the occurrence of corrosion in steel reinforcement thus, decreasing the service life of the structure. Ten locations were tested for carbonation depth. The carbonation depth varies between 5 and 60 mm. Meanwhile, screed thickness varies between 10 and 20 mm. The carbonation depth is inclusive of screed thickness. For chloride content test, the chloride content percentage is between 0.08 and 0.72%. Three of the column samples chloride content exceeded the 0.4% limit stated in Table 15, BS EN 206:2013 and if

reference is made to CP110-1:1972, this result also exceeded the 0.35% limit. One sample for 1st floor column and two samples for 2nd floor column were found to contain high chloride content. No chloride content was detected on ground floor column. The findings from carbonation test and chloride content test shown in Table 2 and Table 3 respectively provide possible links between both which works in tandem with the destruction of the concrete passivity and the attack on the reinforcement bar once moisture entered the concrete infill. It is notable that the concrete quality deteriorates or worsen at higher level of the structure.

Table 1 Summary of Covermeter Survey.

No. of Tests	Floor	Structural Member	Concrete Cover (mm)		Bar Spacing (mm)	
			Min	Max	Min	Max
VSR1	2nd	Top Slab	85	95	250	290
VSR1	2nd	Soffit Slab	25	35	220	300
VSR2	2nd	Beam	11	95	170	300
VSR3	1st	Column	65	-	110	130
VSR4	2nd	Column	75	-	100	140
VSR5	2nd	Top Slab	75	85	190	275
VSR5	2nd	Soffit Slab	30	40	125	130
VSR6	2nd	Beam	40	90	105	200

**VSR denotes as Verification of Steel Reinforcement.*

Table 2 Summary for In-Situ Carbonation Test Results.

No. of Tests	Floor	Structural Member	Carbonation Depth (mm)	Screed Thickness (mm)
ISC1	Grd	Column	35	15
ISC2	Grd	Column	60	15
ISC3	Grd	Column	14	20
ISC4	Grd	Column	38	20
ISC5	1st	Column	20	15
ISC6	1st	Column	5	10
ISC7	1st	Column	37	15
ISC8	1st	Column	40	15
ISC9	2nd	Column	40	13
ISC10	2nd	Column	15	13

**ISC denotes as In Situ Carbonation*.

Structural member hacking was carried out to six (6) locations. The rebar size and condition were exposed by hacking at selected locations using hand-held breaker. Table 4 shows the summary of locations and details of the exposed bars. For concrete hacking works, reinforcement bar size and spacing were recorded. The condition of reinforcement bars for soffit slab, soffit beam and column were found to be corroded.

Half-cell potential measurement test recorded corrosion probability of 5 to 95% probability as shown in Table 5. All the exposed reinforcement bars show signs of corrosion in structural members as indicated by the half cell test results. The half-cell test indicates that there is a possibility that the degradation and corrosion of the reinforcement bar is not significant on both defective and non-defective structural members.

The summation of the findings highlights the possibility that reinforcement corrosion has been independent regardless of the exposure and defective condition and will experience high corrosion potential at areas affected by the diffusion of chloride. Nevertheless, in term of location factor, high probability of reinforcement corrosion is observed on the upper and outer side of the building rather than inside the building which suggests of possible atmospheric corrosion.

Table 3 Summary of Chloride Content Results.

No. of Test	Floor	Structural Member	Chloride Content (% by weight of cement content)
CCT 1	Grd	Column	0.08
CCT 2	Grd	Column	0.16
CCT 3	Grd	Column	0.24
CCT 4	Grd	Column	0.24
CCT 5	1st	Column	0.08
CCT 6	1st	Column	0.08
CCT 7	1st	Column	0.24
CCT 8	1st	Column	0.64
CCT 9	2nd	Column	0.72
CCT 10	2nd	Column	0.4

**CCT denotes as Chloride Content Test.*

Table 4 Summary of Structural Member Hacking Results.

No. of Tests	Floor	Structural Member	Rebar Size	Link Size	Bar Condition
VSR1	2nd	Top Slab	R6	-	No corrosion
VSR1	2nd	Soffit Slab	R10	-	Corroded
VSR2	2nd	Beam	Y16	R10	No corrosion
VSR2	2nd	Beam	Y22	R19	Corroded
VSR3	1st	Column	Y22	R10	Corroded
VSR4	2nd	Column	Y21	R10	Corroded
VSR5	2nd	Top Slab	R10	-	No corrosion
VSR5	2nd	Soffit Slab	R10	-	Corroded
VSR6	2nd	Beam	Y16	R9	No corrosion
VSR6	2nd	Beam	Y22	R9	Corroded

**VSR denotes as Verification of Steel Reinforcement.*

Table 5 Summary of Half-Cell Potential Meter Survey Results.

No. of Test	Floor	Structural Member	Corrosion Probability (%)
HC 1	Ground Floor	Column	5
HC 2	1st Floor	Beam	50
HC 3	1st Floor	Beam	50
HC 4	1st Floor	Column	95
HC 5	2nd Floor	Slab	5
HC 6	2nd Floor	Beam	5
HC 7	1st Floor	Column	5
HC 8	2nd Floor	Slab	5
HC 9	2nd Floor	Column	95
HC 10	Roof Floor	Beam	5

**HC denotes as Half Cell Potential Meter.*

Three samples were carried out for the Petrography Examinations which were extracted from ground, first and second floor column members. Figure 8 shows the cored samples marked with CCT1, CCT6 and CCT10 corresponding to the structural members in Table 3. The results were divided into two sections, visual inspection and microscopic analysis. Table 6 shows the summarized findings from the three samples.

Table 6 Summarized findings on visual inspection and microscopic analysis from sample CCT1, CCT6 and CCT10.

Visual Inspection	Microscopic Analysis
The colour of the cement paste was observed to be earthly to greyish colour;	The cement used for the concrete is observed to be ordinary Portland Cement without any mineral additive recognized;
The coarse aggregate size ranging from 10 to 30 mm with dominant size of 20mm;	The coarse aggregate is made up of arenaceous material of granite rock;
The coarse aggregate shape was some angular to sub angular;	The fine aggregate is mainly consisting of fine quartz, sub angular to sub rounded shape, showing undulatory extinction in cross polarized light;
The fine aggregate was made up of siliceous materials;	The amount of entrapped and compaction air voids is low;
The bonding between cement pastes of the concrete to aggregate was found to be good.	The estimation of apparent water cement ratio is estimated to be within the range of 0.65 to 0.7 when compared to the standard thin sections;
	No crack is observed within the cement paste of the prepared thin section;
	No sign of secondary reaction is recognized using the prepared thin section.

Fig. 7. Photograph showing the side view of three samples marked as CCT1, CCT6 and CCT10. CCT for Petrography samples denotes as Concrete Core Test.

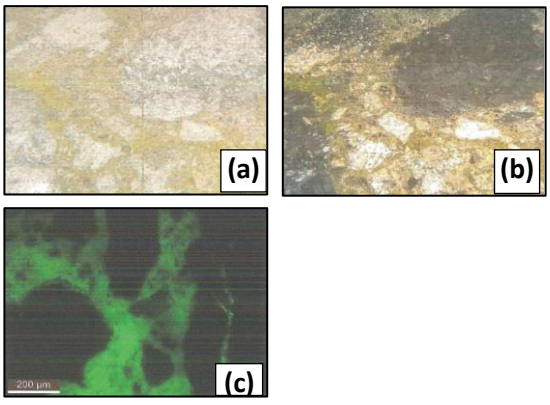

Fig. 8. Microscopic photograph on prepared thin sections for CCT 1 in plane polarized light (a), cross polarized light (b) and in fluorescent light (c).

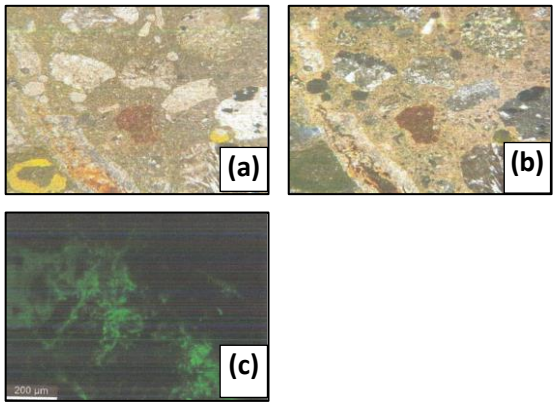

Fig. 9. Microscopic photograph on prepared thin sections for CCT 6 in plane polarized light (a), cross polarized light (b) and in fluorescent light (c).

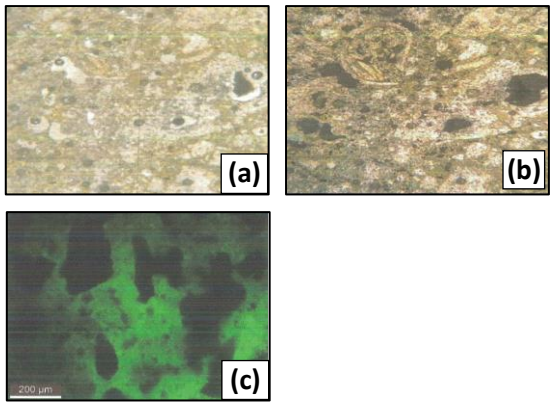

Fig. 10. Microscopic photograph on prepared thin sections for CCT 10 in plane polarized light (a), cross polarized light (b) and in fluorescent light (c).

Figure 8 to Figure 10 show the microscopic photograph on prepared thin sections for CCT1, CCT6 and CCT10 samples. The cement used for examined samples is observed to be ordinary Portland cement without any mineral additive discerned, with good dispersion and high degree of hydration within the observed cement paste. Under the fluorescence microscopy, the micro-homogeneity of the paste is showing some good homogeneity, and the estimated apparent water cement ratio is found to be higher than 0.65 in both cases when compared to that of the standard thin section.

The coarse aggregate in examined samples is found to be made up of granite rock material, with low traces of weathering discerned. However, the grading of the coarse aggregate particularly in one sample is found to be non-uniform. No sign of formation of ettringite crystal is observed within the prepared thin section, with no sign of cracking within the cement paste is discerned. As such, the examined sample are found without any sign of Delayed Ettringite Formation (DEF).

Conclusions

Reinforcement corrosion

The defects observed are general material deterioration from corrosion. Concrete deterioration of structure in this exercise is due to the presence of high free water cement ratio in the concrete. The concrete is deemed to be considered highly permeable which allows the ingress of carbon dioxide into the concrete structure which then neutralized the highly alkaline condition of the concrete cover that protects the reinforcement. Furthermore, seashells were observed in some concrete structural elements suggesting the likelihood of chloride induced corrosion but not extensive.

Remedial and Recommendation

Damaged reinforcement should be compensated, damaged concrete replaced with concrete repair mortars and carbonated areas can be coated with anti-carbonation coating. Choices of repair and/or rehabilitation methods based on Table 1 in BS EN 1504-9 can be deployed. Suitable methods are based on Principals 1: Protection againts ingress, Principal 2: Moisture

control, Principal 3: Replacement of damaged concrete, and Principal 7: Restoring Reinforcement Passivity.

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Enhancing the Building Condition Assessment (BCA) Methodology with Fuzzy Inference Techniques

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Abstract

Building Condition Assessment (BCA) is an integrated comprehensive building asset management approach to evaluate the government's building performance used by the Public Works Department of Malaysia. In conventional BCA, the matrix analysis is used to identify the maintenance priority action. This approach is simple but it suffers from several weaknesses. In an attempt to overcome the weakness associated with the traditional matrix analysis, fuzzy inference technique for BCA matrix analysis is investigated in this paper. A Fuzzy-BCA approach is described, and its performance is evaluated using a case study relating to an office building in Wilayah Persekutuan Labuan. The difference in priority number resulted between conventional BCA and Fuzzy-BCA is in the range of 10 % to 15%. The proposed techniques for the BCA analysis will help engineer to provide a more detail action plan for project take off. For future study, more experts should be involved to obtain more accurate results.

Keywords: Building condition assessment; Defect building; Fuzzy approach; Matrix analysis; Maintenance priority action

Introduction

In line with *Pekeliling Am Bilangan 1 Tahun 2009 dated 27 Mac 2009*, Public Works Department of Malaysia (JKR) has implemented the asset management to ensure that existing government's buildings are maintained systematically and holistically in order to achieve optimal asset benefits. Building Condition Assessment (BCA) by JKR was launched and implemented which consists of guideline and building condition check forms and building assessment rating system. Rating for physical condition of buildings will contribute to one of the requirements in Performance Rating (Building Performance Assessment) as a whole as required in *Aset Tak Alih Kerajaan* (TPATA) [1, 3]. BCA is conducted by identifying defects of the buildings through visual inspection work, rate the building condition and propose review by expert judgment and reporting.

Aim and Objective

Time, cost, quality and safety are the core factors to look at when conducting project management. Among the key challenges of building maintenance project to kick-off is implementation budget. Nothing can move forward without adequate budget. The budget available limits the scope of work, type of the used resources and project duration. Thus, only priority and urgent scope of works will be chosen with limited budget provided. In conventional BCA, the matrix analysis is used to identify the maintenance priority action. This approach is simple but it suffers from several weaknesses such as hard to prioritize the work with the same

result of matrix analysis. The main aim of this study is to introduce an inference technique for BCA matrix analysis with detailed score rating system. The focus is on improving the result of building analysis, choosing the most severe scope of works and prioritize the scope of works based on the priority number.

Importance and Significance of the Study

A successful Fuzzy-BCA approach implementation provides useful guidance to identify the ranking of scope of in maintenance work by Fuzzy Priority Number (FRP) model. This paper contributes toward a new and improved Fuzzy-BCA methodology for tackling the new inspection scale and maintenance action scale. The framework of Fuzzy-BCA is more preferred to the conventional BCA because it allows customization of the Post Model Analysis (PMA) model based on expert's knowledge provided in the form of fuzzy "IF-THEN" rules [4]. Fuzzy-BCA helps to support decision making in achieving the service standard for building maintenance.

Methodology

BCA is performed in several steps. The first step is describing the inspected building component on which BCA is conducted. Once all the building components are obtained, building physical condition level rating and maintenance action rating are assigned to the component to reflect the priority number.

Table 1 Building Physical Condition Level [2]

Grade	Scale	Description
1	Very Good	As New, No Defect, Performing as intended
2	Good	Minor defect, good condition, performing as intended
3	Fair	Major defect, moderate condition, still can function with supervision
4	Poor	Major or minor defect, critical, not functioning as agreed service level
5	Very Poor	• Major or minor defect, critical, not functioning as agreed service level • Very critical, not functioning, risky to safety and health

Table 2 Maintenance Action [2]

Grade	Inspection Scale	Description
1	Normal	No defect or damages element/ component well maintained
2	Routine	Minor defects/ damages, Needs for monitoring, repairs, replaced to prevent serious defect/ damages
3	Repairs	Major defects/ damages, need for major repairs and replacement
4	Rehabilitation	Critical/ serious defects/ damages, needs for urgent and immediate repairs
5	Replacement	Critical/ serious defects/ damages, needs for urgent replacement, refer to expert detail inspection/ expert judgement

The rating scale for the building physical condition and maintenance action are shown in Table 1 and Table 2 respectively. The two ratings are quantified by integer values ranging from 1 to 5 and then multiplied together to obtain the priority number which is then used to determine the repair priority of the defects.

The proposed new rating scale for building condition physical condition level and maintenance action were designed based on the conventional BCA rating with expert judgment as shown in Table 3 and Table 4 respectively. These data were used to develop membership function of input fuzzy set by converting the two factors. The membership function of *Con* and *Act* were designed in Gaussian membership function represented as $\mu_G(x: c, \sigma) = e^{-[x-c]^2/2\sigma^2}$, where c is the center of the membership function, and σ parameterizes the width of the membership function [4] .

Table 3 Proposed New Building Physical Condition Level (*Con*)

Grade	Scale	Description
1-2	Very Good	As New, No Defect, Performing as intended
3-4	Good	Minor defect, good condition, performing as intended
5-6	Fair	Major defect, moderate condition, still can function with supervision
7-8	Poor	Major or minor defect, critical, not functioning as agreed service level
9-10	Very Poor	• Major or minor defect, critical, not functioning as agreed service level • Very critical, not functioning, risky to safety and health

Source: modified based on JKR216002-0004-14(2013)

Table 4 Proposed Maintenance Action (*Act*)

Grade	Inspection Scale	Description
1	Normal	No defect or damages element/ component well maintained
2-5	Routine	Minor defects/ damages, Needs for monitoring, repairs, replaced to prevent serious defect/ damages
6-7	Repairs	Major defects/ damages, need for major repairs and replacement
8-9	Rehabilitation	Critical/ serious defects/ damages, needs for urgent and immediate repairs
10	Replacement	Critical/ serious defects/ damages, needs for urgent replacement, refer to expert detail inspection/ expert judgment

Source: modified based on JKR216002-0004-14(2013)

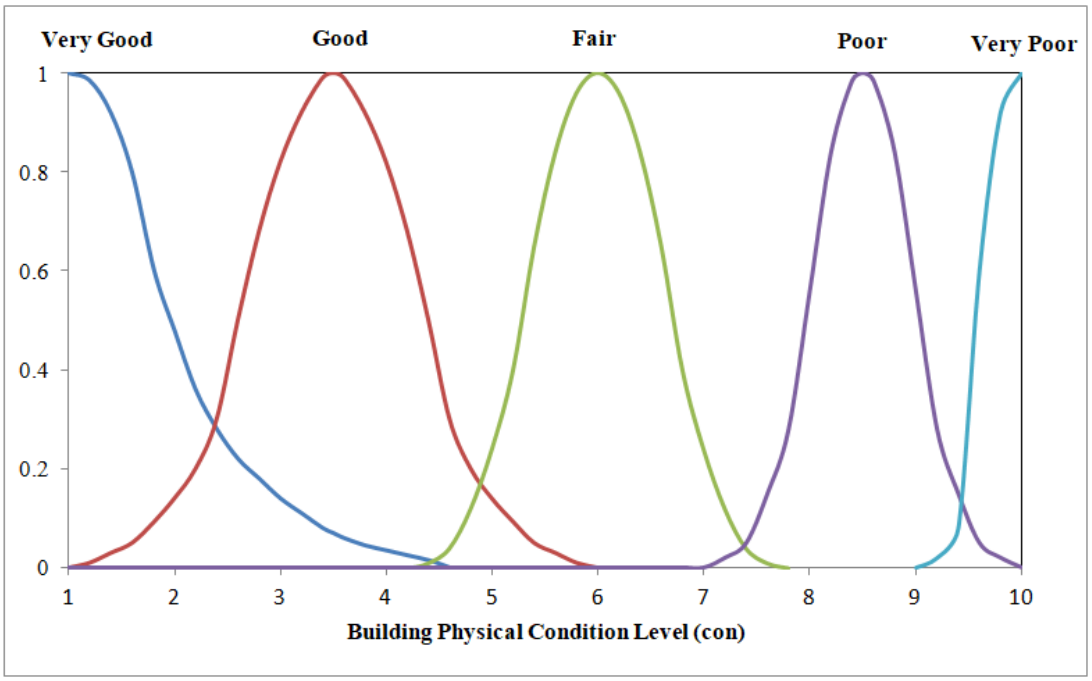

Fig. 1. The membership functions for building physical condition level (Con)

Note: Membership functions of Con ($Very\ Good = \mu(x: 1, 0.9)$; $Good = \mu(x: 3.5, 0.8)$; $Fair = \mu(x: 6,0.6)$; $Poor = \mu(x: 8.5, 0.5)$; $Very\ Poor = \mu(x: 10, 0.3)$).

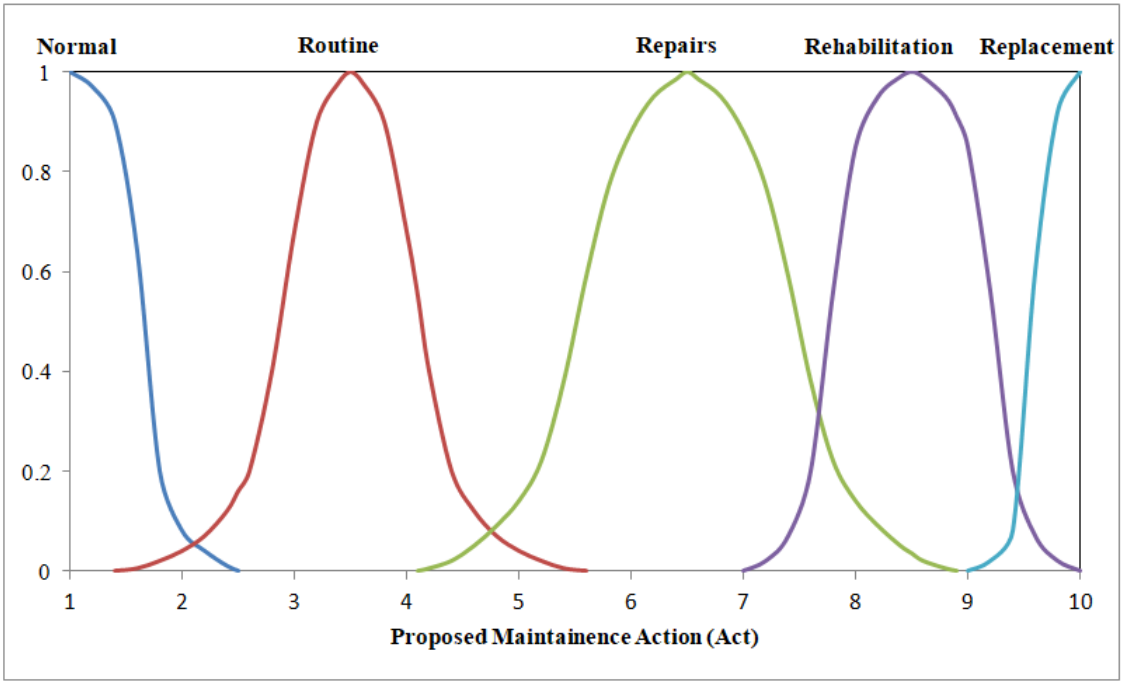

Fig. 2. The membership functions for proposed maintenance action (Act)

Note: Membership functions of Act ($Normal = \mu(x: 1, 0.5)$; $Routine = \mu(x: 3.5, 0.7)$; $Repair = \mu(x: 6.5,0.8)$; $Rehabilitation = \mu(x: 8.5, 0.5)$; $Replacement = \mu(x: 10, 0.3)$).

Secondly, a fuzzy priority number (FPN) is designed ranging from 1 to 100. The fuzzy PN's range is divided into five partitions namely, Remote, Moderate, Sight Urgent, Urgent and Very Urgent, respectively. Each fuzzy membership function is simplified to a fuzzy singleton, i.e., the point that a fuzzy membership function is 1. Fuzzy singleton for each fuzzy membership functions is 1, 20, 45, 70 and 100 respectively as shown in Table 5.

Table 5 Magnitude of Fuzzy Priority Number (FRP)

Grade	Scale
1-10	Remote
11-30	Moderate
31-60	Slightly Urgent
61-80	Urgent
81-100	Very Urgent

Thirdly, visual inspection was done to a single story government office building at Wilayah Persekutuan Labuan. The building was constructed in year 1994 with a buildup area 170m^2. There are some defects found in the inspected building such as pop outs, water leaking, vegetation growth, non-structural failure and termites attack as shown in Figure 3. The results of visual inspection were then compiled and tabulated in the Building Assessment Rating System (BARIS). The input data were analysed using matrix analysis according to the building component, deficiency/ failure, and physical condition level and maintenance action rating. The analysis results as traditional priority number (PN).

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

Fig. 3. Photos of building component defects (a) pop outs at fascia board, (b) nonstructural failure at gutter and downpipe, (c) termites attack at window frame, (d) water mark on ceiling due to roofing leaking

Results and Discussion

In this section, the BCA evaluation results and prioritization outcomes for both traditional priority number (PN) and fuzzy priority number (FPN) are compared. Table 6 summarized the significant results for a government building at Wilayah Persekutuan Labuan.

Table 6 Comparison of failure prioritization outcome between traditional PN model and FIS-based FPN model

No	Element/ component	Deficiency/ Failure	Physical condition level	Maintenance Action Rating	Traditional Priority Number (PN)	PN Output	Fuzzy Priority Number	FRN Output
1	Roofing Sheet	Perforated	4	5	20	Very Urgent	30	Moderate
2	Fascia Board	Rotten	3	3	9	Slightly urgent	36	Slightly urgent
3	UPVC Gutter	Broken, not leveled due to vegetation growth	4	3	12	Slightly urgent	63	Urgent
4	Rainwater Downpipe	Unplugged from gutter	4	2	8	Slightly Urgent	42	Slightly urgent
5	Window Frame	Broken and termite attack	5	4	20	Very Urgent	54	Slightly urgent

The proposed Fuzzy-BCA model involves both qualitative and quantitative information. For example, from Table 6, component #3 is associated with *Con* and *Act* rating of 4 and 3, respectively. *Con* rating of 4 is associated to scale "*Poor*", which denotes that component #3 will cause major or minor defect, critical, not functioning as agreed service level (refer to Table 1). *Act* rating of 3 (associated to scale "Repairs") denotes "major defects/ damages which need major repair and replacement" (refer to Table 2). The calculated PN score is 12 which is considered as "Moderate" PN output. On the contrary, a final FPN score of 63 is obtained from the FIS-based model with "Urgent" FPN output. In short, the model constitutes as an alternative approach to deduce FPN score. Then, different preventive measure sequence and method will be taken based on the FPN score.

One of the most critical disadvantages of the traditional BCA is the various combinations of the *Con* and *Act* rating which produce an identical value of PN. However, the prioritized output may be different. For example components #1 and #5 have the same PN score of 20, and the PN output are "Very Urgent". Conversely, the FPN score for component #1 and #5 are 30 and 54 respectively. The results show that component #5 has a higher risk than component #1 as component #5 is at "Slightly Urgent" output; component #1 is only "moderate". Thus, immediate action should be taken to reduce the failure on component #5.

An analysis was done for 50 sets of BCA input data. The result shows that the difference of priority number resulted between conventional BCA and Fuzzy-BCA is in the range of 10 % to 15%. There are 43 set of data showing the same PN output and FPN output whereas 5 set of data showing that the PN output is more severe than FPN output; and 2 set of data showing that the PN output is less severe than the FPN output. Generally, the main reason for the defects in this case study was caused by not regular building maintenance based on the BCA analysis. Defect caused by termite attack should be avoided by conducting yearly pest control action.

Conclusions

In short, Fuzzy-BCA model was developed to obtain more accurate priority number. The relative importance of each PN score calculated from traditional Failure Modes and Effects Analysis (FMEA) from the two input rating: *Con* and *Act* would be overlooked and result in misunderstanding. The application of scale in Fuzzy-BCA model allows expert to provide a more reasonable and meaningful information for the two inputs. Fuzzy rule based allows expert to construct a more realistic and logical rules. By using the fuzzy set and membership function, the imprecise information is improved to reflect the real situation. Expert's knowledge and experience will be incorporated in this building assessment tool. The developed Fuzzy-BCA model helps to differentiate the risk representations among the component defects, and resolve the difficulties arisen in conducting the procedure of the traditional BCA. The proposed techniques for the BCA analysis will help engineers to provide a more detail action plan for project take off and advise the client with valuable information on the building's maintenance cost on adequate scope of works to be done. In this case, if the client has a limited budget to conduct all repair works, he can choose the scope of works with higher FRN outputs. For future study, more experts should be involved to obtained more accurate results.

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Indoor Air Quality and Prevalence of Sick Building Syndrome in Air-Conditioned Buildings: A Case Study in Three Museum Buildings

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Abstract

A building occupant's health can be affected due to exposure to indoor air contaminants. Indoor air quality (IAQ) is a major contributor to sick building syndrome (SBS) symptoms. This study aims to investigate the impact of IAQ on occupant's health, perceptions and satisfaction in an air-conditioned building. A case study approach is adopted in three air-conditioned museum buildings in Kuala Lumpur. Data was collected through site visits and observations with a combination of field measurements and questionnaire survey. The results from field measurements revealed that there were several locations in each building that were in a state of heat discomfort. Furthermore, the measurement of air velocity recorded a very low average reading and the average level of formaldehyde (HCHO) concentrations in the air in each building records readings that are above the permissible level. The result of a questionnaire survey on the SBS found that ophthalmic symptoms appear to be the most prevalent symptom and frequently experienced by occupants in all buildings. The correlation test between IAQ and SBS satisfaction shows a significant relationship for most of the symptoms. This proves that indoor air quality affects the health of building occupants. The correlation test between the satisfaction level of mechanical ventilation and air conditioning (MVAC) system maintenance on IAQ and SBS also shows significant relationships and proves that maintenance management in buildings affects the comfort and health of the occupants.

Keywords: Maintenance; Indoor air quality; Air conditioning; Sick building syndrome; Occupant satisfaction

Introduction

Building is a basic component that provides protection and convenience for people to carry out their daily tasks. As most people spend time inside a building, IAQ has become an important measure in human life [1]. IAQ explains how indoor air can affect health, comfort and ability to work. Awareness of indoor air pollution is less compared to awareness on outdoor air pollution. However, indoor air quality issues have received the attention of the public when air contaminants are found and increased cases of SBS. The Environmental Protection Agency (EPA) defines IAQ as "the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants" [2]. IAQ is not only for comfort, which is affected by temperature, humidity and odours but also by harmful biological contaminants and chemicals present in the conditioned space [2]. Building occupants are suspected to be exposed to poor quality IAQ when they develop symptoms or health conditions

called SBS when they are in the building however, their symptoms often got better when they left the building [1]. SBS is defined by Industrial Code of Practice on Indoor Air Quality (ICOP) as an illness that is experienced by building occupants due to poor IAQ [15]. The problem that arises from IAQ may contribute to problem which affects the occupant's health, well-being, comfort, and productivity. In the context of maintaining IAQ at a level that meets the recommended standards, the factors that cause the decline of IAQ quality in a building should be particularly noted by the building management. Among the major factors that can cause the decline of IAQ quality in a building is poor maintenance management of MVAC system, occupant's activities and deterioration of the building's components.

Indoor Air Quality and Sick Building Syndrome

EPA defines IAQ as "the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants". [2] The term IAQ refers to the environmental characteristics especially inside buildings that may affect human health. SBS on the other hand is the health symptoms that are usually related to poor IAQ levels, such as skin irritation, eye irritation, nose or throat irritation, headache, and fatigue.[5, 12-14] However, the actual causative sources of SBS are yet to be confirmed [10, 13]. SBS will indirectly contribute to low quality of work and productivity by staff due to exposure to inadequate ventilation, chemical and biological contaminants. [2, 15] The physical parameters of IAQ consist of indoor temperature, relative humidity, and air movement [16-19]. According to the Malaysian Industry Code of Practice on Indoor Air Quality (2010), the acceptable indoor air temperature is between 23℃ to 26℃ and relative humidity is between 40% and 70% [15]. It is important to maintain a building in such condition in order to ensure that the indoor air condition is comfortable and not too dry. Indoor air movement is important to ensure good thermal comfort, adequate air change and spread of air contaminants. For air-conditioned buildings, high air movement will result in extreme cooling and draft while "stuffy" air conditions will occur if air movement is insufficient and as a result air pollution can increase [2, 15].

IAQ and Contaminants by MVAC in Museum Buildings

A museum is an institution that cares and conserves a collection of artefacts and other objects of artistic, cultural, historical, or scientific importance. Many public museums make these items available for public viewing through exhibits that may be permanent or temporary. As highlighted by [7], different categories of environment require a different level of the indoor environment. There is a risk of exposure to SBS by the museum personnel because of poor IAQ in the museum. [9, 20], the failure of MVAC system that provides ventilation and air circulation in the building is one of the contributing factors to poor IAQ levels in the museum building. Failure of MVAC to control air contaminants may lead to poor indoor air quality and is a major contribution to SBS. Available researches also proved that there are indoor air contaminants which originate from the MVAC system including dust or dirt in the air duct, growth of microbiological in condensed water, incorrect use of cooling or cleaning chemicals as well as refrigerant gas leaks [9, 20-22]. [20] in his study identified that the indoor climate control system in several museums was not working properly and resulted in the fluctuation of RH readings.

In addition, the damage that occurred on museum's display materials caused by air-conditioning system's failure will result in the concentration of contaminants in the air inside a building. The display furniture in the gallery contains HCHO which is a contributor of chemical contaminants in the air. It is reported that HCHO is among the most common gases

that produces serious risks to human health. [23] Decaying organic materials in museum buildings such as textile and paper are a major contributor to Volatile Organic Compound (VOC) concentration in the air. With the condition of the MVAC system that does not work properly, the VOCs that originate from organic artefacts can pollute the air and thus, bring health problems to visitors and museum building occupants. [24, 25] states that the museum design itself is also the cause of weak air control system within the museum building. A museum layout involves partitions, and galleries, and a centralized ventilation system cannot ensure good ventilation management within museum buildings. In addition, a large number of visitors contributes to the increase in heat load and RH as well as the increase of level of the carbon dioxide (CO_2). Concentrations of contaminant can be found in the gallery, repository and conservation laboratory where [26] stated that there were chemical contaminants, namely HCHO, found in the highest level in the museum compared to that found in the printer industry and offices. Higher level of chemical contaminants may affect occupants' health including irritation of eyes, respiratory tract and altered respiratory function [23].

Methodology

The present study employed three stages of quantitative methodology in achieving the research objectives through three museum buildings as a case study. The study started with the selection of buildings based on the following criteria:

i. Most visited museum in Malaysia;

ii. Number of exhibitions; and

iii. Significant museology activities (e.g. research, conservation, collection management).

Based on the criteria above, three (3) museum buildings were selected for this study as shown in Table 1.

Table 1 List of museums as case study

No.	Name of building	Location	Floor area (m^2)
1	Department of Museum Malaysia Headquarters (DMM)	Kuala Lumpur	20,000
2	National Museum (NM)	Kuala Lumpur	9,000
3	National Textile Museum (NTM)	Kuala Lumpur	3,200

The first phase was measuring the IAQ level in museum buildings. Physical measurement on IAQ parameters in selected museum buildings was conducted. The IAQ level in selected museum building was determined based on the measured level of:

i. IAQ physical parameter (temperature, relative humidity, air velocity);

ii. Concentration of IAQ chemical contaminants (CO_2, HCHO, Total volatile organic compounds); and

iii. The biological contaminant (total fungal counts).

All physical parameters and chemical contaminants were measured using the pre-calibrated direct reading instruments, while the level of biological contaminant (total fungal counts) was measured using the passive bio-aerosol sampler's method. The time frame for the measurements was performed on a four-time slot basis. For each sample point, the measurement was conducted 4 times a day (morning, afternoon and evening) with a period of 30 minutes (1 minute interval) for each time slot and therefore, for each sample point 120 readings (n = 120) have been gathered. The measurements of total fungal counts were carried out using the SKC Quicktake™ air sampler at each sampling point. The samples were sent to Mycology Laboratory for incubation for 5 days at 25 ° C and then the colony forming unit was counted by using an automatic colony counter.

The second stage was the assessment of SBS among museum occupants. Data was collected through questionnaire distribution. For this study, respondents selected are museum staffs, museum volunteers, intern students, visiting researchers and contractors who occupy each museum every day for work. Using sample size concept by [27], the response rate is shown in Table 2.

Table 2 Percentage of response rate

Building	Number of Populations	Minimum number of sampling	Number of respondents received	Response Rate (%)
DMM	190	127	132	69.4
NM	35	32	32	91.4
NTM	27	27	27	100
Total	249	186	191	76.7

The third stage was conducted to determine the relationship between MVAC maintenance satisfaction level and occupants' IAQ satisfaction as well as the SBS prevalence symptoms. This stage has employed questionnaire distributed among similar respondents in stage 2 of the research. Correlation analysis between air conditioning maintenance satisfaction level and the IAQ value is used to identify the relationship between both variables.

Results and Discussion

Indoor Air Quality Assessment

For the purpose of identifying the level of IAQ and contaminants in three museum buildings, this research conducted measurement of physical parameters, namely temperature (°C), relative humidity (%), air velocity (m/s), HCHO, CO_2, total Volatile Organic Compounds (TVOC) and total fungal counts (cfu/m^3). The assessment of IAQ was performed in accordance with ICOP (2010) guidelines. Comparisons were made between the case study's measurement reading and the acceptable limit set by [15] as shown in Table 3.

Table 3 Comparisons were made between the case study's measurement readings.

Parameter	Acceptable Range	Median (Inter Quartile Range)		
		DMM	NM	NTM
Air temperature (°C)	23 - 26	19.9 - 28.4	25.2 – 28.0	23.8 – 27.0
Relative humidity (%)	40 -70 (%)	53.4 - 69.1	55.4 – 65.8	55.1 – 65.7
Air velocity (m/s)	0.15 - 0.50	0.05 - 0.21	0.06 – 0.18	0.03 – 0.24
HCHO (ppm)	0.1	0.00 - 2.47	0.00 – 0.96	0.00 – 1.18
TVOC (ppm)	3	0.00 - 0.63	0.00 – 0.00	0.00 – 0.00
CO_2 (ppm)	1,000	434 - 699	413 - 473	461- 844
Fungi Count (CFU/m3)	1,000	48 - 552	58 - 311	112 - 844

In the NM building IAQ measurements have been carried out at twelve (12) locations and were carried out by taking two (2) samples at each location. Prior to the measurements, a total number of the indoor climate control systems and the locations were identified for the building. It was found that most of the floor areas were covered by a centralised air-conditioning system. According to the data presented, the average reading for RH, TVOC, CO_2 and fungal counts in all locations were recorded at the acceptable level. However, measurements on temperature, air velocity and HCHO did not comply with the acceptable limit set by [15]. Measurements of average temperature were recorded an average reading higher than the acceptable limit. The highest temperature recorded was 28.4 °C. An observation on the MVAC system found that the Water Cooled Package Unit (WCPU) at the respective locations did not operate at 100% cooling capacity where each unit had a malfunctioning compressor thus, unable to cool the air optimally. Observation on the AHU room found that the condition of the room was dirty and poorly maintained and was one of the factors that contributed to the failure of the air conditioning operation. The concentration of HCHO level was recorded at a high level with average reading for each location between 0.02 ppm to 0.95 ppm. Through observation, it was found a high that the concentration of HCHO was contributed by inoperative air handling unit and also lack of air circulation. This is evidenced by the air velocity readings that were recorded below the acceptable limit.

In the NTM building, sample measurements have been performed at ten (10) locations, where measurements were carried out by taking two (2) samples at locations. The data shows that the average reading for RH, TVOC, CO_2 and fungal counts at all locations are at an acceptable level. However, measurements on temperature, air velocity and HCHO were found not complying with the acceptable limit set by [15]. Measurements on average temperature recorded higher readings than the acceptable limit with an average reading of 26.1 °C to 27.0 °C. The highest temperature recorded was 28 ° C. The air velocity readings were recorded below 0.15 m/s. Measurements on average HCHO level in all locations recorded readings within acceptable limits of 0.19 ppm to 1.18 ppm.

Sick Building Syndrome Assessment

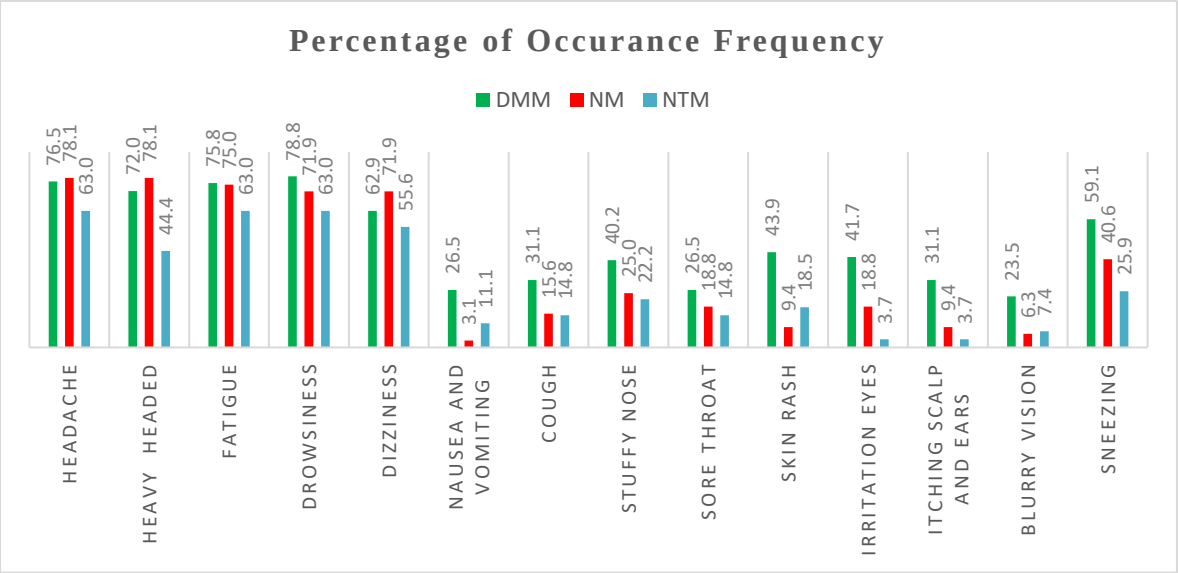

Fig.1. Percentage of Occurrence Frequency

Figure 1 presents an overview of comparison between the accumulative percentage of symptoms occurrences and buildings. Ophthalmic symptoms namely headache, heavy-headed, fatigue, drowsiness, dizziness appear to be the most frequently encountered among the occupants in all buildings with an accumulative percentage exceeding 40% for all building occupants. The result shown was consistent with [1] statement's that the ophthalmic symptoms are the most common groups of symptom that are reported to be associated with the indoor environment.

For the other two ophthalmic symptoms, "irritated eyes" and "blurry eyes", the prevalence of both symptoms was more experienced by occupants in the DMM building (n=131) with the accumulative percentage of 41.6% and 23.5% respectively while the prevalence of this symptom by occupants in NM (n=32) and NTM (n=27) buildings recorded below 20%. Respiratory symptoms such as "cough", "stuffy nose", "sore throat" and "sneezing" recorded a moderate percentage of occurrences for all building residents with "sneezing" and "stuffy nose" being the most common symptoms that recorded accumulative percentage exceeding 20% for all respondents. The symptoms such as "cough" and "sore throat" were more common among occupants in DMM buildings which accounted for 31.1% and 26.5% respectively compared to the NM and NTM buildings that recorded a percentage below 20% for both symptoms. Prevalence of dermal symptom such as "skin rash" and "itching scalp and ears" were only experienced by residents in the DMM building with accumulative percentage of 43.9% and 31.1% respectively, while two other buildings recorded between 6.3% and 18.8%. Other symptoms, such as nausea and vomiting, were only experienced by occupants in the DMM building.

MVAC Maintenance Assessment

The MVAC maintenance assessment is the assessment of the level of satisfaction experienced by the building occupants on the operation and maintenance of air conditioning systems in every museum. For all buildings, 100% of the respondents (n = 191) had experience with breakdown of air-conditioning system whereby 70% of the respondents stated that the response rate for repair work, performed by maintenance personnel, took between 1 and 14 days. More

days taken for maintenance caused uncomfortable conditions in space, affect productivity and also affect the health of building occupants resulting from failure to maintain operations of air conditioning system in the building. The relationship between the level of satisfaction of MVAC maintenance and prevalence of SBS symptoms was also identified through correlation tests between variables as shown in Table 4.

Table 4 Correlation between MVAC maintenance satisfaction and SBS symptoms (n=191)

SBS symptoms	MVAC Maintenance Satisfaction (r value)
Headache	-.261**
Heavy headed	-.308**
Fatigue	-.351**
Drowsiness	-.328**
Dizziness	-.310**
Nausea and vomiting	-.065
Cough	-.106
Stuffy nose	-.108
Sore throat	-.178*
Skin rash	-.153*
Irritation eyes	-.218**
Itching scalp and ears	-.176*
Blurry vision	-.086
Sneezing	-.156*

The result stated that the ophthalmic symptoms which comprise of headache, heavy-headed, fatigue, drowsiness, dizziness and irritated eyes are significantly correlated to the occupants' satisfaction of MVAC maintenance. Ophthalmic symptoms is a SBS symptom commonly faced by occupants, which may arise from environmental irritations and attributed to inadequate fresh air, air temperature and relative humidity [10, 12-14]. Inadequacies of MVAC operations such as failure to control air temperature, RH and air change can cause discomfort to occupants as the level of fluctuations of temperature and RH occurs and increased the air contaminants [22].

Meanwhile, respiratory symptoms (i.e. sore throat and sneezing) and dermal symptoms (i.e. skin rash and itching scalp and ears) are also significantly correlated with occupants' satisfaction of MVAC maintenance. These symptoms may arise when occupants are exposed to a long term in air conditioned workspace as well as contributed by an excessive level of chemical contaminants in the air caused by MVAC system failure to control indoor air contaminants. Negative correlation results between satisfactions of the MVAC system with the prevalence of SBS symptoms suggest that the level of operational performance and maintenance of the MVAC system affect occupants' health in the building. Hence, the performance of MVAC maintenance in museum buildings needs to be improved for the well-being of the building occupants.

The result and analysis demonstrate that maintenance satisfaction is found to be significantly correlated with occupant's perception toward temperature, humidity, dusty air and air freshness. Poor thermal environment may contribute to people's emotional effects, fatigue and comfort. All these health behaviours have an indirect effect on their satisfaction. Based on physical measurements conducted in each museum there are locations that recorded hot condition due to air conditioning malfunctions. Fluctuations of temperature and RH caused by

inoperative air conditioning system can cause serious effects on moisture in the building and can cause serious damage to building components (i.e. paints and wood flooring) and furnishings as well as accelerate the growth of fungi that can adversely affect the health and satisfaction of building occupants [2]. Furthermore, in a museum building situation, the inadequacy of thermal control could cause imbalance and fluctuations of temperature, and relative humidity could risk decaying artefacts and subsequently, it could be a factor in the contamination of air agents inside buildings that affects occupants' satisfaction and health [10]. The presence of dust in the air could be originated from inoperative MVAC caused by failure of maintenance, dust or dirt in the air duct [9, 20, 22]. Thick dust on the filter due to failure of the MVAC system maintenance will result in the failure of the filters to eliminate contaminants in the MVAC system as well as the system may distribute dusk particles in the air. Moreover, based on physical measurement conducted, it was found that air velocity readings in almost all buildings did not comply with the acceptable level [15]. Most of the areas in all three buildings recorded lower air velocity compared to the minimum limit. The evidence indicates that the failure of MVAC operation could contribute to the inadequacy of air circulation in all buildings and concluded the significance toward IAQ's satisfaction.

Conclusions

Referring to the objective of this study which is to highlight the measurement of indoor air quality in selected museum buildings in Kuala Lumpur, Malaysia and to determine the issues in MVAC which influenced the IAQ level in the buildings, it is found that improper MVAC operation contributed to the increase in indoor temperature in all museum buildings. The NM building recorded an average temperature reading which is higher than that in other buildings with four (4) out of six (6) locations recorded average reading temperatures above the acceptable limit. In the NTM building, three locations recorded high temperatures readings caused by an inoperative air conditioning system. Air velocity readings on the other hand show that almost all buildings were not complying with the IAQ standard whereas most of the areas in all selected buildings recorded lower air velocity as compared to the minimum limit. Observations suggested that the failure of MVAC operation contributed to the inadequacy of air velocity in all buildings. Based on the results of indoor air chemical contaminants measurements, there were locations in each building with values exceeding the acceptable limit of HCHO level. Furthermore, there were three spaces in NM and NTM buildings that recorded an average reading exceeding the limit of 0.75 ppm.

The results also show that the ophthalmic symptoms such as headache, heavy-headed, fatigue, drowsiness, dizziness and irritated eyes are significantly correlated to the occupants' satisfaction of MVAC maintenance. Inadequacies on MVAC operations such as failure to control air temperature, RH and air change can cause discomfort to building occupants as the fluctuations of temperature and RH level may increase air contaminants. Negative correlation results between satisfactions of the MVAC system with prevalence of SBS symptoms suggest that the level of operational performance and maintenance of the MVAC system have affected occupants' health in the building. Hence, the performance of MVAC maintenance in museum buildings needs to be improved for the well-being of the building occupants.

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The Application of Alternative Polyurethane (PU) Foam Injection at Bridge and Culvert Approaches - Case Studies at Route FT005

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Abstract

Excessive settlement can occur due to the prolong consolidation of the road foundation layer in the soft ground area. One of the possible factors that lead to differential settlement is insufficient compaction or secondary compression that occurred after the road has been in service. Therefore, one of the alternative methods of ground rehabilitation and modification proposed is Hydrophobic Polyurethane (PU) foam injection. This method is currently in demand to solve differential settlement issues the bridge and culvert approaches, which is an immediate method and suitable for routes with high amount of traffic. In this case study, PU foam injection was executed at two locations in Kuala Selangor, namely Sultan Abdul Aziz bridge approach and Sg. Gulang-Gulang transition culvert approach. The aim of this study is to evaluate the performance of PU foam injection as an alternative rapid ground improvement method to solve differential settlement at the approach bridge and culvert on soft ground area. Based on the result, the alternative solution for the settlement issues at the approach culvert and bridge was a success based on the 14 months of settlement monitoring. This paper presents the findings and the problems that exist underneath the bridge and culvert, thus the settlement monitoring at identified site and the result of analysis is based on the monitoring settlement data from the located settlement marker.

Keywords: Polyurethane; PU foam injection; Settlement; Ground improvement; Bridge and culvert approach

Introduction

The settlement problem after post-construction has always been a challenge to designers and contractors in earth fill deposit and soft ground area. The settlement of soil occurs due to the change of volume as the excess pore water pressure dissipates when the ground was loaded to strengthen the foundation of the building and pavement. In Malaysia, there are many cases of differential settlement that occur at transition bridge and culvert approach, especially on soft soil area. In PWD Manual for Bridge Approach Differential Settlement Improvement (NTJ 39/2019), several factors contribute to the differential settlement at transition bridge approach is due to the movement of the embankment fill because of inadequate compaction and the consolidation settlement that has not achieve 90 % consolidation, poor drainage, inadequate design and weak supervision during construction. There are many methods of ground rehabilitation that can be applied to solve the problem of excessive settlement at transition bridge and culvert such as installation of piles, installation of geotextiles and resurfacing but

these methods mostly need major re-construction and disturbance to the existing structure (Mohamed Jais, 2017). Recently, in Malaysia, rapid remediation work has become a choice and popular solution especially in urban area and route with high traffic volume.

Lightweight Material

Lightweight material has low density than water; therefore, it can float on water. There are several types of lightweight material used in ground treatment to reduce excessive settlement and construction period on soft ground. The types of lightweight material currently in the market are geofoam, air foam, wood chips, sawdust, shredded waste tire, fly ash, slag and a mixture of hydraulic sand with expanded polystyrene beads (Ismail *et.al*, 2021). The uses of the lightweight materials are mostly to reduce the applied load which can significantly reduce the magnitude of embankment settlement, shorten the time required to achieve embankment settlement, lower the driving force in landslide rehabilitation and reduce lateral pressure at the back of the retaining walls, abutments and other structures (Ismail *et.al*, 2021). The function of lightweight material in highway construction is to improve the poor foundation (soft soil) without imposing any additional loading on the existing foundation and at the same time, the increases the soil bearing capacity. Polyurethane (PU) foam or resin is one of the alternative lightweight materials which is widely used in the ground improvement work.

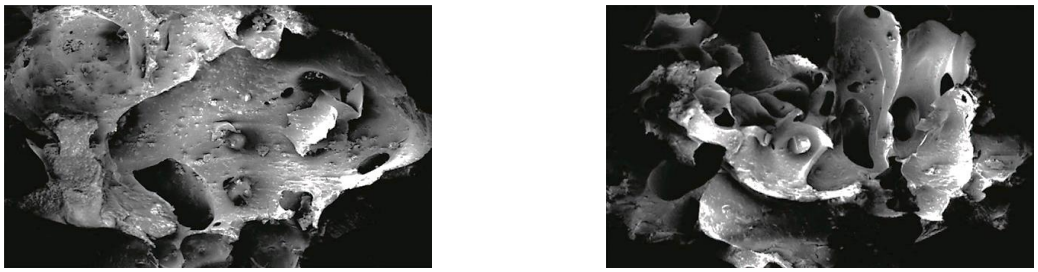
Polyurethane Characteristic

Polyurethane (PU) foam is a polymeric material and has a variety of physical and chemical properties. PU resin or foam is a cellular solid PU polymer like honeycomb structure that is designed to obtain the desired properties (Gary and Krishan, 2021). There are two (2) types of polyurethane foam/resin; namely, hydrophobic and hydrophilic polyurethanes. Hydrophilic polyurethane reacts and absorbs water before it expands up to five (5) to seven (7) times to form flexible foam or gel. Whereas, hydrophobic can expands six (6) to 20 times from its liquid volume, thus naturally repels water and stabilises the surrounding soil. This behaviour shows the hydrophobic polyurethane is more suitable for ground repair and remediation applications (Mohamed Jais, 2017). According to Mohamed Jais (2017) and Lat *et. al* (2020), polyurethane (PU) foam is a reaction of two compounds, namely polyols (-OH) and isocyanates (-NCO) during polymerization of polyurethane. The reaction between polyol and isocyanate is as follows:

$$\text{R-N=C=O + R'-O-H} \rightarrow \text{R-NH-C(O)-O-R}$$

$$\text{Isocyanate+ Polyol} \rightarrow \text{Polyurethane}$$

Figure 1 show the example of the microstructure of PU foam or resin that had been studied by Mohamed Jais, 2017.



(a) (b)

Fig. 1. The image of microstructure by using electron microscope (a) PU foam; and (b) Intrusion of PU foam into laterite soil.

Soil Improvement Using PU Foam Injection

PU foam or resin injection is a rapid method with minor disturbance to the existing structure hereby the process is to inject the material into the ground without any massive excavation work. The procedure of PU foam or resin injection is quite similar to cement grouting. By replacing the cement with polyurethane resin, the settlement can be reduced and simultaneously improving the strength and compressibility of weak foundation soil (Sidek *et al*, 2015; Mohamed Jais, 2017). The design specification of PU form is shown in Table 1.

Table 1 Design specification of PU form (Mohamed Jais, 2017).

Description	Value	Unit
Unit weight of PU form, γ	0.8 – 1.5	kN/m^3
Stiffness modulus, E	10 000 - 15 000	kN/m^2
Poisson's ratio, ν	0.3	
Compressive strength, σ	2.2 - 16	MPa
Permeability, k	1×10^{-12}	m/s

Background of Study Area

Two (2) different sites were selected along Federal Route FT005. One of the sites is situated at the approach bridge of Sultan Salahuddin Abdul Aziz (SSAA) - Section 481.7 Federal Route FT005. The other site is at a box culvert approach Section 491.8, FT005 Sg Gulang-Gulang. The Federal Route 005 is a primary route used by travellers and commuters along the west coast of Peninsular Malaysia. According to Road Traffic Volume of Malaysia 2018, the Level of Service (LOS) along this route is categorised as level D hereby the volume of vehicle per hour is about 3,430 vehicles. Due to the increasing traffic overburden and the existence of soft ground deposit below and surrounding the approach, the section settled, and voids started to appear underneath the transition bridge and box culvert, left and right, since these structures are constructed on piled foundations. The geological formation found in these areas is dominated by quaternary deposits consisting of marine and continental deposition such as clay, silt, sand and minor gravel, shown in Figure 2.

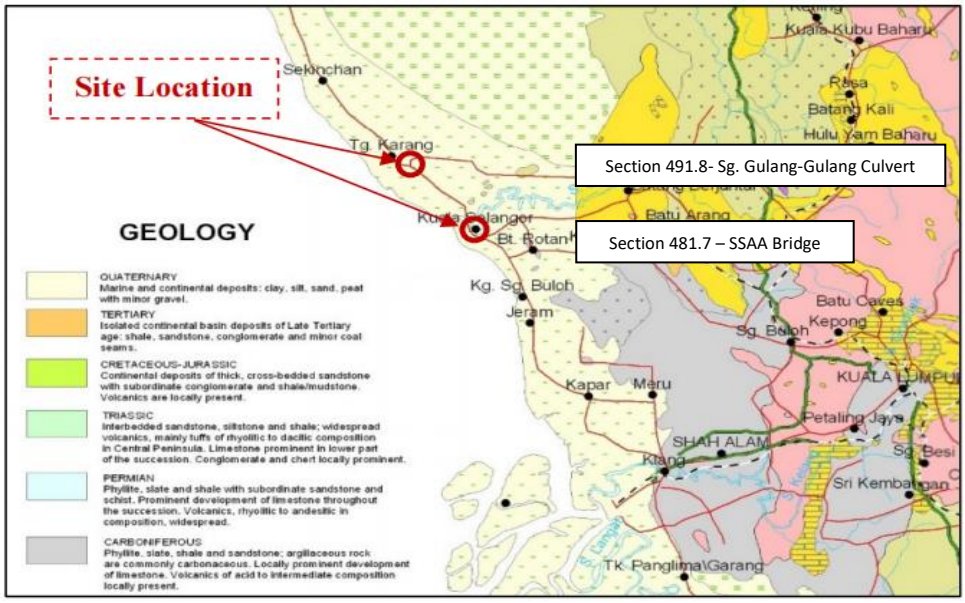
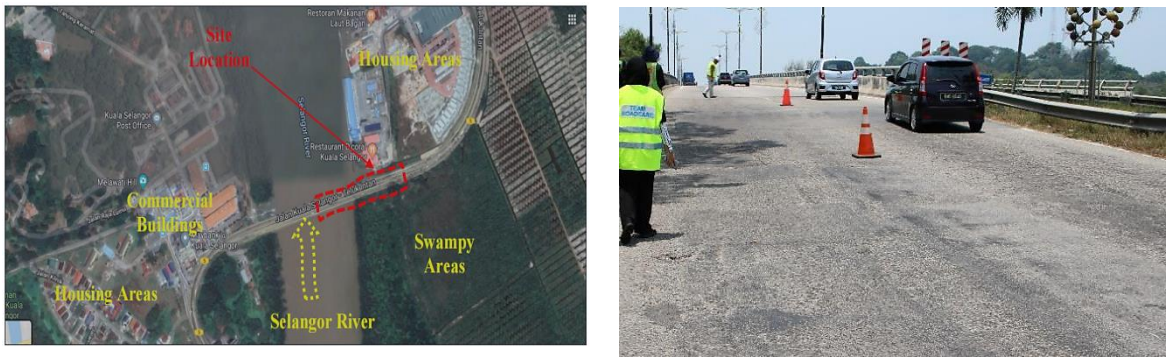


Fig.2. The geological formation of the study area.

Section 481.7, Federal Route (FT) 005 (Bridge of Sultan Salahuddin Abdul Aziz)

This site is situated at 03°20’28.3”N 101°15’17.6”E along the Federal Route FT005. The site topography at the Bridge of Sultan Salahuddin Abdul Aziz (SSAA) or known as Kuala Selangor Bridge consists of flat terrain surrounded by commercial building, housing areas and the most important thing is swampy near the bridge approach (Refer to Figure 3). The swampy areas surrounded all over the bridge is one of the main factors that contributes to the settlement process of the transition section underlain the road on the viaduct section. The abutment approach on the viaduct section of Federal Route FT005 right after Sungai Selangor experienced differential settlement and undulation. This problem has occurred numerously, thus the only solution is to regulate and resurface the settled section with additional premix to realign vertically from the bridge approaches with the transition earth-fill embankment.



(a) (b)

Fig. 3. Site location of Bridge of Sultan Salahuddin Abdul Aziz (a) Plan view of the bridge; and (b) Photo of the bridge from west bound to Klang view.

Section 491.8, Federal Route (FT) 005 (Sg. Gulang-Gulang Box Culvert)

The topography at the Jalan Sungai Gulang-Gulang consists of flat terrain surrounded by commercial building, housing areas and agricultural land (Refer to Figure 4). The settlement occurred on the left and right side of the box culvert causing undulation and discomfort to the traffic users.

(a) (b)

Fig. 4. Site location of a box culvert at Sg. Gulang-Gulang (a) Plan view of box culvert; and (b) View the carriageway from Klang to Sabak Bernam.

Methodology

Rehabilitation work at both case study is aimed to strengthen and improve the formation below the road pavement structure which has experienced settlement causing unstable foundation at the transition approach bridge and box culvert. The PU foam was injected into the ground to fill the cavities and densifies the loosened soil underneath. This study is divided into three (3) phase which are field investigation, injection of PU foam and monitoring of settlement after the ground has been treated.

Phase 1: Field Investigation

There are two (2) types of in-situ test carried out at each study area which is electrical resistivity imaging (ERI) and JKR Probe. The field investigation study was conducted from 20 August 2019 until 25 August 2019. Figure 5 shows the location and quantity of the test position in the layout plan. JKR Probe is to determine the depth of penetration, in situ soil density and correlated strengths. 15 numbers of JKR Probe were conducted at the bridge and 14 numbers of JKR Probe were conducted at the culvert approach of Sg Gulang-Gulang.

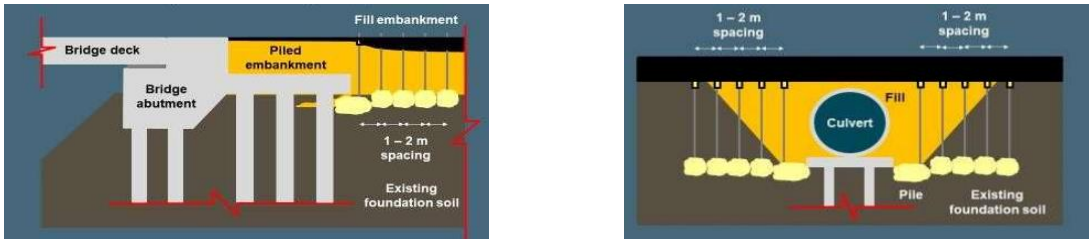
Electrical resistivity imaging (ERI) was used to identify and interpret the condition of the problematic subsurface profile due to its differential stiffness and presence of ground water. The electrical resistivity of the subsurface profile was measured using ABEM Terrameter SAS 4000 Lund Imaging System in a 2D survey. Wenner array was performed in this investigation due to verification purposes representing low and high intensities of electrical resistivity data. Raw data obtained from the data acquisition unit was processed using commercialized RES2DINV software to provide an inverse model that approximates the actual subsurface structure.

(a) (b)

Fig. 5. Lines of resistivity and points of JKR Probes at (a) Bridge of SSAA and (b) Sg. Gulang-Gulang Box Culvert.

Phase 2: Injection of PU Foam or Resin

According to Mohamed Jais (2017), the concepts of typical implementation of PU foam at bridge and culvert approach are shown in Figure 6. The injection points were arranged from 1 m to 2 m spacing. The curing time of the expansion foam is about fifteen (15) minutes after each injection. The packer was dismantled, and the holes were grouted with a suitable material. Any diffused and spilt PU needs to be removed before the crack repair can be executed. This stage is executed to plug the voids beneath the culvert or abutment structure, thus preventing the adjacent soil from migrating into the voids. This will reduce the migration of the soil into the void spaces, hence reduces the rate of differential settlement at the approach section.



(a) (b)

Fig.6. The rehabilitation technique applying polyurethane foam at (a) bridge and (b) culvert approach (courtesy of Geocon Engineering Sdn. Bhd.)

PU foam injection work was carried out during the midnight hours to avoid heavy traffic and complaint by the traffic user because of road closure. The photos of rehabilitation work using PU injection method are shown in Figure 7 and Figure 8.

Fig. 7. The asphalt layer needs to be cored first before inserting the injection pipe into the ground.

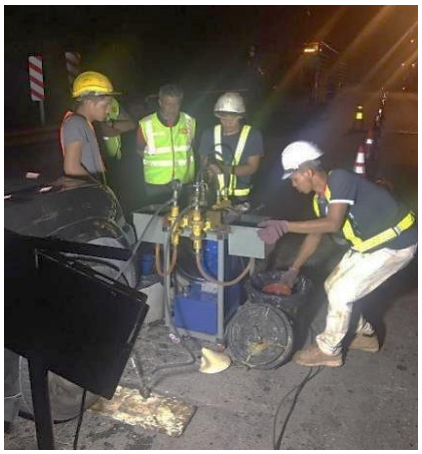
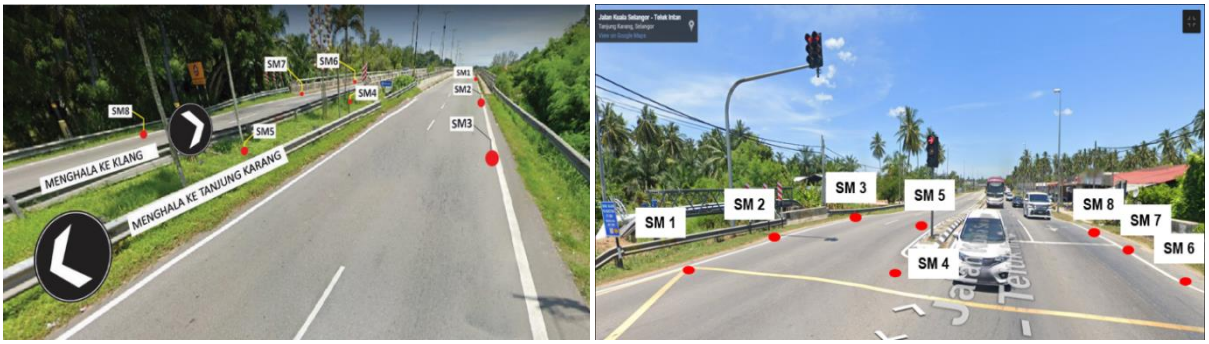


Fig. 8. Injecting the PU foam by mixing the two-liquid resin in situ into the ground.

Phase 3: Monitoring of Settlement after Rehabilitation Work

Deformation survey or deformation monitoring was performed to measure displacement or settlement at Sultan Salahuddin Abdul Aziz bridge and culvert at Sg. Gulang-Gulang using the automatic electronic digital level known as DL-500 Topcon Digital Level. The monitoring of settlement executed for 14 months to evaluate the performance of the PU foam injection as an alternative rehabilitation solution. Figure 9 shows the arrangement of settlement markers for monitoring the deformation of the ground after PU foam injection treatment. The settlement marker was permanently fixed on the surface of the pavement and marked as SM 1 until SM 8 for each of location. At Bridge of SSAA, the settlement markers located on the bridge are SM 1 and SM 6. SM 2, SM 3, SM 7 and SM 8 are located before/after transition bridge section, SM 4 and SM 5 are located on the ground at the median between two bridges. At Sg Gulang-Gulang, all the settlement markers located outside the alignment of culvert/piled embankment.



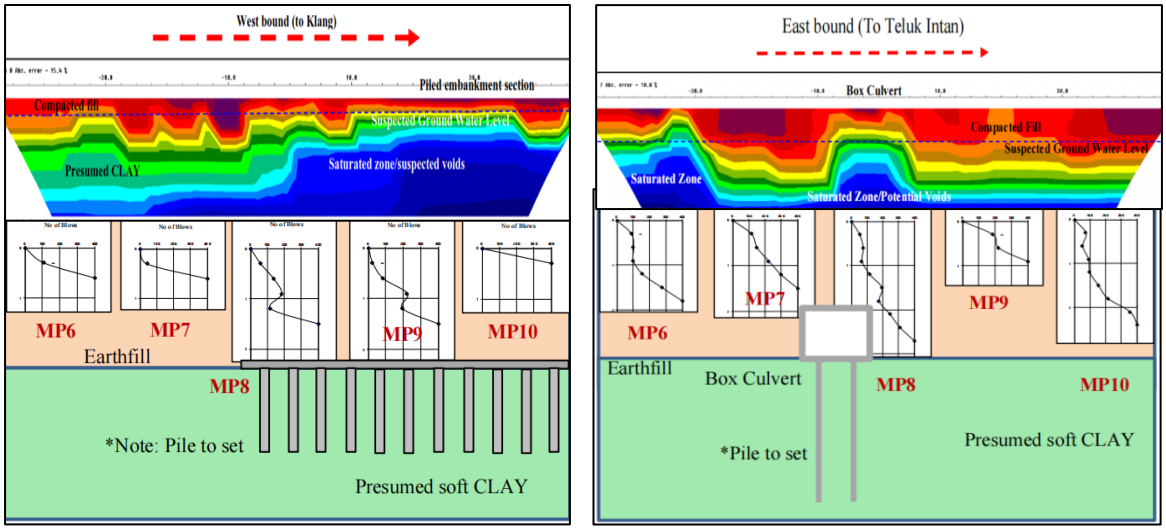
(a) (b)

Fig. 9. The photos show the arrangement of settlement markers located at (a) Bridge of SSAA; and (b) Sg. Gulang-Gulang Box Culvert.

Results and Evaluation of the Settlement Monitoring Activity

Field investigation

The analysis results of electrical resistivity imaging (ERI) show a good correlation with the JKR probe data. The application of ERI in conjunction with the JKR probe points and geological information was being applied to the evaluation of the ground settlement due to its ability to detect the weak layer within the subsurface profile. The existing ground condition consist of 2.5 – 3 m thick of compacted fill or sand layer, underline by thick of soft to firm CLAY layer. ERI and JKR Probe results show the critical or weakness point located at the transition zone between the piled embankment/ box culvert and the earthfill embankment. The voids or saturated zones below the piled embankment could cause the earthfill material to migrate towards the cavity beneath the piled foundation structures. This factor causes the differential settlement between the earthfill transition and the structures. Figure 10 shows the result of Line 2 at Bridge of SSAA and Sg. Gulang-Gulang box culvert that clearly show the saturated/void zone.

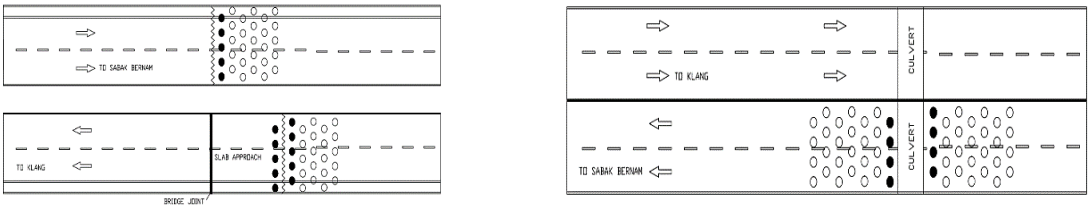


(a) (b)

Fig. 10. The analysis of results from JKR Probe and shallow electrical resistivity image (ERI) for Line 2 (a) Bridge of SSAA; and (b) Sg. Gulang-Gulang Box Culvert.

Injection of PU Foam or Resin

According to the results of ERI and JKR Probe, the construction of a grout curtain using the PU foam injection method at the edge of the piled embankment can plug the void and prevent migration of fill material into the cavities created due to the global settlement of the ground surrounding the bridge and culvert approaches.



(a) (b)

Fig. 11. The area injected with PU foam at (a) Sultan Salahuddin Abdul Aziz Bridge (both direction of one of abutment); and (b) Culvert at Sg Gulang – Gulang (Route from Klang to Teluk Intan).

The quantity of PU foam needed to fill the cavities detected below the piled box culvert or piled embankment was calculated based on the analysis data from ERI and JKR Probes results. About 2,605 liter of PU foam was injected below the bridge transition at SSAA and about 2,250 liter of PU foam was injected beneath the transition approach of culvert at Sg. Gulang-Gulang (Refer to Figure 11).

Performance of PU Form Injection Method

The performance of the PU foam injection as an alternative ground rehabilitation method was monitor based on the deformation survey at every settlement marker as shown in Figure 9. According to the geotechnical design requirement stipulated by the Public Works Department (PWD) for ground treatment and stabilization, performance characteristics of the embankments are:

(i) Differential settlement – Allowable settlement for five (5) years post construction:

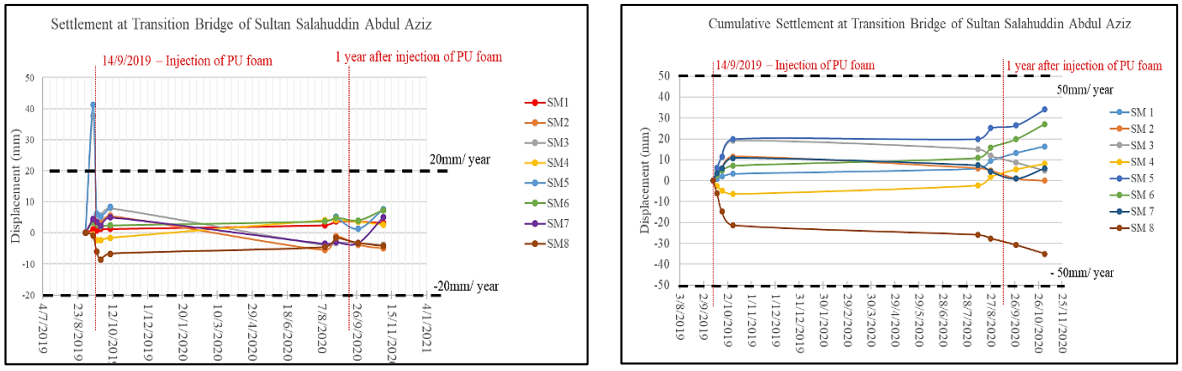
- within 50 m from structures < 100mm; and
- within 100 m remote from structures < 150mm for five (5) years post construction; and

(ii) Total settlement – Allowable settlement for road < 250mm for five (5) years post construction.

(a) Section 481.7, Federal Route (FT) 005 (Bridge of Sultan Salahuddin Abdul Aziz(SSAA)

Based on the eight (8) recorded data observed, it can be concluded that the settlement readings for all the settlement markers during the period of 14 months are considered within tolerable limits which is 250mm/5 year (total settlement) and 100 mm/5 years (differential settlement). After a year, at settlement markers SM 2 and SM 3 (which seated on compacted fill) show that the road experienced drastic drop just after PU foam injection. PU foam expands and plug the edge of piled embankment and filled the cavities. At the same time, it densifies and increase the soil beneath the structures. The settlements at SM 4 and SM 5 are slowly increased because at median of the approach, there were no injection points located. All the data are still not stable

within 14 months from 4th September 2019 until 3rd November 2020 because uplifting occurred due to the lightweight capability of the PU foam and rearrangement of soil particles to achieve a stable compaction condition. The graphs shown in Figure 12 (a) and 12 (b) illustrated that the displacement is either settlement or uplifting due to buoyancy effect of the PU foam injected at SSAA bridge.

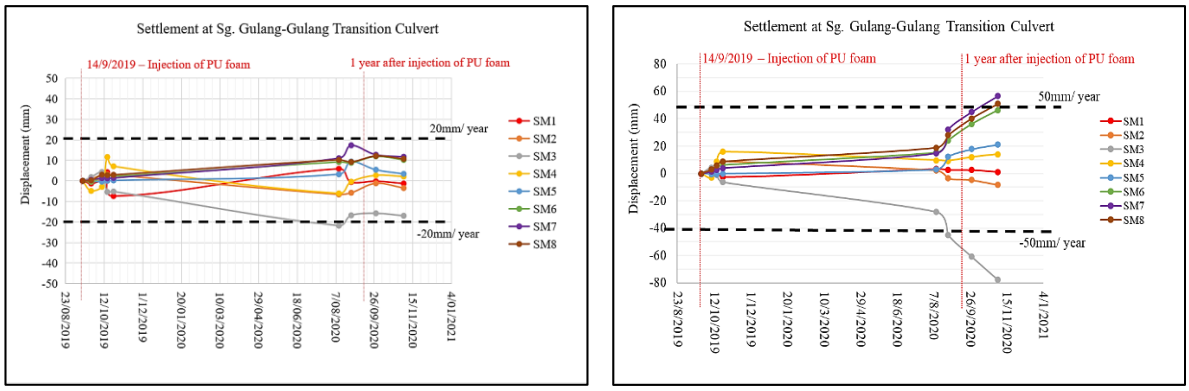


(a) (b)

Fig. 12. The pattern of ground movement at transition Bridge of Sultan Salahuddin Abdul Aziz (a) settlement (b) Cumulative settlement

(b) Section 491.8, Federal Route (FT) 005 (Sg. Gulang-Gulang Box Culvert)

The graphs shown in Figure 12 (a) and (b) illustrated that the settlement data from 14th September 2019 until 3rd November 2020. The result shown the settlement were kept increasing or decreasing after a year of improvement. Figure 13 (a) and (b) show the displacement monitored at Sg. Gulang-Gulang Box Culvert. From the observation of displacement monitoring, the differential settlement readings for all the settlement markers during the period of 14 months are considered within tolerable limits which is 100 mm/5 years. Displacements at settlement markers SM 6, SM 7 and SM 8 were kept increasing and near to the limit set for differential settlement. Settlement markers, SM 6, SM 7 and SM 8 located at west bound (slow lane direction from Teluk Intan to Klang), were not injected by PU foam due to limited cost of repair work and the during that time, the route was already repaired by other method. Furthermore, the possibility of settlement at SM 6, SM7 and SM 8 because the area was founded on the loosen compacted material, hence causing migration of the fill material into the enlargement of void present underneath the piled box culvert.



(a) (b)

Fig. 13. The pattern of ground movement at transition box culvert (a) settlement (b) Cumulative settlement.

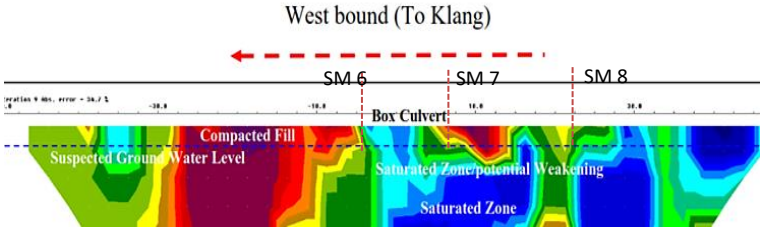


Fig. 14. Settlement marker SM 6, SM7 and SM 8 located on the weak ground layer which is suspected to be saturated loose compacted material.

At settlement marker SM 3 located on compacted fill, the settlement value is slightly excessive and there is presence of uplifting due to the lightweight capability of the PU foam. The data at settlement markers SM 1, SM 2, SM 4 and SM 5 are within the tolerable limit and show consistency. Within 14 months monitoring of settlement at these four (4) points indicated the effectiveness and excellent performance of PU foam injection method to stabilise differential settlement at the transition approach of the box culvert.

Conclusions

The selection of ground improvement method depends on the effectiveness of data analysis from field investigations. Based on these case studies, PU foam injection is more successful in mitigating the settlement at approach of box culvert within the study period. However, it is recommended that the settlement monitoring should be continued for a longer period in order to evaluate the performance of PU foam at the bridge and culvert transition approaches. In addition, this treatment is an alternative rapid solution without road closure and stationed traffic diversion. Since PU foam is a lightweight material, therefore it needs adequate surcharge that can control its buoyancy effect. The limited data analysis cannot conclude that the PU foam injection method is the best ground improvement method, but PU foam injection method can be listed as one of alternative ground rehabilitation solution to reduce the effect of differential settlement at bridge and culvert transition approaches.

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Application of Geophysical Electrical Resistivity Tomography (ERT) Survey in Identifying Road Problems at Rengit, Batu Pahat Johor, Malaysia

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Abstract

The use of geophysical Electrical Resistivity Tomography (ERT) Survey in identifying road problems has become widespread in recent years. It enables the determination of subsurface profiling related to cavities, overburden materials, boulder, ground water and fault zone at site. This approach is conducted in investigating the root causes of pavement distress at Federal Road FT005, Rengit, Batu Pahat, Johor. Two (2) ERT profiles were taken at 200-meter and 100-meter at Section 90.0, Rengit using Gradient_XI protocol. The aim of ERT survey is to obtain subsurface profiling of the 20 meter to 40 meter depth along the road stretch of problematic area. This ERT survey integrates with other geotechnical forensic methods using Trial Pit, Mackintosh Probe and Borehole. Based on ERT results, the majority of the apparent resistivity value is less than 100 ohm.m, which indicates that the subsurface ground is in a saturated condition, experiencing a decrease in porosity and slightly increases its density with depth. ERT result of RL2 profile shows that the top layer has high apparent resistivity of up to 500 ohm.m due to close spacing electrode of 2.5 meter. This spacing enables the measurement of the apparent resistivity of pavement and concrete slab at shallow depth or layer. The apparent electrical resistivity result is confirmed by the boreholes data, which shows lower SPT-N value at 16.5 meter depth due to the presence of soft clay layer. Therefore, the results of the boreholes are consistent with the soil profile from the ERT survey. In conclusion, ERT survey is significant in determining the subsurface profile and identifying soils physical properties to find the best solution to solve pavement distress problems.

Keywords: Electrical resistivity tomography; Subsurface profiling; Apparent resistivity value

Introduction

The geophysical survey is widely used in determining the sub-surface profile especially in investigating the root causes of damaged roads. The existence of soft soil underlying the pavement road usually causes pavement distress. In addition, pavement distress may also arise due to the difference in methods of construction during widening or rehabilitation of roads thus, causing longitudinal crack and differential settlement to occur. These problematic road conditions become a hazard, in term of safety and comfortability, to road users. A non-destructive method using geophysical survey offers certain advantages such as cost-effective relative to large area information, time-saving due to rapid method execution and ease of handling due to site accessibility and portable equipment. Furthermore, execution of geophysical survey gives minimum impact to the environment as compared to that by the

destructive method. The types of geophysical survey include Seismic Refraction, Ground Penetration Radar (GPR) and Electrical Resistivity Tomography (ERT).

Literature Review

Electrical Resistivity Tomography is a geophysical technique for imaging sub-surface structure from electrical resistivity measurements made at the surface or by electrodes. ERT is a very effective technique to detect the presence of any soft soil layer. It is helpful in detecting the intrusion of any soft layer pocket within a hard stratum or vice versa. ERT is very efficient, reliable and time efficient technique to obtain the extent of soil layers in a heterogeneous ground. ERT can be used to predict settlement behavior of any embankment (A.Saha, S.Kundu and A.K.Dey, 2019).

The resistivity method basically measures the resistivity distribution of the subsurface material. The property of the electrical resistance of a material is usually expressed in term of its resistivity. If the resistance between opposites faces of a conducting body of length ⌊ and uniform cross-sectional area A is R, the resistivity, ρ, is expressed as

$$\rho = RA/\lfloor \quad \text{(Eq. 1)}$$

The SI unit of resistivity is ohm meter (Ω m) [2].

Archie (1942) observed that the apparent resistivity of material (R_o) is directly proportional to the resistivity of the fluid (R_w). The constant of proportionality *F* is called the formation factor and describes the effect of the variables tortuosity (α), the porosity (ϕ^{-m}) and the water saturation (S_W^n). The parameters that are affected by tortuosity is related to path length of the current flow and mostly determined by the pore structure and grain sizes ranges from 0.5 to 1.5 depending on the type of formation. The saturation exponent, n, is usually fixed to 2 and under fully saturated condition the saturation is considered 1. Porosity is a measure of void spaces in the material and is a factor of fraction of volume of voids over the total volume, between 0 and 1. The porosity is influenced by the particle sizes and density. The porosity exponent is called cementation factor, m, usually varies from 1.7 to 3. For unconsolidated ground, the values of m and n are 2.05 and 0.62, respectively (Asquith, 2004). These formula explain the parameters that affects the measured resistivity.

$$R_o = F\, R_W \quad \text{(Eq. 2)}$$

$$F = \alpha\, \phi^{-m} S_W^{-n} \quad \text{(Eq. 3)}$$

Table 1 shows the resistivity values of some typical rocks, soil materials and water (Keller and Frishchknecht, 1996). Igneous and metamorphic rocks typically have high resistivity values. The resistivity of these rocks is reflected to the Archie's law, i.e. tortuosity, degree of fracturing related to porosity, degree of satutarion and the resistivity value of groundwater. As a result, the soils/rocks above the water table are drier and having higher resistivity values of several hundreds to several thousands ohm-m, while below the water table generally the resistivity values are less than 100 ohm-m. In addition, clay has a significantly lower resistivity value as compared to sand due to its porosity. Table 2 shows some resistivity value that had been used in the interpretation and analysis results.

Table 1 Resistivity of some common rocks and soil materials in the survey area (Keller and Frischknecht, 1966)

Material	Resistivity (Ohm.m)
Alluvium	10 to 800
Sand	60 to 1000
Clay	1 to 100
Groundwater (fresh)	10 to 100
Sandstone	8 - 4000
Shale	20 - 2000
Limestone	50 - 4000
Granite	5000 to 1,000,000

Table 2 Electrical resistivity of some types of water (Keller and Frischknecht, 1966)

Type of water	Resistivity (Ohm.m)
Precipitation	30 to 1000
Surface water, in areas of igneous rock	30 to 500
Surface water, in areas of sedimentary rock	10 to 100
Groundwater, in areas of igneous rock	30 to 150
Groundwater, in areas of sedimentary rock	> 1
Seawater	≈ 0.2
Drinking water (max. salt content 0.25%)	>1.8
Water for irrigation and stock watering (max. salt content 0.25%)	>0.65

Generally, the resistivity data from the field are apparent resistivity. For field practice, different electrode configurations have been designed. Several commonly used linear array-time arrangements are Wenner, gradient, Schlumberger, pole-dipole and dipole-dipole array as shown in Figure 1. C1, C2 and P1, P2 denote the positions of the current and potential electrodes respectively. For the gradient and symmetrical Schlumberger arrays, it is common to use symbols A, B for the current electrode and M, N for the potential electrodes (Prem, 1997).

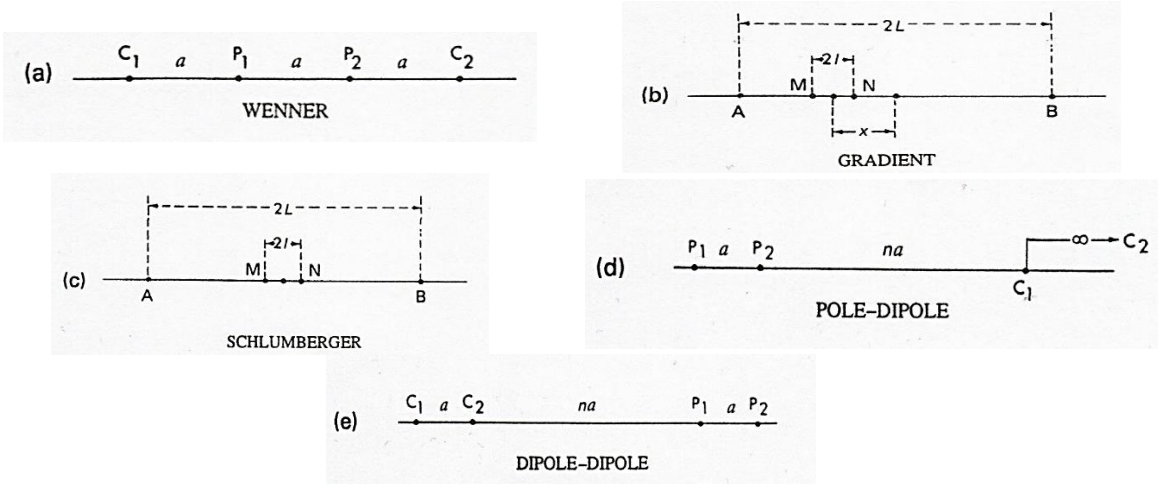


Fig. 1. Commonly used electrode arrays in resistivity.

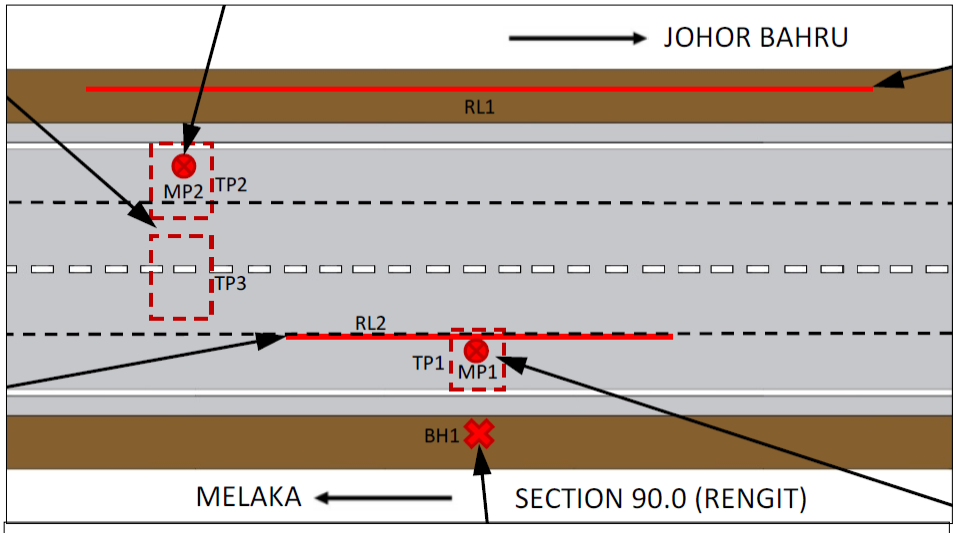
There are various researchers who had conducted ERT by using multiple-gradient array. The multiple-gradient array provides very stable field data acquisition with good signal-to-noise ratio. Inverted models based on multiple-gradient array data generally compare well with those based on Wenner and dipole-dipole data. The multiple-gradient array is well suited for multichannel data acquisition, but is also a good alternative for single-channel data acquisition (Torleif Dahlin and Bing Zhou, 2016).

Background of Study

The conditions of damaged roads consist of signs of deformation and surface pavement distress. There are longitudinal and patches cracks along Federal Road FT005 at Rengit, Batu Pahat, Johor. In an attempt to determine the root cause of this problem, a non-destructive method using ERT was conducted at Section 90.0. Meanwhile, destructive methods, including Trial Pit, Mackintosh Probe and Borehole, were also conducted to verify and complement the results of ERT. The integration of all the data from different methods gave significance information to find the solutions to this problem. Field investigation was conducted by Preston Sdn. Bhd with close monitoring by Pusat Kecemerlangan Kejuruteraan dan Teknologi JKR (CREaTE), Cawangan Kejuruteraan Geoteknik (CKG), and Jabatan Kerja Raya (JKR) Daerah Batu Pahat, Johor.

Methodology

Two (2) ERT survey lines were conducted at 200 meter in length for RL1 using four multipurpose cables with 2.5 m of electrode spacing, and 100 meter in length for RL2 with 1.25 m of electrode spacing. The survey line RL1 was conducted at the edge of the road shoulder lane towards Johor Bahru meanwhile, RL2 was conducted on the road at the lane heading towards Melaka as shown in Figure 2. The location of ERT survey lines, Trial Pit, Borehole and Mackintosh Probe test are tabulated in Table 3 and Table 4.



Abbreviation:
RL1 & RL2 = Resistivity Line No.1 & No.2
MP1 & MP2 – Mackintosh Probe No.1 & No.2
TP1, TP2 & TP3 – Trial Pit No.1, No.2 & No.3
BH1 = Borehole No.1

Fig. 2. Location of Electrical Resistivity Tomography test, Trial Pit test, Mackintosh Probe test and Borehole at Section 90.0

Table 3 Coordinates and lengths of resistivity line at Rengit, Batu Pahat, Johor.

Line	Start		End		Length of Profile (m)
	Northing, N (00° 00’ 00’’)	Easting, E (00° 00’ 00’’)	Northing, N (00° 00’ 00’’)	Easting, E (00° 00’ 00’’)	
RL1	1°40'9.54"N	103°10'38.89"E	1°40'6.72"N	103°10'44.27"E	200
RL2	1°40'8.48"N	103°10'39.95"E	1°40'7.17"N	103°10'42.62"E	100

Table 4 Coordinates of Borehole Point, Trial Pit and Mackintosh Probe points at Rengit, Batu Pahat, Johor.

Point	Coordinates		Point	Coordinates	
	Northing, N (00° 00’ 00’’)	Easting, E (00° 00’ 00’’)		Northing, N (00° 00’ 00’’)	Easting, E (00° 00’ 00’’)
BH1	1°40'7.73"N	103°10'38.89"E	TP1	1°40'6.1"N	103°10'44.5"E
MP1	1°40'6.1"N	103°10'44.5"E	TP2	1°40'6.1"N	103°10'44.5"E
MP2	1°40'6.1"N	103°10'44.5"E	TP3	1°40'6.1"N	103°10'44.5"E

The proper planning before data aquisition works at site will give a great influence in term of time saving. Feasibility study needs to be conducted before mobilizing to the site. Such site information including topographical maps, geological maps, aerial photographs, google earth, report etc. are needed to consider the suitability of ERT method for such area before proposing the best profile lines. Additionally, any obstruction needs to be avoided before setting up of the equipment. The electrode cables arrangement is shown in Figure 3 with cables distance according to profile lines length as tabulated in Table 5. Four cables were used to maximize the quantity of data, which provide better tomography plot.

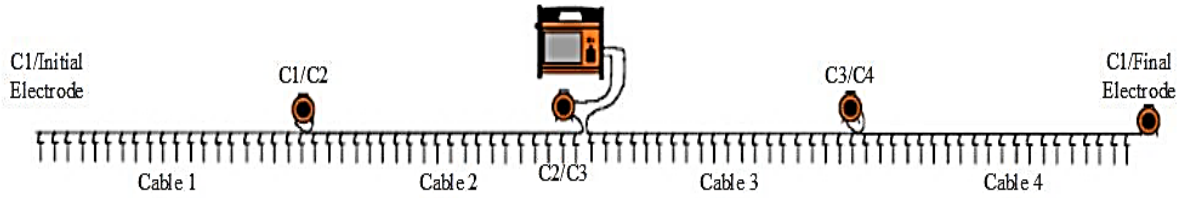


Fig. 3. Electrode cables arrangement

Table 5 Electrode cable distances according to profile lines length

Profile Length (m)	C 1/ Initial electrode – C1/C2 (sharing)	C1/C2 (sharing) – C2/C3 (Center)	C2/C3 (Center) – C3/C4 (sharing)	C3/C4 (sharing) – C4 / Last electrode
200 m	50 m	50 m	50 m	50 m
100 m	25 m	25 m	25 m	25 m

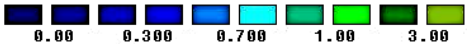
All imaging cables were rolled out in the direction of the profile with increasing take out numbers, in the same direction as the increasing coordinate numbers. The electrode cables were connected to the Terrameter LS 2, which needs to be connected in the order related to the cable layout where Cable 1 and Cable 2 were known as Connector 1, and Cable 3 and Cable 4 were known as Connector 2. After connecting all the equipment, the Terrameter LS 2 was connected to the external power supply and the instrument was switched on.

Results and Discussion

Interpretation of Results for Electrical Resistivity Tomography (ERT)

This is the classification of soft clay at the study area based on Electrical Resistivity Tomography (ERT) testing. Table 6 shows the resistivity value range that was adopted in the interpretation of the ground profile.

Table 6 Resistivity value interpretation.

Resistivity Value (Ωm)	Legends	Interpretation
1 – 100		Zone of saturated soil
> 100		Zone of unsaturated soil

The RES2DINV program was used to process the conversion of raw data in the extension of the DAT format. RES2DINV uses a least-squares inversion scheme to determine the appropriate resistivity value, so that the calculated apparent resistivity values agree with the measured values. The inversion process was carried out to obtain three types of resistivity section that consist of calculating apparent resistivity, measured apparent resistivity and inverse model resistivity (Archie, 1942). The misfit between measured and calculated apparent resistivity produce root mean square (RMS) values. The RMS error may be due to random and systematic errors. Random errors may be caused by the effect of telluric current that gives influence to the whole resistivity readings, while systemic errors may be caused by infirm contact between the electrode and earth. The resistivity contour values were adjusted based on geological information that fit the resistivity range with different colors. The summary of data before and after the analysis using RES2DINV is tabulated in Table **7**.

Table 7 Summary of data before and after being processed.

Location	Profile Line	Protocol	Number of Original Data	Negative Data	Total data after analysis	"Bad Data"	RMS Error (%)
Rengit,	(RL1)	Gradient_XL	827	152	620	207	39.9
Batu Pahat	(RL2)	Gradient_XL	1030	255	775	255	38.8

The electrical resistivity tomography results for RL1 and RL2 at Rengit are shown in Figure 4 and Figure 5 respectively. Figure 4 shows the result for survey RL1 at a 200 meter length of a 40 meter depth profile. The majority of the apparent resistivity value is less than 100 ohm.m, which indicates that the subsurface ground is in a saturated condition. The apparent resistivity value slightly increases with depth from 0.5 ohm.m to 100 ohm.m. The apparent resistivity tomography shows that the soil profile can be divided into three layers, namely below 30 ohm.m, between 30 and 60 ohm.m, and more than 60 ohm.m. It shows that the soil profile decreases its porosity and increases in density with depth. Figure 5 shows the result of survey RL2 at a 100 meter length of a 20 meter depth profile. The majority of the apparent resistivity value is less than 100 ohm.m, which indicates that the subsurface ground is in a saturated condition. The top layer shows high resistivity of up to 500 ohm.m due to the presence of pavement and concrete slab layer. The close spacing of electrode of 2.5 meter is able to measure the apparent resistivity of the top layer. Below the pavement, the soil apparent resistivity

tomography profile can be divided into three layers similar to that at RL1, namely below 30 ohm.m, between 30 and 60 ohm.m, and more than 60 ohm.m. It shows that the soil decreases its porosity and increases in density value with depth. The borehole result from 1.5 meters to 15.0 meters indicates a very soft clay from the borehole (BH1 at Section 90.0 – Rengit).

The electrical resistivity results are supported by the borehole data, which shows lower SPT-N values at 16.5 meter depth. It was found that the clay soil layers are up to 40.5 m deep which has been supported by the results from the apparent resistivity measurements. By reducing the electrode spacing, it is expected that the apparent resistivity of top layer of pavement and concrete slab will be increased. It is worth to note that the apparent resistivity is related to porosity. It shows that the soil profile decreases its porosity and increases in density with depth. Meanwhile, the porosity is associated to many factors such as density, particle size and shape, pore structure, clay content and mineralogy (Asquith, G. and Krygowski, 2004). Therefore, the results of the boreholes were consistent with the soil profile from the geophysical survey.

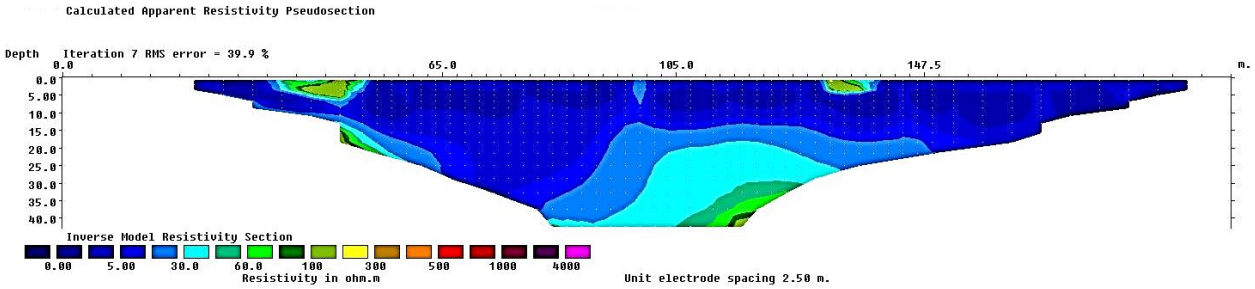


Fig. 4. Resistivity result for Line RL1 @ Section 90.0 – Rengit

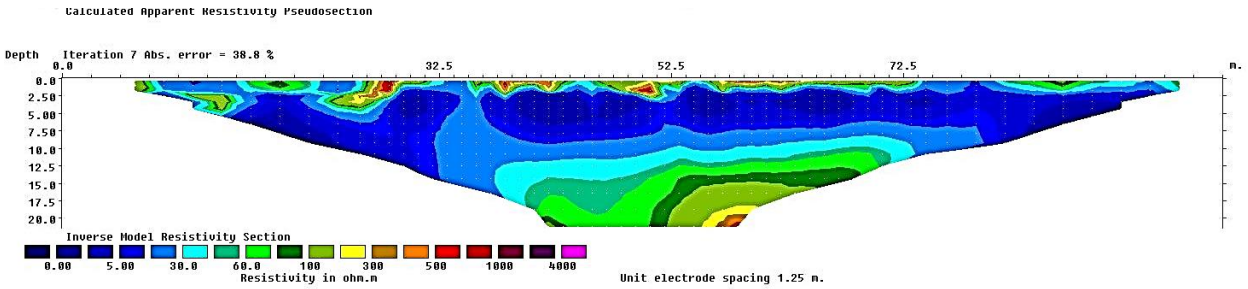


Fig. 5. Resistivity result for Line RL2 @ Section 90.0 – Rengit

Conclusions

ERT survey is a significant approach in determining the subsurface profile. ERT revealed a subsurface environment characterized by similar geological materials such as clay whose thicknesses and resistivities vary and/or in conformity with the elevation of the surface. Therefore, this study has shown that ERT can reasonably be used in identifying soils physical properties in an attempt to find the best solution to solve engineering problems.

Acknowledgements

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Effects of Additive to the Binder Properties and Asphalt Stability

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Abstract

Additives can be incorporated into asphalt using two techniques referred to as wet process and dry process. In wet process, additive acts as a bitumen modifier to improve the binder properties. While in dry process, additive is used to be part of the fine aggregates to improve aggregate-bitumen bonding. The objectives of this study are to compare the changes in main binder properties which are softening point and performance grade when the binder is modified via a wet process, and to assess the Marshall stability and retained Marshall stability properties of the modified asphalt (wet and dry processes) produced. This paper highlights the findings from field studies in Malaysia on binder and their asphalt mixes produced by incorporating various forms of additive, which are synthetic polymer (e.g., hard wax, waste plastic), natural polymer (e.g., natural rubber latex, natural rubber cup lump and crumb rubber) and fibre (e.g., cellulose), by wet or dry processes. The field trials have been carried out in year 2019 on Muar – Tangkak, and Kampar – Tanjung Malim roads. The results indicate that the softening point temperature increases when bitumen grade 60-70 is modified with any form of additive via wet process. The performance of bitumen grade 60-70 from PG70 has improved to at least PG76 by adding additive. The asphalt mixes resistance to water was also enhanced. Furthermore, the stability of the asphalt mixes is mainly influenced by aggregate's grading and type of binder, which develop the asphalt skeleton structure.

Keywords: Asphalt modification; Additives; Bitumen modifier; Binder properties; Asphalt stability

Introduction

Lately, the issue of premature road pavement distresses, has been a hot discussion topic among the community. These distresses, whether structural or functional, are often associated withthe quality of the pavement material. The fact is, there are various factors which could contribute to road pavement distresses, such as unexpected traffic loading increment, overloading commercial vehicles, and global warming effects. A lot of efforts have been done by the road authority to overcomethese problems, such as upgrading the road structure and enforcement of weight restriction order for commercial vehicles. Researchers and technologists in the road industry are trying hard to look for the best solution to enhance the quality of road pavement by modifying the pavement material, of which asphalt is mostly used. Innovation in asphalt modification started in the 1930s; and the technology was widely used around the world in 1980s due to the demand for more durable asphalt [1]. This technology development has contributed to the diversity of additives used, and techniques of incorporating into the asphalt [2].

In Malaysia, Jabatan Kerja Raya Malaysia (JKR) is the main technical agency in the road industry, which plays an important role to provide good and quality road network for the

community. Their continuous effort in enhancing the quality of road pavement never ends. JKR has the expertise in the production and placement of conventional asphalt mixes since its inception in 1872. It is reported that the first trial using rubberised bitumen was initiated in the 1950s, when 100 yards of road between Kota Bharu and Kuala Krai was laid, and the innovation continues until now. The largest scale project in Malaysia, using modified asphalt, was constructed in Kuala Lumpur International Airport (KLIA) runway and taxiway in 1997 using synthetic polymers Low Density Polyethylene (LDPE), Ethylene Methacrylate (EMA) and Styrene-Butadiene-Styrene (SBS). Of late, various forms of additive such as synthetic polymer (e.g., waste plastic), natural polymer (e.g., natural rubber latex, natural rubber cup lump and crumb rubber) and fibre (e.g., synthetic and cellulose), have been intensively incorporated into asphalt by wet and dry process.

The objective of this paper is to highlight the findings obtained from field studies done in 2019 on binder and their asphalt mixes which have been incorporated with various forms of additive.

Literature Review

Asphalt Modification Techniques

As reported by Federal Highway Administration Research and Technology, US (FHWA-RD-97- 148) (2016), additives can be incorporated into asphalt via two techniques, which are wet process and dry process [3]. The wet process involves mixing additives with the bitumen; while, in the dry process, the additives is used to replace part of the fine aggregates. Both techniques modify the properties of the modified asphalt. Among these two techniques, the wet method is the most widely used [4].

a. Wet Process

The wet process can be used to modify the binder to produce a hot asphalt mixture, as well as chipseal or surface treatment. The wet process can also be used in developing joint and crack sealant mixtures. According to FHWA, the main properties that change when a binder is modified via wet process are the viscosity and softening point of the binder; resilient modulus, permanent deformation, thermal cracking, and resistance to aging of the asphalt mixtures. Wet process improves binder properties, mainly their stiffness and elasticity. Better binder stiffness contributes to higher asphalt pavement deformation resistance which reduces the rutting, and higher binder elasticity reducing the fatigue cracking formation [5].

b. Dry Process

For the dry process, the additives are heated together with the aggregates before being mixed with the bitumen to produce an asphalt mixture. Dry process improves aggregate-bitumen bonding. The additive acts as a substitute to the aggregate they replace. This modified asphalt increases skid resistance, and reduces the reflective and thermal cracking, fatigue cracking and rutting formation [5]. Currently, most researchers and industry players are less interested in modifying asphalt mixes through dry process due to the lack of standards and guidelines for its production as well as reported inconsistent asphalt mix performance [6].

The most significant difference between these two techniques is the binding property; the binding property is more effectively modified in the wet process than in the dry process, because of its direct interaction with the additives [7].

Asphalt Modification Advantages

Researchers have recognized the advantages of using modified asphalt to reduce pavement distresses in term of amount and severity, and to increase the pavement service life. High performance modified asphalt can mainly improve rutting resistance, reduce thermal cracking, and improve mixture durability. Some modified binders can also improve stripping resistance.

Walker D. (2014) in his article 'The benefits of modified asphalts' reported that many agencies estimate that pavement life could be extended to an additional of four to six years using a modified asphalt binder, depending on the site condition. He summarized the expected increase in service life of flexible pavement and hot mix asphalt overlays as shown in Table 1 [2].

Table 1 Expected increase in service life for flexible pavements and hot mix asphalt overlays [2].
(Assuming that polymer modified asphalt (PMA) mixtures are used in the wearing surface and base layers and that the conventional mixtures were designed for 20 years)

Site feature	Condition description		Increase inservice life,years
Foundation soils	Non-expansive soils, coarse-grained soils		5 – 10
	Expansive soils, moderately to highly plastic soils (PL>35)		2 – 5
	Frost susceptible soils in cold climates; moderately to highly frost susceptible (Class 3 and 4)		2 – 5
Water table depth	Deep		5 – 10
	Shallow, adequate drainage		5 – 8
	Shallow, inadequate drainage		0 – 2
Traffic	Low	Stop & go/ intersections	5 – 10
		Thoroughfares	3 – 6
		Heavy loads/ special containers	5 – 10
	Moderate volumes		5 – 10
	High volumes		5 – 10
Climate	Hot		5 – 10
	Mild		2 – 5
	Cold		3 – 6
Existing Pavement Condition	HMA	Good condition	5 – 10
		Poor condition, extensive cracking	1 – 3
	PCC/ JPCP	Good condition	3 – 6
		Poor condition, faulting & mid-panel cracking	0 – 2

Notes:

- *The range of the increase in service life was based on the comparison of actual distress measurements.*
- *The increase in service life is an estimate based on assumed layer properties and conditions.*
- *Without the use of any reflection cracking mitigation techniques.*

Even though the advantages of using modified asphalts are widely acknowledged, not all asphalt mixes or treatments need to be modified. Each application of modified asphalt should be assessed to justify the use of modifiers which is appropriate to the traffic loading, anticipated service life, environmental conditions, and desired performance [2]. Modified asphalts can be a good investment depending on its needs and usage.

Full-Scale Road Trial in Malaysia

JKR's continuous effort in supporting the use of new technology in pavement material can be seen through an increase in allocation for specialty mixes every year in the Federal Road maintenance program: 5% in 2018, 44% in 2019, 56% in 2020 and 41% in 2021. The specialty mixes used in between 2018 and 2021 were stone mastic asphalt (SMA), polymer modified asphalt (PMA), crumb rubber – gap graded asphalt (CR-GGA), latex asphalt, cup lump modified asphalt (CMA), super fibre mix (SFM), micro-surfacing, concrete pavement, polymer modified chemical (PMC), road base stabiliser and others.

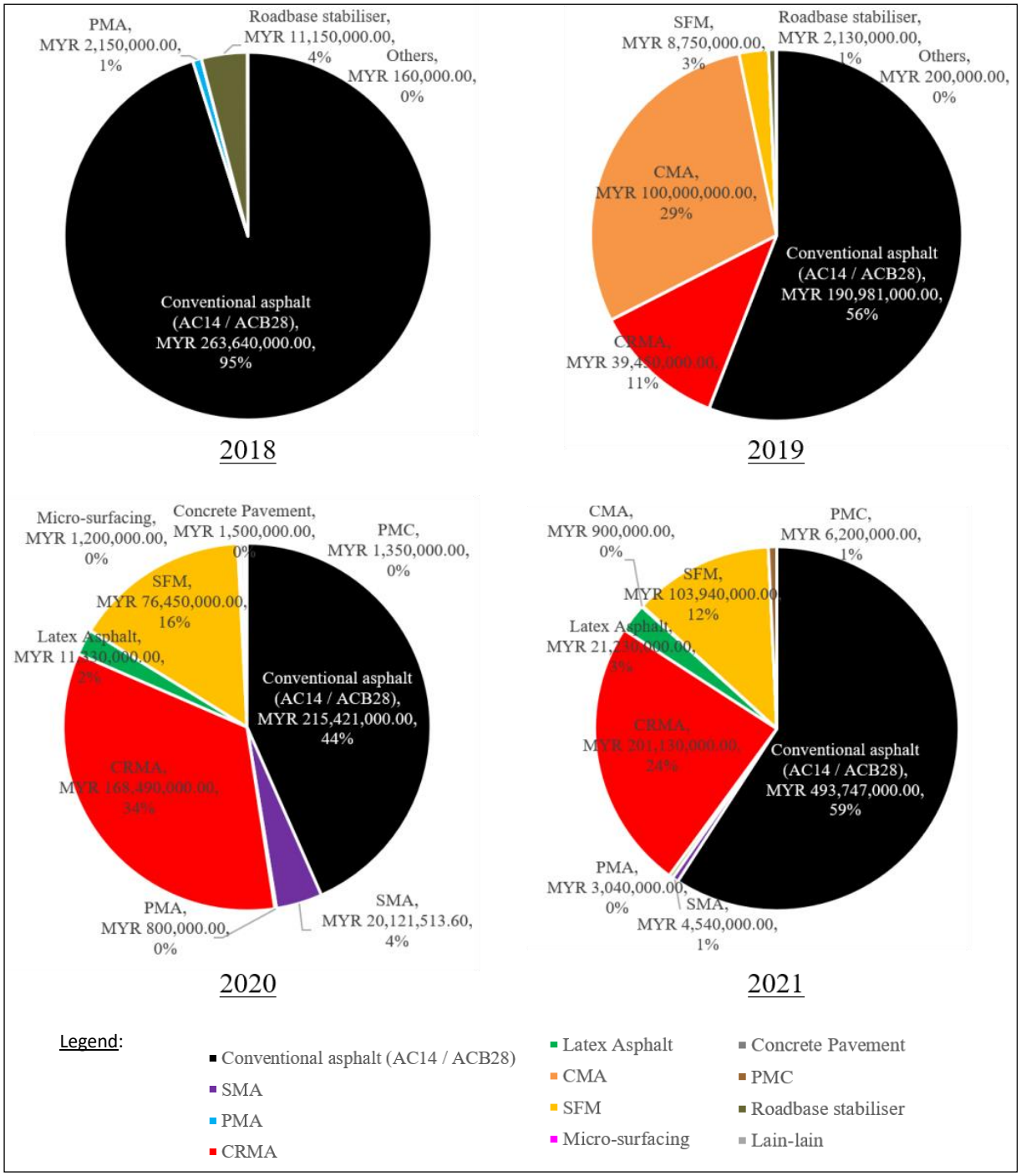

Fig. 1. Federal road maintenance budget allocation in year 2018 to 2021 according to the types of pavement material.

With the establishment of JKR Centre of Excellence for Engineering and Technology (CREaTE) in Alor Gajah, Melaka in 2016, a more concerted effort was given by JKR in the research works of modified asphalt. A lot of full-scale road trials have been built using various forms of additive, such as synthetic polymer (e.g., hard wax, waste plastic), natural polymer (e.g., natural rubber latex, natural rubber cup lump and crumb rubber) and fibre (e.g., synthetic and cellulose), intensively incorporated into asphalt by wet and dry processes.

Objectives

The objectives of this study are to compare the changes in main binder properties, which are softening point and performance grade, when the binder is modified via a wet process, and to assess the Marshall stability and retained Marshall stability properties of the modified asphalt (wet and dry processes) produced.

Experimental Design

In this study, the test results from a few full-scale road trials conducted by Road Research Laboratory (RRL), CREaTE in 2019 were compiled. The recent field trial sites have been carried out on a few locations using various types of additive via both wet and dry process asphalt modifications as shown in Table 2 and 3. Laboratory tests were done on the binder and asphalt samples taken from these projects, in addition to tests done for quality control.

Table 2 Full-scale field trial sites.

Year	Location	Additive		Type of binder	Type of asphalt
		Material	Quantity		
2019	Muar – Tangkak road	waste plastic (agglomer)	0.5% by weight of aggregate	bitumen 60-70	dense-graded asphalt
			4% by weight of bitumen	plastic modified binder	dense-graded asphalt
		synthetic hard wax	3% by weight of bitumen	warm mix binder	dense-graded asphalt
	Kampar – Tanjung Malim road	natural rubber cup lump	5% by weight of bitumen	cup lump modified binder	dense-graded asphalt
		cellulose fibre	0.3% by weight of total mix	bitumen - latex	stone mastic asphalt (gap-graded asphalt)
		natural rubber latex	3% by weight of bitumen		dense-graded asphalt
		crumb rubber	20% by weight of bitumen	crumb rubber modified binder	gap-graded asphalt

Additives in Asphalt Modification

Additives, as listed in Table 2, used in these field trial sites were waste plastic (agglomer), synthetic hard wax, natural rubber latex, natural rubber cup lump, crumb rubber and cellulose fibre. The asphalt modification processes are as in Table 3.

Table 3 Asphalt modification for field trial sites.

Additive				Modification process			
Type	Material	Form	Photo	Type	Location	Photo	Purpose
Synthetic Polymer	waste plastic (agglomer)	solid		dry process	field blend		To improve aggregate-bitumen bonding.
				wet process	field blend		To improve binder properties.
Synthetic Polymer	synthetic hard wax	solid		wet process	field blend		To improve binder properties.
Natural Polymer	natural rubber cup lump	solid		wet process	terminal blend		To improve binder properties.
	natural rubber latex	liquid		wet process	field blend		To improve binder properties.
	crumb rubber	solid		wet process	terminal blend		To improve binder properties.
Fibre	cellulose fibre	solid		dry process	field blend		To reduce binder drain-down in stone mastic asphalt.

For wet process, bitumen 60-70 was mixed with the additive to improve their properties. Then, the modified binder was mixed with the aggregate to produce modified asphalt. However, for conventional binder, which is bitumen 60-70, is appropriate to prepare modifed asphalt using the dry process. Except for stone mastic asphalt, cellulose fibre was added into the aggregate via dry process, and bitumen - latex was used as binder grade PG76 as specified in the JKR Standard Specification for Road Works Section 4: Flexible Pavement. These dry and wet processes of asphalt modification can be done at the asphalt production quarry, also known as field blend. However, because of the solid form of cup lump and crumb rubber, as additives in binder, blending process to produce cup lump modified binder and crumb rubber modified binder

is more complex hence, terminal blend (mixing in the factory) to produce a homogenous bitumen - rubber blend is recommend.

All mix designs for the modified asphalt in this study were done according to the Marshall method as specified in the current JKR Standard Specification for Road Works Section 4: Flexible Pavement.

Modified Binder Properties

To ensure that the quality of modified binders produced achieves the quality specified, modified binder samples are taken prior to asphalt production. Then, the modified binder samples were tested for penetration, softening point, flash point, viscosity, mass loss and dynamic shear properties. In this study, assessment was done on the main parameters namely softening point and dynamic shear properties due to limited tests required in the specifications and data availability on other parameters.

Meanwhile, the softening point test was performed according to the ASTM D36 procedure to determine the temperature point at which the binder begins to soften and change properties from semi-solid to liquid. The softening point value should be higher than the highest temperature of the road pavement. If the pavement temperature exceeds the softening point temperature, the binder will become soft, and will cause rutting and bleeding to the road pavement.

Dynamic shear testing, using dynamic shear rheometer (DSR) equipment, was performed according to the AASHTO T315 procedure to determine the performance grade (PG) of the modified binder. The DSR can measure the elastic and non-elastic components in the binder. The phase angle, δ, gives an indication of the elastic component. Smaller value of δ indicates higher elastic component. If $\delta = 0°$, the binder is considered totally elastic. Conversely, if $\delta = 90°$, the binder is totally viscous or non-elastic. Whereas, the value of complex shear modulus, G*, gives an indication of the binder viscosity. The more viscous the binder, is the higher the G*value.

Modified Asphalt Marshall Properties

Asphalt production samples were tested under the Marshall standard to ensure that the modified asphalt produced meet the quality specified. For this study, only Marshall stability and retained Marshall stability parameters were assessed. However, retained Marshall stability parameter was not specified in the applicable specifications. Hence, the retained Marshall stability value of not more than 85% was taken into consideration, based on literature review. To assess these parameters, other common parameters on asphalt Marshall properties (e.g., stability and flowtest, specific gravity, and voids analysis) must comply to the requirement as in the specification.

Asphalt specimens were tested after immersions in a water bath at 60°C for 24 hours. The percentage of retained Marshall stability indicates the effects of water on the mixes. A higher value indicates higher water resistance. The retained Marshall stability was used to evaluate resistance of specimen to water as some researchers have used retained Marshall stability for evaluating resistance of asphalt mixtures to moisture [8, 9]. It is well known that the presence of water in asphalt is a critical factor which can lead to premature failure of asphalt pavement.

Results and Discussion

Softening point and dynamic shear properties of the binder samples tested for this study are show in Table 4.

Table 4 Softening point and dynamic shear properties of the binder.

Parameter			Bitumen 60-70	Modified binder				
				PMB	WMB	CMB	Bitumen - latex	CRMB
Softening point (°C)			49	53	62	57	54	61
Dynamic shear (prior to RTFOT)	Test temperature, 76 °C	G* (kPa)	1.06	1.14	1.81	1.26	1.03	1.57
		δ (°)	85	81	77	78	81	63
		G*/sin δ (kPa)	1.06	1.15	1.86	1.29	1.04	1.76
	Performance grade		PG70	PG76	PG82	PG76	PG76	PG82

Notes:
PMB – plastic modified binder
WMB – warm mix binder
CMB – cup lump modified binder
CRMB – crumb rubber modified binder
RTFOT – rolling thin film oven test

The results of the softening point test show that the softening point temperature increases when the bitumen grade 60-70 is modified with any kind of additive. This indicates that the temperature point at which the binder begins to soften and change properties from semi-solid to liquid has increased. The results of this test also indicate that the bitumen 60-70's viscosity at 49°C is equal to the PMB's viscosity at 81°C, WMB's viscosity at 62°C, CMB's viscosity at 57°C, bitumen- latex's viscosity at 54°C, and CRMB's viscosity at 61°C. As stated in the Buku Ujian Makmal - bitumen, aggregate & asphalt (2018), previous studies have found that the viscosity value of bitumen at softening point temperature is 1,200 Pa.s or 12,000 poise [10]. This indicates that the resistance to rutting and bleeding can be improved by the addition of various forms of additive into bitumen grade 60-70.

The results of the dynamic shear test show that bitumen grade 60-70 gives a value of δ, 85° which is almost 90°, meaning almost no elastic component. When additive was mixed with bitumen grade 60-70 (wet process) to produce a modified binder, the value of δ is smaller. This indicates that there is an increase of the elastic component in the binder, of which the highest elastic component is in the CRMB. The G* value for modified binder is also higher than the G* value for bitumen grade 60-70; except bitumen-latex which has a lower G* value than the G* value of bitumen grade 60-70 which is 1.04 kPa compared to 1.06 kPa. This indicates that the binder material becomes more concentrated when modified by adding additive. The value of G*/sin δ for fresh samples of all modified binders reached the value set at 76°C by JKR specification which is 1.0 kPa. Therefore, it can be concluded that the addition of various forms of additive into bitumen grade 60-70 is able to improve the performance grade from PG70 to at least PG76. Asphalt Marshall stability of the asphalt samples and, after 24 hours immersion samples test results are as shown in Table 5.

Table 5 Asphalt Marshall stability.

Parameter		Dense graded asphalt							Gap graded asphalt
		Conventional asphalt	Modified asphalt						
		AC14	PMA_{dry}	PMA_{wet}	WMA	CMA	AC14 latex	SMA20 latex	CR- GGA
Stability(N)	Specification	> 8,000		> 13,000				> 6,200	> 6,000
	Result	12,249	13,920	14,690	13,800	14,550	13,919	8,863	9,455
	Compliance	√	√	√	√	√	√	√	√
Retained Marshall stability, 24 h (%)	Specification	> 85*							
	Result	89	92	103	103	103	95	133	122
	Compliance	√	√	√	√	√	√	√	√

Notes:

AC – asphaltic concrete
PMAdry – plastic modified asphalt (dry process)
PMAwet – plastic modified asphalt (wet process)
WMA – warm mix asphalt
CMA – cup lump modified asphalt
SMA – stone mastic asphalt
CR-GGA – crumb rubber – gap graded asphalt
** based on literature review*

Results of stability of the asphalts as shown in Table 5 indicates that the stability of the asphalt mixes increases when modified with additive whether by dry or wet process. However, stability of gap graded asphalt is much lower than that of dense graded asphalt because of the stone-to-stone contact skeleton structure of the gap graded asphalt but, still complying to the specification requirement. Stability of the asphalt mixes is mainly influenced by their material, which are aggregate's grading and type of binder.

The Marshall immersion tests, found that stability increased when the binder is modified with waste plastic (agglomer) or natural rubber cup lump for dense graded asphalt; as well as when the gap graded asphalt is bonded with natural rubber latex or crumb rubber incorporated binder. Contrary to the dense graded asphalt bonded with bitumen-latex, the stability decreased after samples were immersed in water for 24 hours. According to Siswanto H (2017), loss of the stability might be due to the excessive additive (more than optimum additive quantity to achieve binder performance grade PG76) or poorly blended modified binder. The absorbed water may have penetrated between the binder film and the aggregate surface, causing a weakening in the bonding and adhesion between the aggregate particles, so that immersion of the mixtures decreased the Marshall stability. Cohesion is developed in a mastic (aggregate skeleton structure) and is influenced by the rheology of the filled binder. The cohesive strength of the mastic is contributed by the interaction between the binder and mineral filler; not only from any individual component alone. The cohesive strength of a mastic is weakened due to the saturated condition, and through increased and swelling or expansion of the voids. Nonetheless, the stability value observed after the asphalt samples were immersed 24 hours in water are within the compliance criteria.

Conclusions and Recommendations

The results of this study lead to the following conclusions: that the softening point temperature increases when the bitumen grade 60-70 is modified with any form of additive via wet process; and additionally, able to improve its performance grade from PG70 to at least PG76.

The results of the retained stability are mixed, which might be due to excessive adding of additive (more than optimum additive quantity to achieve binder performance grade PG76) or poorly blended modified binder. However, additive could improve asphalt mixes' resistance to water. The stability of the asphalt mixes is mainly influenced by their material, which are aggregate's grading and type of binder, which develop the asphalt skeleton structure.

Further study on the additive content and blending process is recommended to get optimum improvement on the modified binder and asphalt mixture.

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Warm Mix Asphalt: Malaysian Experience on Federal Road

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Abstract

Maintaining the hot mix asphalt temperature during compaction works is an important factor that needs to be considered in constructing a good and quality road pavement. The asphalt compaction process will only be effective if the asphalt mixture is still hot. When hot mix asphalt is laid and compacted at a lower temperature than required, the level of compaction of the asphalt pavement cannot be achieved and consequently fine cracks will form on the pavement surface. This condition will lead to the pavement premature failure. To overcome this problem, warm mix asphalt is recommended to replace hot mix asphalt because warm mix asphalt can be produced, laid and compacted at temperatures up to 30°C lower than that of conventional asphalt (hot mix asphalt – HMA). The objective of this study is to identify the effectiveness of the use of synthetic hard wax as an additive to modify the conventional bitumen grade 60-70 to produce warm mix binder, to be used in warm mix asphalt. A trial site has been constructed at Federal Road Muar to Tangkak route in November 2019. This paper highlights the warm mix binder blending process and findings on binder and asphalt improvements, which are softening point and performance grade of binder and asphalt Marshall properties, as compared to that of the conventional. This study found that synthetic hard wax additive has effectively lowered the compaction temperature of HMA by 20°C, at the same time, the WMA produced is comparable to polymer modified asphalt.

Keywords: Warm mix asphalt; Warn mix binder; Synthetic hard wax; Additive

Introduction

Currently, road pavement failure that occurs before its lifespan, has been a hot topic in our community. Many believe that poor quality pavement material contributed to this failure. The fact is that there are various factors that contribute to road pavement failure; such as, sudden increase in traffic load and overloaded commercial vehicle which exceeds the allowable axle load limit [1]. In addition, pavement failure is also contributed by the quality of the pavement which is influenced by the asphalt compaction temperature [2].

There are asphalt paving locations on Federal Roads whicg are located far away from the quarry and requires long travelling hours, more than three hours, through climbing roads by asphalt tip trucks, for example, paving location in Cameron Highland, Pahang normally gets asphalt supply from the nearest quarry in Simpang Pulai, Perak. Long travel time and distance, cause the asphalt temperature to drop to less than the allowable asphalt laying temperature. Cold temperature such as in highland areas also contributes to a drastic drop of asphalt temperature.

There are also asphalt paving locations on narrow road or separated by bridge which couldn't be accessed by 20 tons tip truck, especially on State Roads, which require the transported asphalt to be transferred to smaller tip trucks. As such, the double handling of asphalt

contributes to the drop of asphalt temperature. Year 2020 Malaysian road statistics stated that 92.3% of Malaysian road are State roads, of which 74.8% are paved roads [3].

When hot mix asphalt was laid and compacted at a lower temperature than required, the level of compaction of the asphalt pavement cannot be achieved, and consequently fine cracks will form on the surface of the pavement during compaction process, as shown in Figure 1.

Fig. 1. Fine cracks formed on asphalt pavement due to the compaction at low temperature.

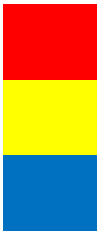
To overcome this problem, warm mix asphalt is recommended to replace hot mix asphalt because warm mix asphalt can be mixed, laid and compacted at up to 30°C lower temperature compared to that of the conventional asphalt (hot mix asphalt – HMA).

In Malaysia, the use of warm mix asphalt as an alternative to HMA has been seen as a potential strategy to be implemented in National Green Technology Policy 2009 which was launched by the Prime Minister [4].

Literature Review

Warm Mix Asphalt Technology

Asphalt, widely used pavement surfacing material, is a mixture of various combinations of aggregate, asphalt binder and additives, depending on the type of asphalt mixture. There are three (3) types of asphalt mix based on their production temperature, namely hot mix asphalt (HMA), warm mix asphalt (WMA) and cold mix asphalt [5]. Hot mix asphalt is a conventional asphalt produced at a temperature of 155 to 165°C, resulting in high combustion cost and greenhouse gases production [6]. Figure 2 shows the comparison of asphalt mixing temperature of these asphalt mixes.



Hot mix asphalt (HMA) (≥ 155°C)

Warm mix asphalt (WMA) (120 – 135°C)

Cold mix asphalt (25 – 35°C)

Fig. 2. Comparison of asphalt mixing temperature [6].

Overseas researchers agreed that there are a few benefits of WMA technology over HMA, which are good to the environment, cost saving and better construction quality. WMA is able to be produced at lower temperature hence, reduces harmful gases emission, which would benefit the workers and communities. WMA has better workability, making it possible to be paved during cold season, has longer hauling distance and can be opened to traffic earlier. WMA could also reduce binder aging hence, reduces pavement hardening and cracking. These advantages are because WMA is produced at a temperature close to its service temperature [7–9].

Warm Mix Binder (WMB) Production Process

Based on previous studies the warm mix binder (WMB), which was used in the production of WMA, can be produced via three categories, as follows:

i. Foaming technique;
ii. Organic additives; and
iii. Chemical additives.

a. Foaming technique

WMA can be produced by foaming technique i.e. by injection or by naturally adding water or synthetic zeolite, into the asphalt mixture during its mixing process. Or by other ways, water is sprayed into hot bitumen, or wet sand is mixed into the asphalt mixture [10, 11]. During the process, a lot of foams will be produced. At high temperatures, water condenses rapidly, resulting in reduced viscosity of the bitumen. The bitumen is easier to wrap the aggregates' surface at lower viscosity, and results in lower compaction effort of the asphalt layer. However, excessive water content can cause stripping problems on asphalt pavements [6, 10–12].

b. Organic additives

Organic additives are used to modify the bitumen, to reduce the viscosity of the binder. Organic additives that are commonly used are organic wax, fatty acid amide and recycled polyethylene pyrolytic wax. The effect of the use of these additives can only be seen when the temperature of the binder has cooled. At low temperature, the additive in the modified binder becomes crystalline, forming a lattice structure with very fine particles (microscopic) thus, increases the hardness of the binder and resistance to rutting [11].

c. Chemical additives

Chemical additives are also used to modify the bitumen. However, the purpose is not to reduce the viscosity of the binder. Basically, this method involves a blending of emulsifying agent, surfactant, polymer and other additives, to improve the binder-

aggregate bonding, increase the asphalt workability, and act as an anti-stripping agent [13]. The effect of the use of this type of additive depends on the materials used to produce the products.

Full-Scale Trial on Malaysian Federal Road

Objectives

The objective of this study is to identify the effectiveness of the use of synthetic hard wax as an additive to modify the conventional bitumen grade 60-70 to produce warm mix binder, to be used in warm mix asphalt.

Experimental Design

In this study, the additive used to modify conventional bitumen grade 60-70 to produce WMB was synthetic hard wax as shown in Figure 3. WMB used was produced by wet process by blending conventional bitumen grade 60-70 with the synthetic hard wax by field blending at TKC Quarry, Pagoh, Johor. The additive was added into the bitumen at a rate of 3%, as recommended by the supplier of the additive based on their experience abroad.

Fig. 3. Synthetic hard wax was used as an additive.

A total of two (2) blends were prepared as shown in Table 1 for two (2) trial sites on Federal Road at Section 16 to 19, and Section 32 to 33, Route 23, Jalan Muar to Tangkak, Tangkak District, Johor.

Table 1 WMB blending.

Date of blending	Quantity (Ton)		
	Bitumen 60-70	Additives	WMB blending
18 November 2019	16.20	0.5 (25 bags x 20 kg)	16.70
22 November 2019	23.28	0.72 (36 bags x 20 kg)	24.00

The quantity of WMB blending has been limited, according to the bitumen tank and motorized stirrer capacity, to ensure homogenous blending at tank temperature of 150°C, within one hour. This quantity was determined based on the capacity of the bitumen tank which is 30 tons, and the number of motorized stirrer which is only one. At the quarry, WMB samples were taken,

as shown in Figure 4, each time before the WMA production, for ring and ball softening point test and dynamic shear test (DSR).

Fig. 4. WMB samples were taken from bitumen tank at quarry.

Mix Design

The asphalt mix design is to determine the composition of asphalt binder, coarse aggregate, fine aggregate, and mineral filler; to produce a durable road pavement according to JKR/SPJ/2008-S4 Flexible Pavement specification [14] for HMA, and WMA. The mix design process, in the laboratory, is carried out several times to get the optimum quality, according to the specification. The job mix formula (JMF) is the result of the mix design that successfully meets the design requirements of aggregates gradation and bitumen content, with specified tolerance values and complies all tests and analysis parameter requirements.

Aggregates Gradation

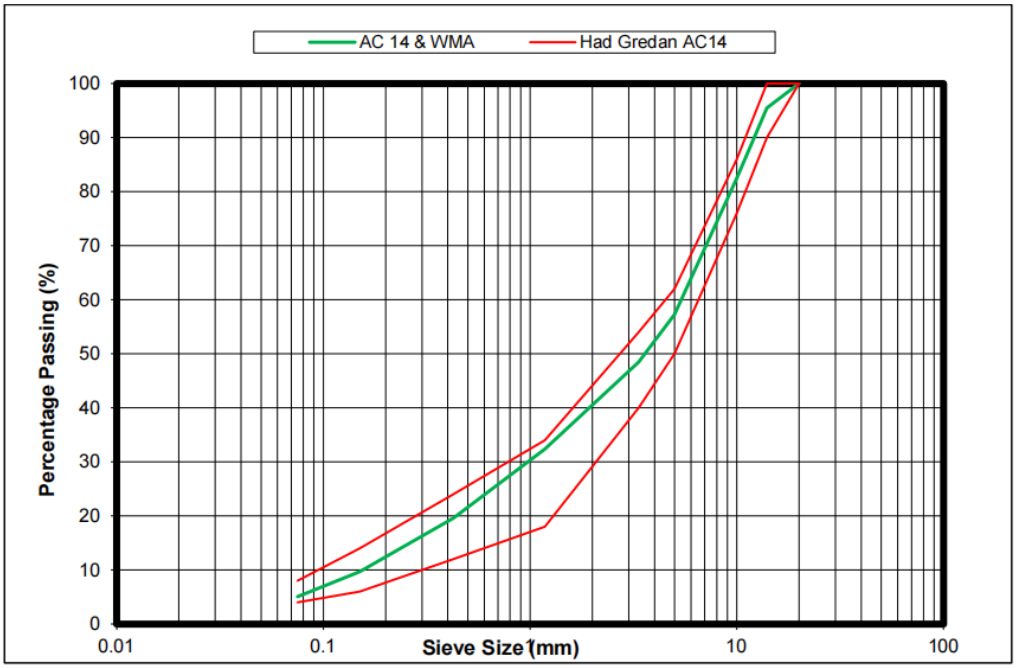


Fig. 5. JMF's aggregates gradation for HMA and WMA (TKC Quarry, Pagoh, Johor).

The aggregates gradation for JMF is where the value of the percentage passing for each sieve size follows the specification. The hot bin combination used was also checked to ensure that the target aggregates combination gradation was produced as the specified JMF's aggregates gradation. This target aggregates combination gradation should be able to produce a smooth line curvature in the grading envelope. The aggregates gradation for both HMA and WMA for this study are the same i.e., using AC14 as shown in Figure 5.

Results and Discussion

Warm Mix Asphalt (WMA) Compaction Temperature

At preliminary stage, four (4) sets of WMA Marshall samples were prepared with variation in compaction temperatures, which were 80, 100, 120 and 140°C. Four (4) samples were prepared for each compaction temperature. The volumetric analysis results of the Marshall samples are as shown in Table 2.

Table 2 Marshall volumetric analysis to determine the WMA compaction temperature.

	HMA		WMA				
Compaction temperature (°C)	Specification	140	Specification	80	100	120	140
Density (kg/m3)	-	2.309	-	2.198	2.254	2.293	2.319
Stability (N)	> 8,000	15,700	> 8,000	6,600	10,900	15,400	17,100
Flow (mm)	2.0 - 4.0	3.2	2.0 - 4.0	3.5	2.8	2.5	2.4
Stiffness (N/mm)	>2,000	5,000	>2,000	1,900	4,000	6,200	7,000
VIM (%)	3.0 - 5.0	3.8	3.0 - 5.0	8.4	6.0	4.4	3.3
VFB (%)	70 - 80	76	70 - 80	57	65	72	78
Compliance with specifications		√	-	X	X	√	√

The results show that the WMA compacted at 80°C and 100°C did not meet the Marshall mix design specification. Meanwhile, the compaction temperature of 140°C was applied for HMA. Thus, the most effective WMA compaction temperature is 120°C because its volumetric analysis meets the specification requirements. The 120°C compaction temperature is the compaction temperature used in preparing Marshall samples in the laboratory, which is also used to design the WMA. The compaction temperature which should be used at site was 5°C less than in the laboratory. So, the WMA compaction temperature applied at site was 115°C.

Warm Mix Binder (WMB) Quality Control

The test results on the WMB samples are as shown in Table 3.

Table 3 Binder sample test results.

Binder		Softening point test (ºC)	Dynamic shear test			
			Test temperature (ºC) 76ºC			Performance grade
			G*(kPa)	δ (º)	G*/sin δ (kPa)	
Bitumen grade 60-70		48	0.62	86	0.62	PG70
WMB	Mix 1	62	1.81	77	1.81	PG82
	Mix 2	61	1.66	78	1.70	PG76

The softening point test results show that the softening point temperature increases from 48°C to more than 60°C when synthetic hard wax was added into the bitumen grade 60-70. This

shows that the temperature increase when the binder softens as it turns from semi solid to liquid. Besides that, the results also show that the viscosity of bitumen 60-70 at 48°C is equal to the viscosity of WMB at 60°C, which is 1,200 Pa.s or 12,000 poise at softening point of the binder according to Ujian Makmal – bitumen, aggregate & asphalt book [15]. The results indicate that the rutting and bleeding resistance of the asphalt pavement could be increased with the use of synthetic hard wax modified binder.

The dynamic shear test results show that the addition of synthetic hard wax into the bitumen 60-70 could increase the elastic component in the binder, as can be seen by the decrease in the δ values. Meanwhile, the G* value increases indicating that the binder became more viscous when the additive was added. The G*/sin δ value also achieved the requirement for PG76 in the specification.

Asphalt Mix Design

The mix design results of HMA and WMA at optimum binder content (OBC) are as shown in Table 4. The OBCs were obtained from volumetric analysis according to Marshall design method. The values of stability, flow, voids in mix (VIM) and voids filled with bitumen (VFB) at OBC were obtained from the plotted graphs. The asphalt mix designs that met the specification requirements were then used as the Job Mix Formula (JMF).

Table 4 Asphalt mix design results at OBC.

Asphalt		Parameter	Density (kg/m³)	Stability (N)	Flow (mm)	Stiffness (N/mm)	VIM (%)	VFB (%)
AC14	HMA	Specification	-	> 8,000	2.0 - 4.0	> 2,000	3.0 - 5.0	70 - 80
		Result @ OBC 5.12%	2.298	12,100	2.90	4,172	4.2	73
		Compliance	-	√	√	√	√	√
	WMA	Specification	-	> 13,000	2.0 - 5.0	> 2,600	3.0 - 5.0	70 - 80
		Result @ OBC 5.37%	2.299	15,300	3.7	4.250	3.6	77
		Compliance		√	√	√	√	√

Parameter	HMA		WMA	
	Specification	Result	Specification	Result
Density (kg/m³)	-	2.298	-	2.299
Stability (N)	> 8,000	13,000	> 13,000	13,800
Flow(mm)	2.0 - 4.0	2.83	2.0 - 5.0	3.1
Stiffness (N/mm)	> 2,000	4,600	>2,600	4,500
VIM (%)	3.0 - 5.0	4.0	3.0 - 5.0	3.9
VFB (%)	70 - 80	75	70 - 80	75

Table 5 Asphalt Marshall samples test results.

Parameter	Specification	Result	
		HMA	WMA
Contabro loss (%)	< 15	7.8	11.5
Resilient modulus (MPa)	> 2,500	3,800	4,300
Retained Marshall stability, 24 h (%)	> 85	89.1	90.1

Results in Table 5 show that the Marshall volumetric analysis for both HMA and WMA produced for trial sites complied with the specification. Results of Cantabro loss, resilient modulus and, Marshall stability, and flow test on the samples immersed in 60°C water for 24

hours show that both HMA and WMA met the specification requirements for Cantabro loss, resilient modulus and retained Marshall stability values. Even though the WMA is compacted at a temperature of 20°C lower than HMA compaction temperature, the WMA was found to be comparable to HMA. In addition, WMA achieved the polymer modified asphalt specification.

Trial Sites Performance

Monitoring of the trial sites' performance has been carried out in August 2020, which is at the 9th month after the site completion, comprising of the measurement of rut depth and area of crack. The data reported are as shown in Table 6. These data were observed for both HMA and WMA segments for the purpose of controlling and comparing the pavements performance.

Table 6 Field performance test results.

Period after site completion	Parameter	Section 16 to 19 (Towards Muar)		Section 32 to 33 (Towards Sagil)	
		HMA	WMA	HMA	WMA
9^{th} month	Rut depth (mm)	0	0	0	0
	Cracks area (%)	0	0	0	0

The results of the rut depth and cracks area at the study segments show that both segments HMA and WMA are still in good condition which is there are no rut and crack found at 9 months after site completion. To compare the performance of these HMA and WMA, field monitoring should be continued to at least until the pavement is expected to fail, which is up to eight years after site completion, as that recommended by the World Bank study [16].

Conclusions and Recommendations

Overall, it was found that the synthetic hard wax additive used in this study effectively lowered the compaction temperature of hot mix asphalt by 20°C, at the same time the WMA produced is comparable to polymer modified asphalt. This is because the warm mix binder produced is better than conventional bitumen 60-70, due to the softening point temperature could be increased from 48°C to more than 60°C, and the performance grade was also able to be upgraded to at least PG76. Field performance monitoring at the trial sites at 9th month found that both segments of HMA and WMA were still in good condition; no rut and crack. However, it is still too early to compare the performance of the pavements at these study sites. Therefore, monitoring of the trial sites needs to be extended up to eight years after site completion or when the pavement failure occurs.

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Electrical Power System Installation Power Quality Case Study

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Abstract

Power Quality (PQ) in general is the concept of powering and grounding sensitive (electronic) equipment in a manner that is suitable for the reliable operation of the equipment. Power quality relates to the equipment's immunity level when faced with power disturbances such as voltage transients, voltage variations, imbalances, voltage fluctuation and waveform distortions. Electrical equipment damage can occur when faced with the disturbances as mentioned above. In this study, the power quality of an electrical power system was studied with an objective to investigate the fitness of the electrical system. The Fluke 1750 power recorder and the Fluke Analyze software version 2.4 were used to conduct the power quality study. The PQ monitoring and analysis was carried out in actual practical environment using the field measurement method. A total of five (5) measurement points were identified, measured, analysed and evaluated. Voltage sag, phase shift, high neutral to ground impulse and imbalances are some of the power quality disturbances found in this study of the electrical power system. The problem with these disturbances, affects the lifespan of sensitive (electronic) equipment and sound operation of the facility. In summary, the analyzed power quality data findings is to recommend mitigation methods in order to improve the power quality at the facility.

Keywords: Power quality; Voltage sag; Electrical distribution; Voltage dip; Electrical measurement

Introduction

Power quality (PQ) plays an important role in the electrical distribution system in ensuring continuous delivery of electrical power supply and Quality or purity of the voltage input [1], [2]. This power quality can be defined as the problem taking place involving voltage, current or frequency deviations from the standard value which can result in failure, mis-operation of electrical equipment or to maintain the integrity of the power supplied to the system [3]. Poor PQ 'events' such as voltage sag, over voltage, harmonics, unbalance, under voltage etc. are the various issues on power quality[4]. It is important to perform power quality monitoring and assessments to identify PQ problems in the system. The assessment helps to understand the current power in the system and to ensure proper operation of the facility and for future maintenance plans[5].

The PQ disturbances are mainly important to equipment which are very sensitive to the slightest change in the electrical power supply [6]. It is very much necessary to perform power quality assessment to determine various power quality problems existing in a system, to find causes of these problems, and to minimize the effects of these problems. Due to recent developments in solid state technologies, a large number of equipment used nowadays are very sensitive to power quality disturbances. Examples of these loads are computer networking and telecommunication facilities, semiconductor and electronics manufacturing facilities, biotechnology and pharmaceutical laboratories, and financial data-processing centers. Power

Electronics which make use of semiconductor technology are more efficient and energy saving than normal linear loads[7]. However, such equipment are sensitive to power disturbances resulting in reduced performance and will cause equipment misoperation or premature failure [8].

Here we would like to present a case study of the power assessment conducted on a government research and training centre. Actual site monitoring was conducted and the raw measurement data is gathered, analyzed and interpreted into useful information for better understanding of power quality characteristics variation on the power supply.

Research Methodology

The PQ monitoring and analysis was carried out in actual practical environment using the field measurement method in the flowchart represented in Figure 1. The study was carried out by initially identifying the Monitoring points in the electrical system to analyse the overall performance of the electrical system. Monitoring was carried out using Fluke 1750 three phase Power Quality analyser. Depending on the location of the installation, a maximum of five (5) voltage Probes (all three phases, neutral and earth) and five (5) current probes (all three phases, neutral and earth) were connected to the installation at each monitoring point.

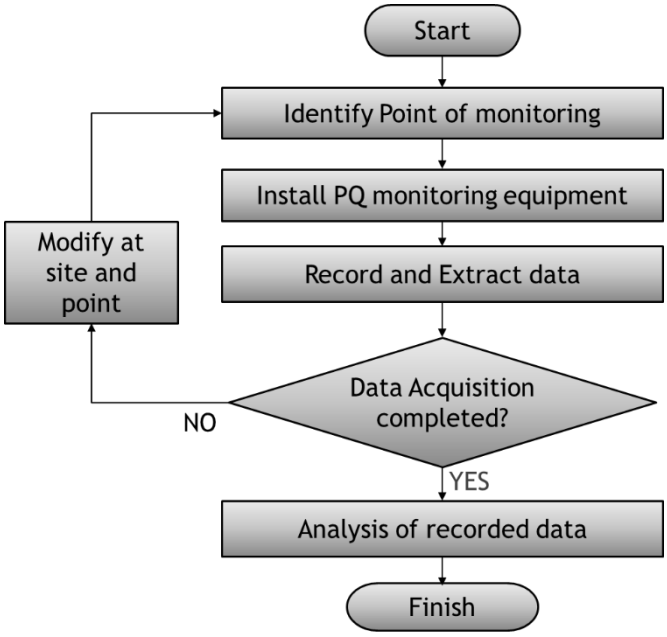

Fig. 1. Data collection method flowchart

The setting up of the power quality monitoring equipment and suggested monitoring at each point of monitoring was made by competent personnel (electrical charge man). Data of Voltage and current Profiles was recorded continuously with a measurement rate of 256 samples per cycle of 50Hz for a minimum of one week. Snapshots of the voltage and current waveform were recorded every 10 minutes.

The data stored is later analysed with deviation from normal values based on the standard recommendation in IEEE 1159 and local electrical supply utility company guidelines, in this case Tenaga Nasional Berhad (TNB) Electrical Supply Application Handbook (ESAH) 3.1.

The monitoring is repeated on other identified locations. Finally characteristics tables are drawn, deviation in parameter in the form of tables and graphs are stored for record.

Case Study Background

The JKR Centre of Excellence for Engineering and Technology (CREaTE) has been in operation since September 2016. Throughout its operation, until today, electrical disturbances including nuisance tripping, frequent inoperation of lifts and air conditioning system have been reported.

To get a better understanding of the power distribution system and electrical usage and behaviour in the facility, a Power Quality Assessment was conducted. The study was conducted on the premises of CREaTE situated in Alor Gajah, Malacca, Malaysia. The study focuses on the main electrical distribution equipment in the premises which are the main medium voltage incoming facility and two distribution substations.

The construction of CREaTE was completed in September 2016 and the development consists of Main Administration and Training blocks, five separate Research Blocks, Multifunctional Hall, Cafeteria, Surau, and Two accommodation blocks for trainees.

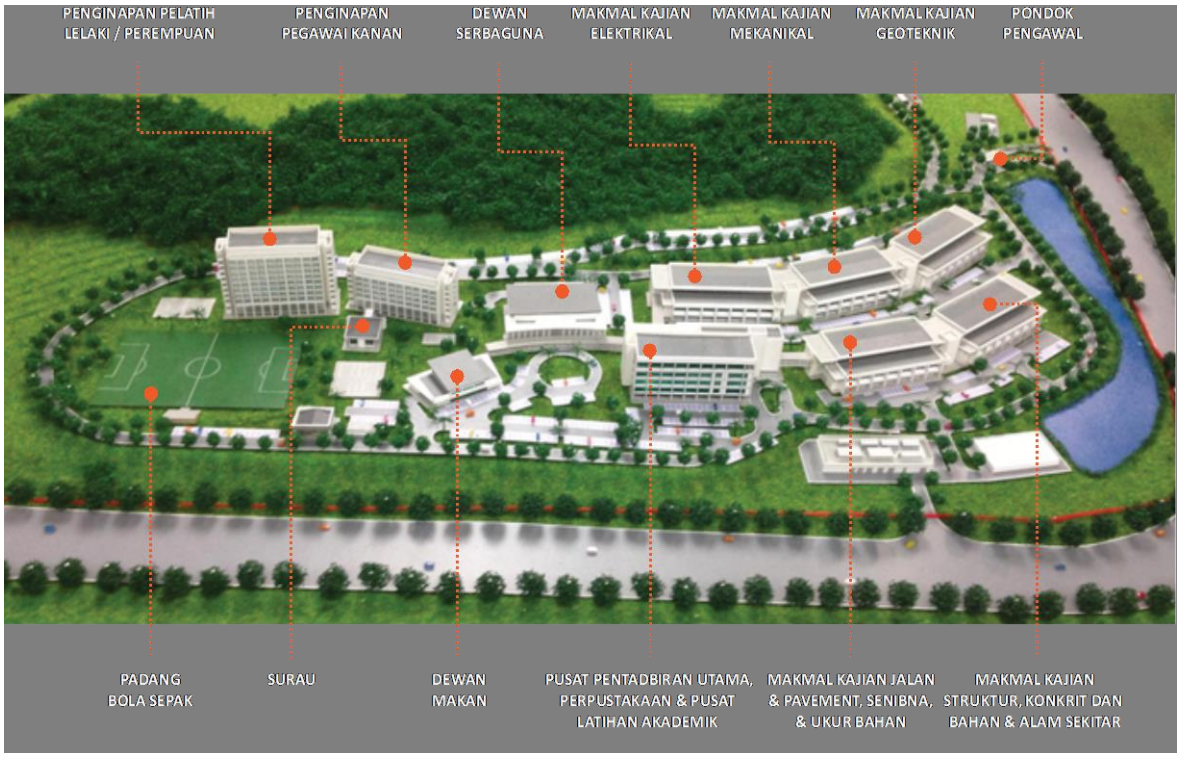

Fig. 2. Site Plan of CREaTE

Figure 2 shows the site plan of CREaTE. The electrical distribution system in CREaTE consists of a Medium Voltage 11 kV supply which is distributed to two substations inside the facility compounds. Substation 1 covers electrical distribution to the main chiller, main administration building and laboratory facilities. Substation 2 electrical distribution system covers the multifunctional hall, surau, and the accommodation block for trainees. Overview of the simplified block diagram of the electrical distribution system and points of monitoring is shown in Figure 3

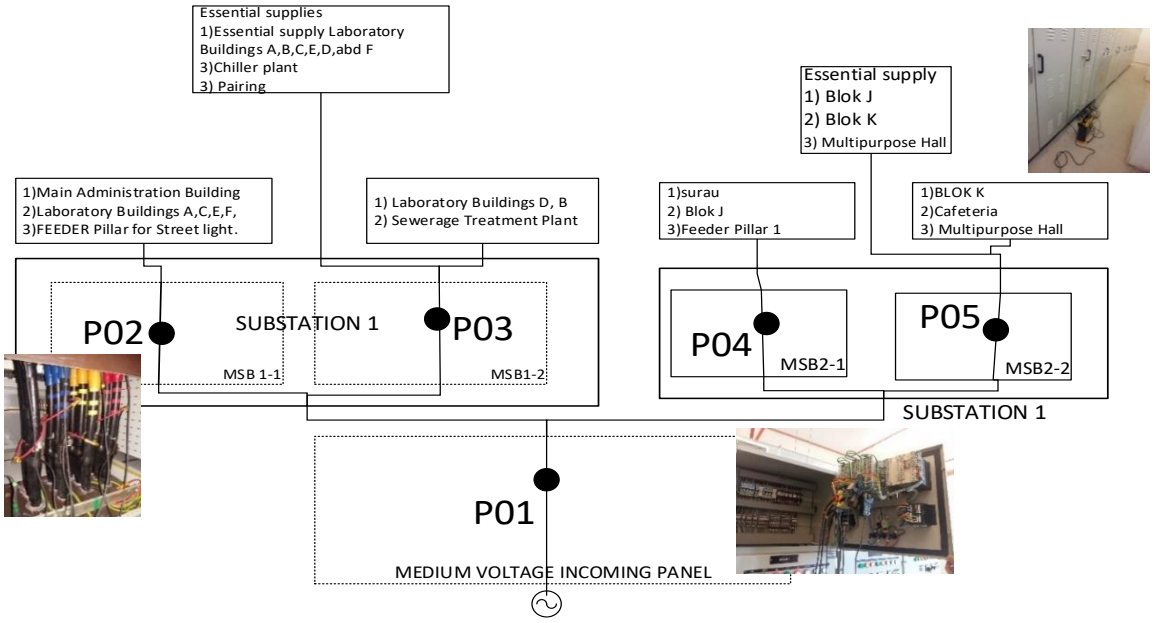

Fig. 3. Electrical Distribution System at Study Site

The electrical loads in the laboratory facility consist of testing equipment such as motors, testing chambers, analysis apparatus and measuring equipment. The administration block electrical loads consist mainly of lighting load and electronic equipment for office use such as computer, projector, public announcement system and printers. There are also general electrical equipment such as refrigerators and electric kettles used in the facility but the number is very small.

Results and Discussion

The incoming supply from the utility (Tenaga Nasional Berhad; TNB) is a smooth sinusoidal supply with low voltage harmonics. The incoming medium voltage supply is slightly higher than the normal condition of 11000 V ±5% as shown in Figure 4. However, it is still within the value of contingency operation of 11000 V ±10%.

The voltage supply at substation 1 for 1-1 MSBD for P02 and 1-2 MSBD for P03 are within the voltage limits of 230 V (+10%, -6%). However, it is slightly near the upper value of the voltage limits as shown in Figure 5 and Figure 6 respectively.

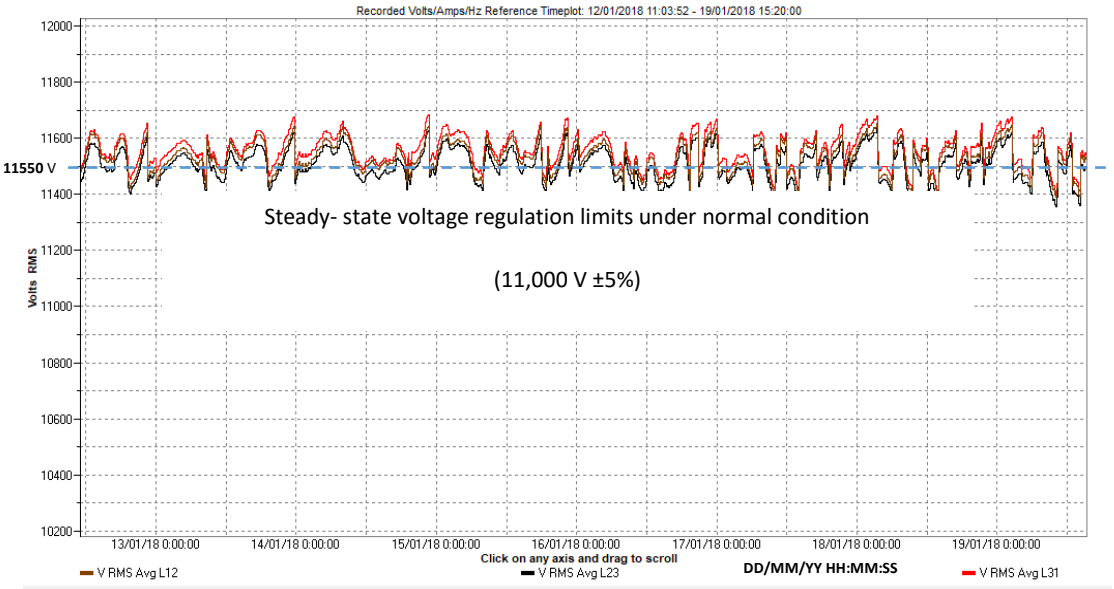

Fig. 4. Steady State Voltage at Medium Voltage main incoming supply

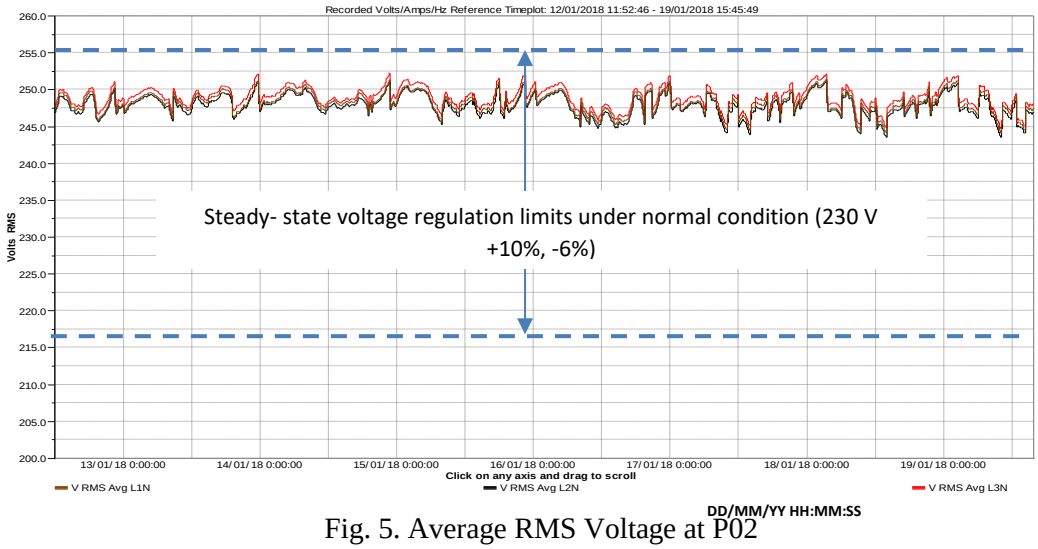

Fig. 5. Average RMS Voltage at P02

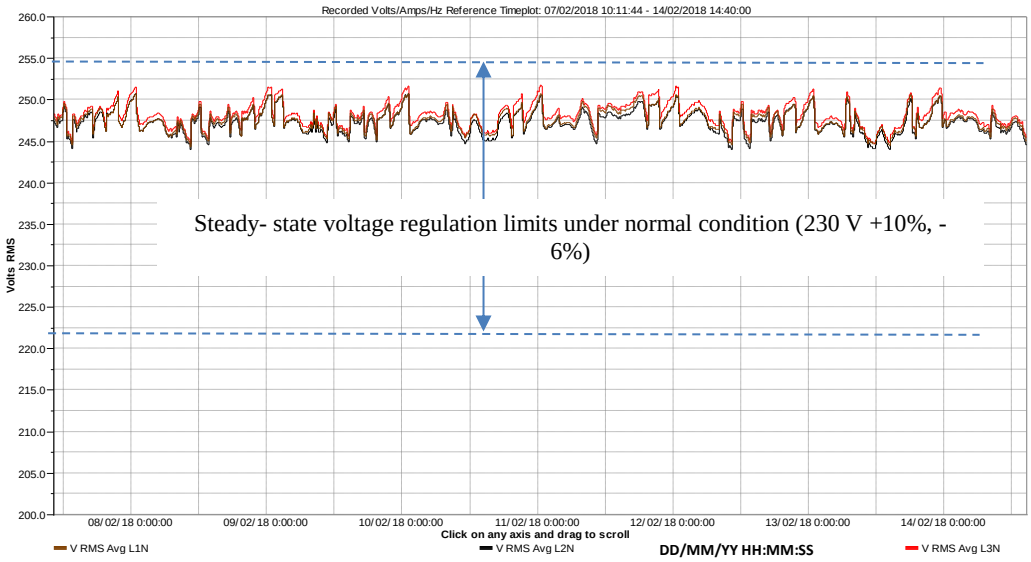

Fig. 6. Average RMS voltage at P03

The voltage fluctuation is low indicating adequate wiring in the installation. The average steady state V_{NG} is low indicating good Neutral to Ground Bond. The voltage supply at substation 2 for 2-1 MSBD for P04 and 2-2 MSBD for P05 are also within the voltage limits of 230 V (+10%, -6%). The voltage is slightly lower than that at Substation 1 due to the long distance from the main incoming supply. The voltage fluctuation is low indicating adequate wiring in the installation. However the V_{NG} is on the upper limit of the maximum voltage limit of 3.0 V and may create noise or disruption for operation of sensitive equipment as shown in Figure 7.

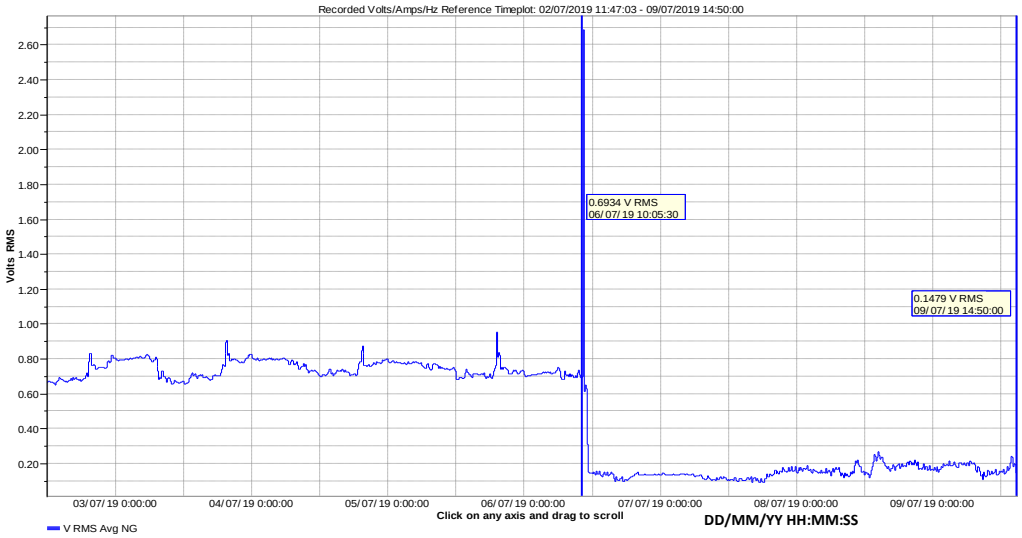

Fig. 7. Steady State V_{NG} at P05

The recorded maximum load phase current at the main Medium Voltage Incoming supply is at 51% of the rated load current. The Main usage of the facility is during working days as indicated by the higher load during weekdays as shown in Figure 8. High inrush current has been recorded during the starting of office hours which can be related to operation of the chiller plant in the facility which can be seen in Figure 9. The average total power consumed during the measurement is 628.71 kW. This is 39.29 % of the maximum demand of the system which is 1500kW. Large power consumption is mainly during office hours. The supply frequency at all points of measurement is in compliance with IEEE 1159 standard and TNB requirements.

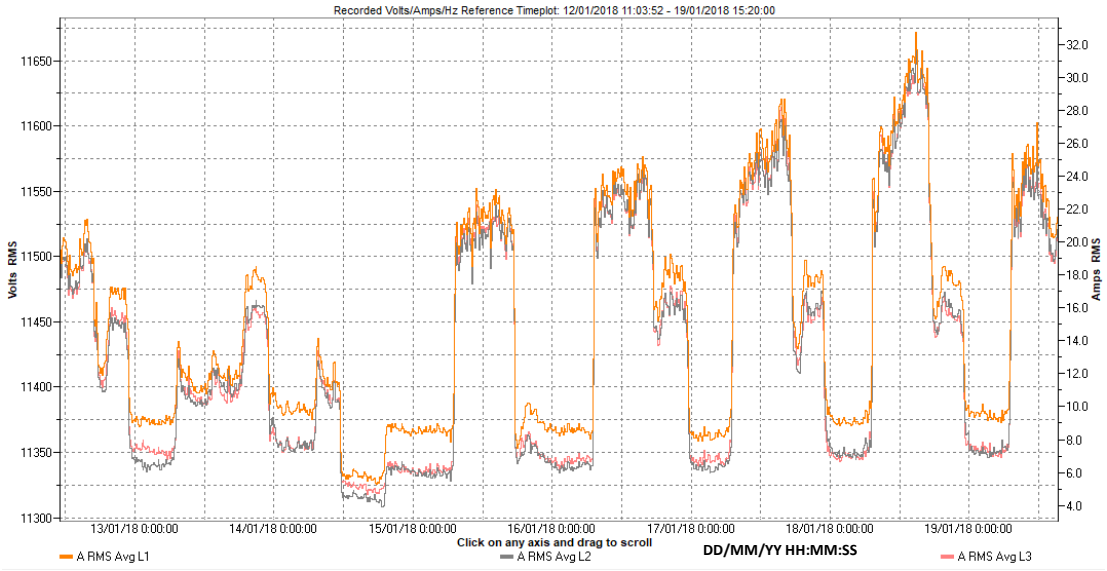

Fig. 8. Ten (10) minutes data trend of current profile at P01

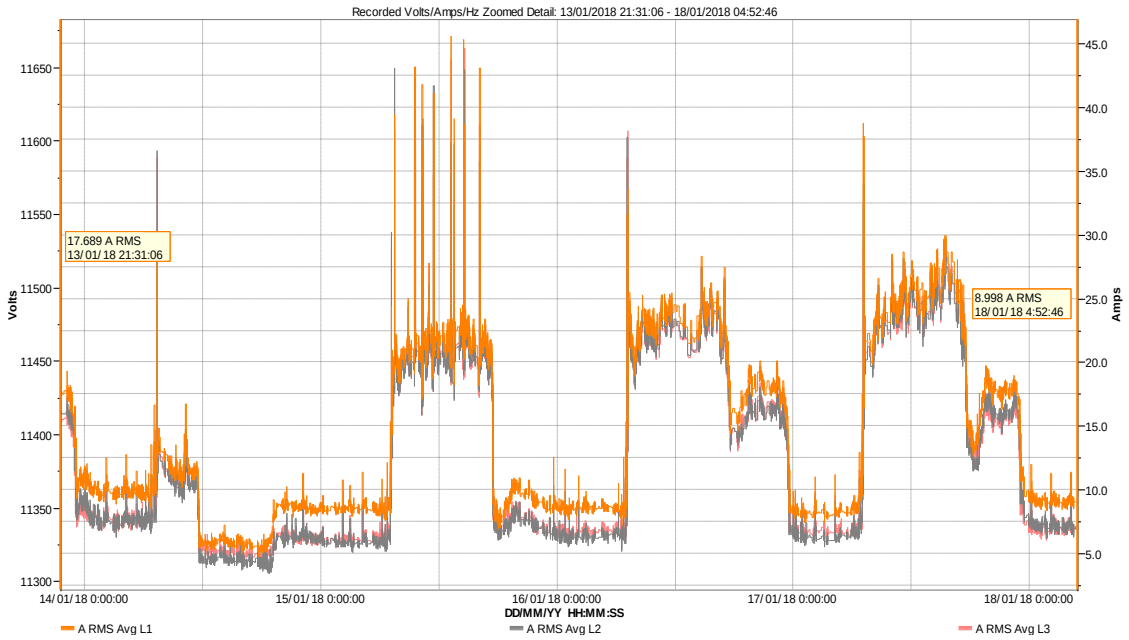

Fig. 9. Zoomed Detail Average RMS Current Profile at P01

Figure 10 shows the incoming supply voltage waveforms recorded from the utility which is a smooth sinusoidal waveform with low THD. The current waveform is slightly distorted. However, it is still within the limits of the standard with low TDD.

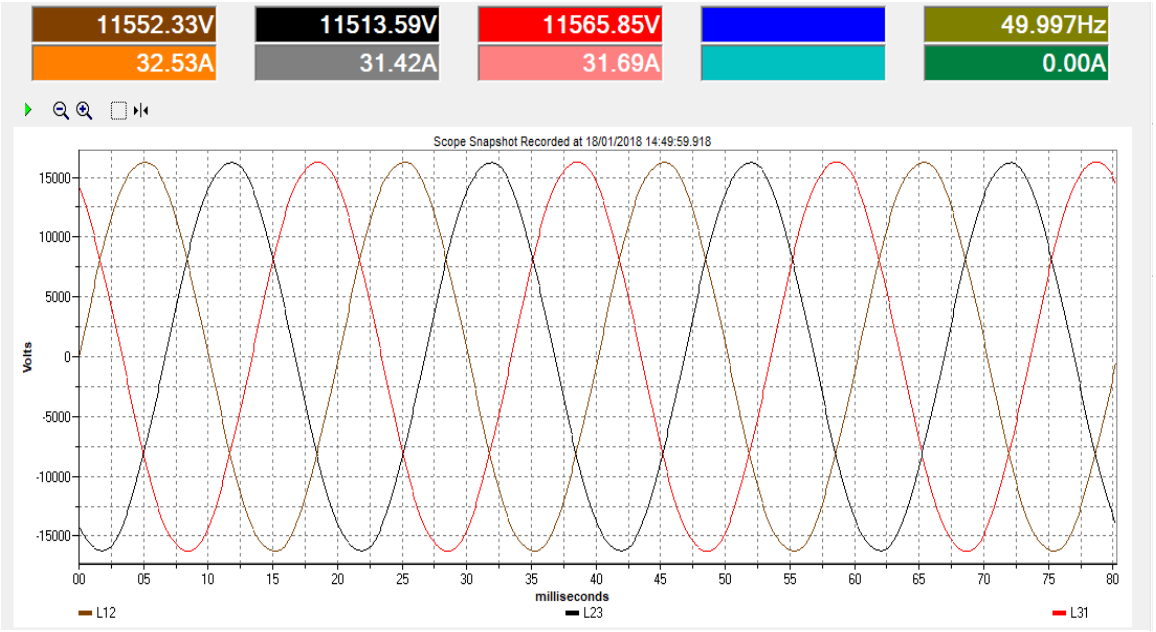

Fig. 10. Voltage Waveform during maximum load at medium voltage panel P01

The voltage and current events for measurement at HT panel are within the safe operating zone of the CBEMA curves as shown in Figure 11, in general indicating satisfactory operation of the electrical loads. A number of two voltage swell events for phase N-G occurred during the measurement period at substation 1, 1-2 MSBD at point P02 as shown in Figure 12.

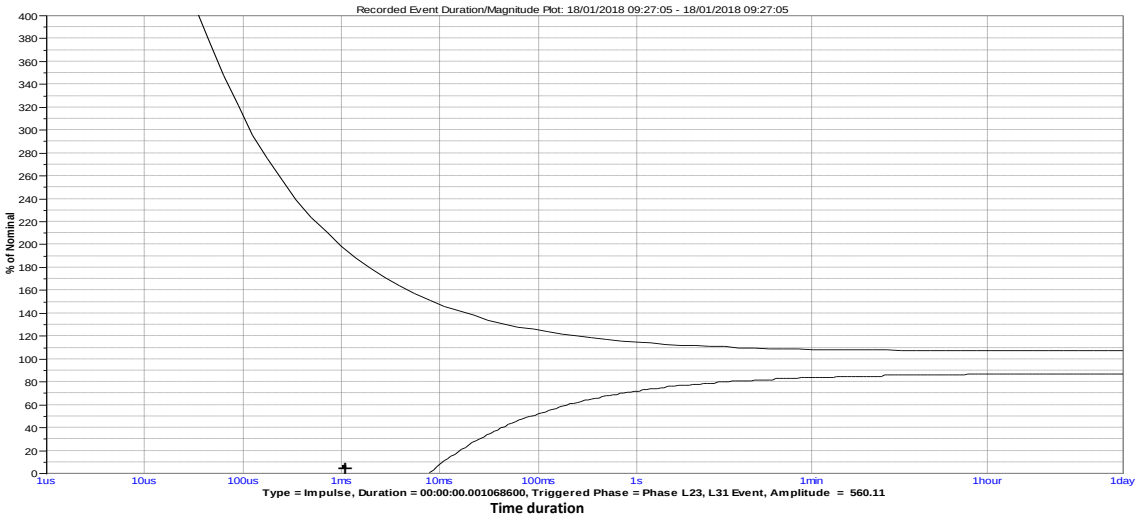

Fig.11: CBEMA tolerance curve for monitoring point P01.

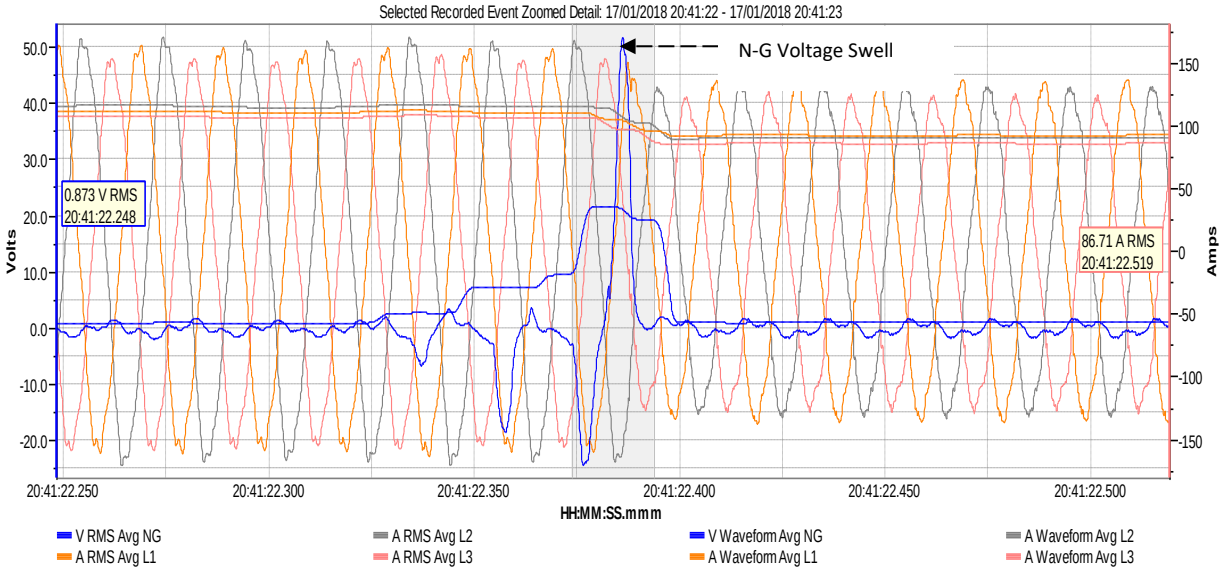

Fig.12: N-G voltage swell at P02

For the measurements at substation 2, a total of thirteen (13) voltage swell events at phase N-G and two (2) voltage sag events were recorded. One of the voltage sag events were of non-symmetrical voltage sag affecting only phase L1N, while the other voltage sag events were for all phases. Both point of measurements P04 and P05 at Substation 2 recorded the same events. There was no sudden increase in the current magnitude during the voltage sag indicating the origin of the voltage sag was upstream from point of measurement. Three (3) current events were recorded at P04. The first event due to high neutral current throughout the measurement period and two (2) inrush current events which may be due to starting of motors or energizing of transformers or similar events.

Conclusions

In this study, the power quality of the electrical power system in CREaTE was studied with an objective to investigate the fitness of the electrical system in CREaTE. A total of 5 measurement points were identified, measured, analysed and evaluated.

Power quality disturbances such as voltage sag, High Neutral to Ground Voltage (V_{NG}) swell, phase shift, Neutral to Ground Voltage Impulse and load imbalance were evaluated. From the measurement and analysis, it was found that the electrical system is stable with minimal voltage fluctuations. The main incoming supply from utility is a strong supply, a smooth sinusoidal supply with minimal harmonic content. The electrical system inside the facility has high harmonic content due to usage of electronic equipment. The current waveform at substation 2 is more distorted and has a high TDD % value.

Several recommendations were given to improve the power quality of the electrical system such as improving grounding system to reduce V_{NG}, tightening loose connections to reduce system impedance in the system and utilizing isolation transformer to protect sensitive electronic equipment from high V_{NG} Impulse.

Future Work

This study was conducted on CREaTE facility to get an overview of the electrical system. The study was concentrated on the main medium voltage incoming and two (2) main distribution substations. Thus, further study is required to monitor and evaluate additional points of measurement to mitigate the power quality issues that have been discussed in this study.

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An Overview of Steel Fibre Reinforced Concrete (SFRC) Confinement for Structural Engineering Application

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Abstract

Steel Fibre Reinforced Concrete (SFRC) has been studied in terms of its ability to enhance the failure mode of concrete, besides increasing its opposition towards loading. This material has been widely used due to its improvised mechanical properties for fracture toughness, energy absorption capacity, fatigue resistance, tensile strength, ductility, and crack-width control. Adding steel fibres in concrete can reduce brittleness and increase ductility of concrete. SFRC is seen to have the ability to improve the bond strength of steel reinforcing bars due to confinement effect from the steel fibres and concrete. However, this confinement effect has not been examined thoroughly yet. This paper gives a comprehensive literature review on the main characteristics of SFRC, such as toughness, fracture energy ductility, and confinement effect, which are highlighted as the main keys in bridging and delaying crack formation in reinforced concrete structures. Furthermore, the confinement methods used in prior studies to increase the bond strength is also discussed. Although many methods of confinement can be used to increase the bond behaviour between reinforcing bars and surrounding concrete, the fibrous confining method is the most popular among researchers because fibres promote fracture toughness and energy absorption capacity of the concrete. This paper also presents an overview of the mechanical properties of SFRC, its advantages, and its applications.

Keywords: Steel fibre reinforced concrete; Mechanical properties; Bond strength; Confinement effect; SFRC applications

Introduction

Steel Fibre Reinforced Concrete (SFRC) has been studied in terms of its ability to enhance the failure mode of concrete, besides increasing its opposition towards loading. This material has been widely used due to its improvised mechanical properties for fracture toughness, energy absorption capacity, fatigue resistance, tensile strength, ductility, and crack-width control. Adding steel fibres in concrete can reduce brittleness and increase ductility of concrete. Prior studies showed that substituting plain concrete with Fibre Reinforced Concrete (FRC) can enhance the bond between concrete and reinforcing bars [1-3].

Furthermore, past researchers [4-7] concluded that the bond strength depends largely on the rib pattern of the steel bar, the strength of concrete, and the confining effects provided by the surrounding concrete. Due to the importance of the interaction between steel reinforcement bars and concrete, a number of studies [4,5,8,9] have investigated the effects of reinforcing bar and concrete in influencing the bond strength in particular the confinement. Thus, confinement

is a parameter that has a significant impact to increase the bond behaviour between concrete and reinforcement bar.

Steel Fibre Reinforced Concrete (SFRC)

Over decades, SFRC has been proven to offer toughness, resistance against tensile stresses after cracking, enhanced tensile behaviour, and better crack controller properties, particularly with increased utilisation of steel fibres in many researches. The existence of fibres in concrete improves the fatigue performance of SFRC for high tensile stresses and extends its structural life due to the enhanced toughness provided by SFRC to endure heavier load levels [10].

Steel fibres are used to improve concrete characteristics related to tensile behaviour by preventing crack growth and by controlling brittle fracture, which ultimately result in enhancement of mechanical behaviour, such as tensile strength, flexural strength, toughness, reliable peak, and post-peak bond strength [11,12]. As a result of the improved concrete properties, due to the inclusion of steel fibres, several further improvements are noted, such as increment in toughness or energy absorption capacity, tensile strength, fatigue resistance, and ductility [13,14]. Furthermore, the important considerations for the application of SFRC are the type of fibre and its geometry, as well as the distribution, orientation, concentration, and bonding properties of fibres within the concrete matrix [12,15]. Since the application of FRC has found its way in the construction industry, it must be able to compete economically with the existing reinforcing system.

Mechanical Resistance of SFRC

Basically, the essential properties of SFRC are resistance to crack and crack propagation. Steel fibre composites have the ability to delay cracking and increase tensile strength under flexural loading. Also, steel fibres have the capability to hold the concrete matrix together even after extensive cracking and noticeably post-cracking ductility, in comparison to normal concrete (NC). SFRC has the potential to increase the energy absorption characteristics and sustain from abnormal or cyclic loading [16].

Compression Behaviour of SFRC

Neves and Almeida [17] investigated the influence of steel fibre volume fraction, diameter, and matrix strength on SFRC compressive behaviour. The findings showed that the maximum compressive strength significantly depended on matrix strength and fibre characteristics. Steel fibre offers reinforcing behaviour at a micro level to endure the development of micro cracks, while controlling crack aperture or opening at the macro level. The ability of fibre to control micro cracks mainly depends on its volume fraction, deformability, and bond to the concrete matrix. Furthermore, micro crack bridging of fibre can increase the compression strength, whereas additional voids caused by fibre addition can decrease compression strength.

Tensile Behaviour of SFRC

The observation on tensile splitting strength of SFRC is discussed in many studies, which highlighted that the inclusion of steel fibres increased the performance. Table 1 shows the comparison findings by previous studies.

Table 1 Tensile strength of SFRC from prior studies

Author	Volume Fraction (%)	Increment of tensile strength compare to NC (%)
Gao, Sun and Morino (1997)	0.5 – 2.0	9 – 78
Song and Hwang (2004)	0.5 – 2.0	19 – 98
Altun, Haktanir and Ari (2007)	1.0 – 2.0	38 – 60
Yazici, Inan dan Tabak (2007)	0.5 – 1.5	39 – 53
Ramadoss (2012)	0.5 – 1.5	13 – 76
Shende and Pande (2011)	1.0 – 3.0	9 – 19

According to Gao, Sun, and Morino [18], the increment of tensile strength was truly significant at a small amount of volume fraction (exceeding 1.0%) and the rate of increment was between 9% and 78%, when compared to Normal Concrete (NC). Nonetheless, contradicting outcomes from other researchers stated that high amount of steel fibres significantly improved the splitting tensile strength of SFRC. Song and Hwang [19]; Altun, Haktanir and Ari [20]; Yazici, Inan and Tabak [21]; Thomas and Ramaswamy [22]; and Ramadoss [23] mostly agreed and reported that their results showed the tensile strength of SFRC enhanced in the range of 40% to 98% with volume fraction of steel fibre ranging between 1.5% and 2.0%, when compared to NC. This explains that the bonding of steel fibre in concrete matrix significantly increases the splitting tensile strength of the concrete.

Flexural Behaviour of SFRC

The addition of steel fibre exhibited significant improvement in flexural strength, when compared to compressive strength and splitting tensile strength. Previous studies have shown that flexural strength of SFRC can reach more than 100%. For example, an investigation by Yazici, Inan, and Tabak [21] showed that the improvement of SFRC flexural strength, when compared to NC, was between 3% and 81%. Similarly, Song and Hwang [19] also discovered that the presence of steel fibres significantly increased the flexural strength with increment in fibre volume fraction from 0.5% to 2.0%, while the increment of flexural strength ranged from 28.1% to 126.6%.

SFRC Mechanism

Fibres are used to improve concrete characteristics related to tensile behaviour such as tensile strength, flexural strength, toughness, peak, and post-peak bond strength by preventing crack growth, which ultimately enhances the mechanical behaviour. As a result of improved concrete properties due to the inclusion of steel fibres, several improvements were noted, such as increment in toughness or energy absorption capacity, tensile strength, fatigue resistance, and ductility [13,14,24].

The study on the introduction of the effect of steel fibres can be promising as SFRC is used for sustainable and long-lasting concrete structures. Steel fibres are widely used in FRC across the globe. SFRC has been the subject of numerous studies, and a number of famous researchers are currently researching on it. This review focuses on the most significant effects of addition of steel fibres into concrete mixes. Previous studies have found that adding steel fibres affects the workability of concrete. Hence, in order to address this problem, super plasticizer can be used without affecting the other properties of the concrete [22].

Toughening Mechanism

Toughening is the main mechanism in SFRC behaviour. This mechanism is strongly related to the fibre-bridging effect and pull-out of fibres. Normally, SFRC behaves as a composite material that resists additional load after the first crack. This can be observed when the pull-out of steel fibres at the first crack is higher than the load at the first crack. At the crack section, the role of steel fibres is to carry the tension load by bridging the higher stress to the composite matrix throughout the bond stress. The development of additional cracking due to fibre bridging effect will continue until the total failure of steel fibres occurs, which leads to fibre pull-out. This mechanism alters the brittleness of NC into ductile material to enhance the energy absorption properties [16, 25].

From the structural point of view, the presence of steel fibres in concrete improves the structural behaviour and the fracture properties. This is related to the ability of steel fibres in bridging and delaying crack formation. Figure 1 illustrates how the steel fibres improve the serviceability and the ultimate limit state of concrete [26]. Steel fibres increase the serviceability state by controlling crack propagation that positively decreases the crack width thus, resulting in flexural stiffness enhancement. Additionally, steel fibres improve the ultimate limit state of concrete by increasing shear load and punching failure. These positive effects contribute to prevent the sudden failure event and change the mode of failure from brittle to ductile.

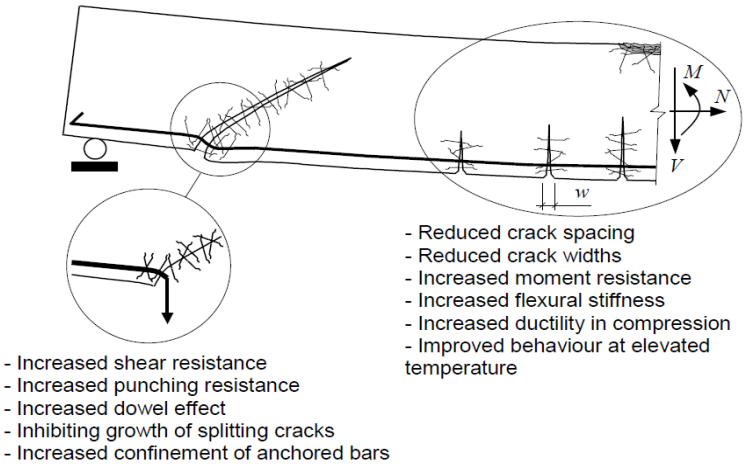


Fig. 1. Toughening mechanisms of steel fibres [26]

Fracture Energy

Bayramov, Taşdemir, and Taşdemir [27] discovered that SFRC obtained higher values of fracture energy when compared to NC. The fracture energy of SFRC increased as the fibre volume fraction increased. The increment in fracture energy with increasing fibre volume fraction is derived from the behaviour of fibres that sews the crack, forms a bridge in the crack, and resists increasing levels of stress when the crack opens hence, limiting crack propagation. In contrast, NC would have failed as soon as crack initiation starts [13, 27].

Durability

According to Ezeldin and Balaguru [28], the term ‘ductility’ describes the post-peak behaviour. The stability of post-peak behaviour and area under load slip curve were used as indicators of

ductility. Ductility increases with the addition of fibres [13, 29]. The slip value at maximum pull-out load increased consistently with increase in fibre content and this suggests that the increase in slip is derived from stable failure pattern when the pull-out of bars took place due to split tension failure.

Confinement

Steel fibres enhance bond performance because they confine reinforcement, which has a similar role to that of the transverse reinforcement and because they broaden the range of crack width values within which passive confinement remains active [28, 30]. Although it is true that their influence on bond strength is of little importance, enhancement in bond performance of concrete is definitely essential in terms of toughness/ductility of the material fatigue/weakness [13, 31].

Concrete confinement is one of the most effective and practical methods for improving the bond strength of steel reinforcements. Furthermore, concrete confinement is needed for decreasing the bond deterioration and augmenting the energy absorption and dissipation capabilities of the structural systems [32]. Prior studies show that the practical method for concrete confinement is using close spaced ties within the anchorage zone or splice region and using steel fibre reinforced concrete (SFRC) in concrete beam-column connections, hybrid steel beam-RC column connections, low rise structural walls, and coupling beams in order to minimise their structural damage by increasing their energy absorption and dissipation capacities [32, 33].

Bond of Reinforcing Bar in Concrete

Within the reinforced concrete structural systems, interaction and bonding between reinforcement and concrete is crucial to establish good structural strength and serviceability performance. Bond strength is contributed by three elements: adhesion, friction, and bearing (see Figure 2). Adhesion and friction are reliant on bar surface condition, while bearing depends on the pattern of bar deformation [7, 34].

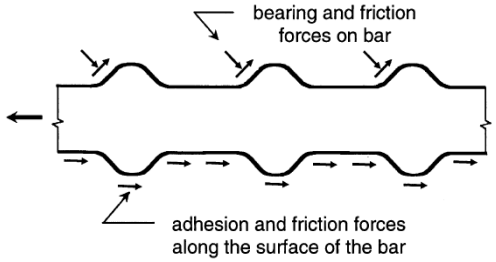


Fig. 2. Bond force transfer mechanisms [7]

The basic behaviour of reinforcing bar and concrete interface is presented in Figure 3. Bond is interpreted as bond stress and bond strength. Bond stress refers to a tensile or compressive force on an embedded reinforcing bar that prompt the interactive forces at the surrounding concrete. This is represented as the intensity of applied force per unit contact surface area of reinforcing bar, which resists the movements between the reinforcing bar and its surrounding concrete, while the latter reflects the maximum resistance towards separating bars from concrete. The radial action of the interfacing forces prompts the hoop tensile stress in the surrounding concrete as it depends more on concrete cover. In case of inadequate concrete cover, parallel cracking can occur to the reinforcing bar [4, 6].

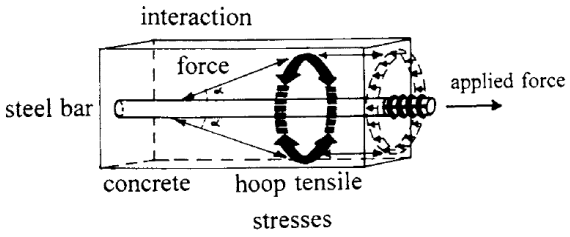


Fig. 3. Reinforcing bar and concrete interaction [4]

The correlation of bond stress-slip is determined as the registered tensile force-slip relationship related to the force that reinforces bar and concrete interface. The measured slip is represented by the average local slip in the middle of the bar embedded length with sufficient accuracy, as the slip is measured at the unloaded end of the specimen. Reinhardt and Balazs [4] and Chao, Naaman, and Parra-montesinos [8] determined the bond stress (τ) between the reinforcing bar and the surrounding concrete by using the following formula:

$$\tau = \frac{F}{\pi DL} \qquad \text{Eq. 1}$$

where:
F = Applied load (kN);
L = Embedment length (mm); and
D = Bar diameter (mm).

The correlations between bond stress, τ, and relative slip, δ, between steel reinforcing bars and concrete are essential because they influence the response of the reinforced concrete structures. Pull-out tests are normally performed to determine bond stress, wherein the results of bond stress may vary along the embedment length measured at one end of the specimen, which is stated as the average bond stress versus slip [35]. A number of prior studies investigated the relationship of the impact of parameters, such as geometric formation and material properties, and defined the average bond stress-bar slip correlation.

Factors That Influence Bond Behaviour

Several studies [4, 7, 13, 31, 36-39] have identified a number of factors that affect bond strength and bond-slip behaviour, namely bar size and deformation pattern, concrete cover, tensile properties of the cementitious material, compressive and splitting tensile strength, space between adjacent bars, transverse bar, level of corrosion bar, size of aggregate, casting direction, presence of confinement, state of stress in both reinforcement and concrete, location and orientation of the reinforcing bar, and mix additives, such as silica fume and fibres.

Table 2 presents the parameters that can influence the bond strength between concrete and reinforcement bar. Among these parameters, the bar geometry and the confinement method are shown to have most significant impacts upon concrete bond behaviour. Types of fibre seem to be the least significant parameter, compared to the other parameters investigated in past studies.

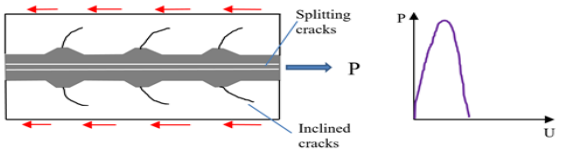
Table 2 Factors that influence bond behaviour from prior studies.

Author	Parameter							
	Bar geometry	Embedded length	Cover	Compressive strength	Different type of fibres	Confinement	Loading	Concrete Type
Reinhardt and Balazs (1995)	√			√		√	-monotonic -cyclic load	NC
Bouazaoui and Li (2008)	√	√					-monotonic	NC
Chao et. Al. (2009)	√			√	√		-monotonic -fully reversed cyclic	High strength fibre reinforced cement
Dancygier, Kartz and Wexler (2010)	√		√	√			-monotonic	High strength concrete
Bandelt and Billington (2016)			√			√	-monotonic	High performance reinforced fibre
Kang and Tan (2016)		√				√	-monotonic -cyclic load	NC
Garcia-Taengua, Marti-Vargas and Serna (2016)	√		√			√	-monotonic	SFRC

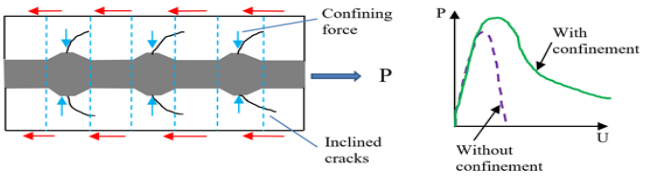
Confinement Effect on Bond Behaviour

The two types of confinement approaches in studies related to bond are: passive and active confinement. Passive confinement is commonly used to increase structural confinement by applying the confining pressure that is directly dependent on the lateral expansion of the concrete due to axial load [37]. Taengua [13] discovered that the consequence of the constraining effect upon concrete cover and transverse reinforcement can be categorised as passive confinement. This constraining effect is progressively activated with the commencement of bond stresses. Next, the active confinement is a method that increases bond capacity of connected reinforcing bar. Active confinement is contributed by the forces that are directly applied to the anchorage area. This method of confinement is unaffected by crack growth and effective in conditions when concrete cover starts to split [13, 37].

Figure 4 illustrates the types of failure for concrete specimens with and without confinement. The impact of confinement results in various mechanical behaviours. Passive confinement generated from clamping action at a certain level of concrete cover and steel fibre offers effective bond strength and crack control [5, 40]. The absence of confinement effects leads to concentration of tensile stresses within the surrounding concrete, which is caused by radial component of the bearing forces. As concrete has brittle tensile behaviour, this situation may cause splitting cracks that would grow wider and break the whole cover when the bond resistance drops after hitting the peak load. In comparison to confined concrete with fibre, the existence of confining forces enhances the concrete resistance to bond splitting failure, apart from increasing the ductility of concrete prior to loss of bond. At this state, it is assumed that concrete can sustain some stresses at large displacement before the ultimate failure that occurs when the confining effects have reached the limit, where the steel fibre is completely mobilised.



(a) Without confinement



(b) With confinement

Fig. 4. Failures in concrete specimens; with and without confinement [5]

To date, many methods of confinement can be used to increase the bond behaviour between reinforcing bars and surrounding concrete. Table 3 presents several confinement methods proposed by past researchers. All the listed confinement methods seemed to significantly affect the bond behaviour between concrete and reinforcing bars in terms of strength and ductility. Transverse reinforcement appears to be the most popular confining method to increase concrete bond strength [4, 32, 33, 41- 47] introduced several other methods of confinement, such as fibre reinforced polymer (FRP), prestressed steel rings, FRP jacket, FRP wire jacket, and continuous rectangular spiral transverse reinforcements, respectively, which increased bond strength and bond stress-slip response. Looking at the usage pattern of the confinement methods listed in Table 3, the fibrous confining method is popular among researchers because fibres promote fracture toughness and energy absorption capacity of the concrete.

Table 3 Method of confinement

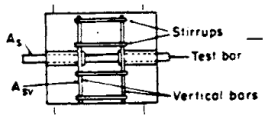
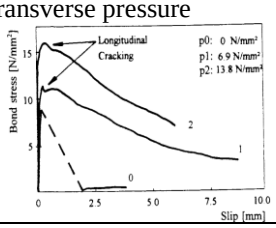
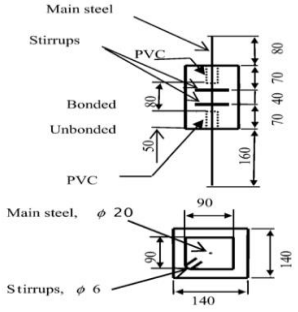
Author	Method of confinement	Concrete type	Loading type	Effect
Reinhardt and Balazs (1995)	i. Transverse reinforcement  ii. Transverse pressure 	Plain concrete	Monotonic load	The confinement provided by transverse reinforcement or by transverse pressure, has a strong influence on bond behaviour.
Fang et al. (2006)	Transverse reinforcement 	Plain concrete	Monotonic load	Steel bars at medium corrosion level (4% - 6%) confined with stirrups showed significant effect on bond strength

Table 3 Method of confinement (continue).

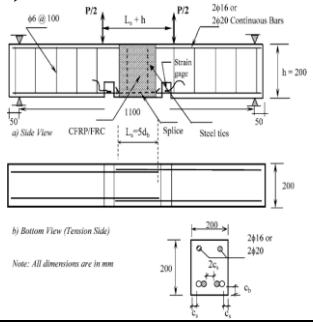
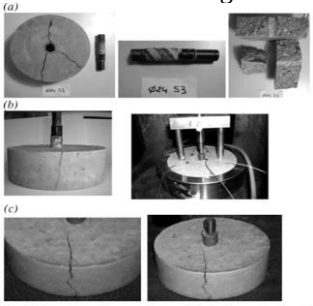
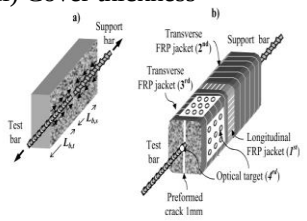
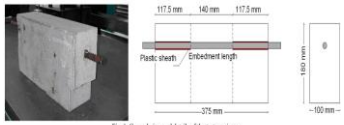
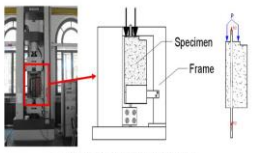
Author	Method of confinement	Concrete type	Loading type	Effect
Harajli (2006)	i) Steel fibre ii) FRP ii) Transverse reinforcement 	i) Plain concrete ii) SFRC	Cyclic load	Confining the concrete in the splice region internally by ordinary transverse steel or steel fibre concrete, or externally using FRP laminates leads to significant improvement of the bond strength between the spliced or developed bars and concrete.
Cattaneo and Rosati (2009)	i) Steel fibre ii) Prestressed steel rings  Fig. 6—Tested specimens: (a) unconfined; (b) confined; and (c) fiber reinforced.	i) SCC ii) SCC with fibres	Monotonic load	i) SCC bond strength was higher than that of NC ii) Adding fibres improved fracture toughness and energy absorption capacity of concrete, but slight decrease on bond strength iii) External pressure by prestresses steel rings significantly changed the bond behaviour (strength and ductility)
Tastani and Pantazopoulou (2010)	i) FRP jacket ii) Cover thickness  Fig. 3. (a) Morphology of the DTP Bond Test; (b) specimen preparation with FRP jackets and optical targets	Plain concrete	Monotonic load	i) Increased cover thickness and bond strength by 85% and 20%, respectively ii) FRP jacket improved the bond mechanism to allow ductile behaviour up to failure with large values of recorded slip
Valente (2012)	i) Longitudinal bars ii) Transverse stirrups  	Plain concrete	i) Monotonic load ii) Cyclic load	i) Longitudinal bar with low corrosion level increased steel-concrete bond ii) Increase in stirrup confinement delayed the onset of bond deterioration, but enhanced bond strength

Table 3 Method of confinement (continue).

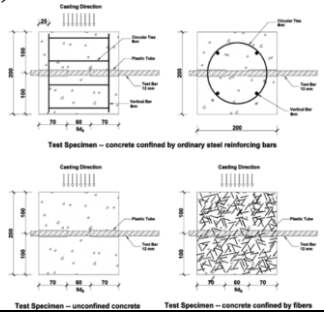
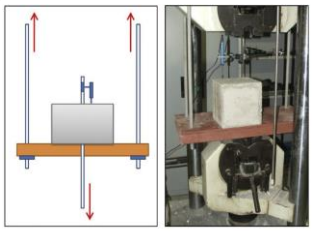
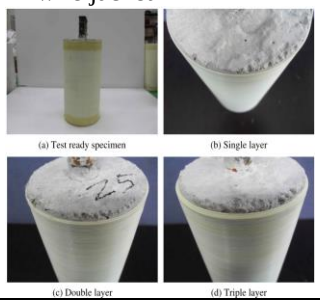
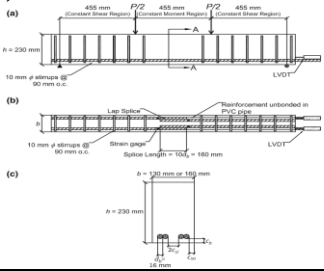
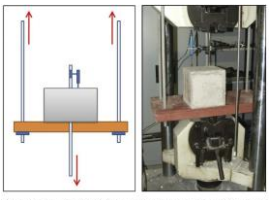
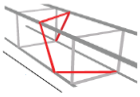
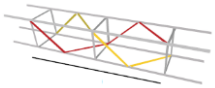
Author	Method of confinement	Concrete type	Loading type	Effect
Hameed et al. (2013)	i) Reinforcement bars ii) Metallic fibres 	i) Plain concrete ii) Fibred concretes	Monotonic load	Local bond stress-slip behaviour of deformed steel bar in concrete: similar results when confined with either ordinary confining reinforcement or hybrid metallic fibres
Garcia-Taengua, Marti-Vargas and Serna (2014)	i) Steel fibre ii) Cover thickness 	i) Plain concrete ii) SFRC	Monotonic load	Higher fibre slenderness, fibre length, and concrete cover significantly improved bond capacity
Choi et al. (2014)	FRP wire jacket 	Plain concrete	Push-out load	Better bond strength with increased FRP wire jacket layer
Bandelt and Billington (2016)	i) Reinforcement bars ii) Transverse stirrup iii) Cover thickness 	i) Plain concrete ii)HPFRCC	Monotonic load	Larger amounts of cover allowed more fibres to be oriented in transverse and resulted in higher bond strength for HPFRCC materials
Garcia-Taengua, Marti-Vargas and Serna (2016)	i) Steel fibre ii) Cover thickness 	i) Plain concrete ii) SFRC	Monotonic load	Enhanced passive confinement of bond strength by adding fibre content or cover/diameter ratio

Table 3 Method of confinement (continue).

Author	Method of confinement	Concrete type	Loading type	Effect
Azimi et al. (2015)	Continuous Rectangular Spiral Transverse Reinforcements  DCL-SINGLE  DCL-DOUBLE	Plain concrete	Cyclic load	A higher bond strength due to energy dissipation capacity was demonstrated by the DCL-DOUBLE specimen compared to that of the DCL-SINGLE and conventional one which it resists efficiency to cyclic loading.

It has been proven that the application of steel fibre exerts a considerable confinement effect upon concrete and prevents splitting failure. Following this behaviour, the dominant mode of failure is shear pull-out failure [5]. In case of deformed bar confined by steel fibre that reacts as transverse reinforcement, the failure was characterised by splitting failure, where the concrete between the ribs tend to crush/shear off and the ribs rub against the concrete without any increment in the wedging action. The confinement from steel fibre seems important in affecting bond failure and bond performance in terms of bond strength and bond failure ductility [13].

SFRC Application

According to Behbahani, Nematollahi and Farasatpour [48], addition of steel fibres into the conventional reinforced concrete members brings a number of advantages, as follows:

(i) Addition of steel fibres can provide an increased impact resistance to conventional reinforced concrete members, thereby enhancing the resistance to local damage and spalling.

(ii) Addition of steel fibres can inhibit crack growth and crack widening; this may allow the use of high strength steel bars without having excessive crack width or deformation at service loads.

(iii) Addition of steel fibres increases the ductility of conventional reinforced concrete members, and hence, enhances their stability and integrity under earthquake and blast loadings.

(iv) Addition of steel fibres increases the shear strength of reinforced concrete members. As a consequence punching shear strength of slabs will be increased and sudden punching failure can be transformed into a gradual ductile failure.

Conclusions

This paper presents an overview of the mechanical properties of Steel Fibre Reinforced Concrete (SFRC), increasing of bond strength between reinforcing bar and concrete due to confinement effect and its applications. The main characteristics of SFRC, such as toughness, fracture energy ductility, and confinement effect, are highlighted as the main keys in bridging and delaying crack formation in reinforced concrete structures.

Knowledge on bond mechanism and factors that influence the bond capacity between reinforcing bars and surrounding concrete seem to be crucial in improving bond performance,

especially in reinforced concrete structure. Confinement emerges as the main factor to be highlighted that could contribute in increasing the bond strength between reinforcing bars and concrete. Meanwhile, the fibrous confining method is a popular method among researchers as fibres possess the ability to improve fracture toughness and energy absorption capacity of concrete. It was believed that this particular confinement technique has been successful in controlling the development of splitting cracks either by bridging or by resistance provided by the expansion materials surrounding the steel bars.

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Alginate Encapsulated *Geobacillus Stearothermophilus* (AE-GS) as a Self-Healing Agent in Autonomous Healing Mortar

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Abstract

The autogenous healing of concrete by microbially induced calcite precipitation has sparked a lot of interest in sustainable concrete repair and maintenance solutions. The biologically inspired material for self-healing concrete has been introduced with alginate encapsulated *Geobacillus stearothermophilus* (AE-GS). In this study, the vegetative cells of *Geobacillus stearothermophilus* were introduced and encapsulated into alginate-hydrogel before incorporation into the mortar. Scanning Electron Microscopy (SEM) was used to examine the encapsulated strain and its characteristics to confirm the presence of encapsulated bacteria. The performance of AE-GS in the mortar mixture as a self-healing agent was measured by compressive strength and crack-healing efficiency. The healing efficiency of AE-GS was used to determine its suitability as a crack repair material. When comparing those with a lower replacement level of AE-GS and a lower concentration of bacteria, the results showed that incorporating 15% AE-GS with 1×10^{11} colony forming units per ml (cfu/ml) bacteria concentration resulted in maximum crack healing at 80%. *Geobacillus stearothermophilus* was found to be capable of inducing self-healing by utilising the available nutrients in its environment. The combination of *Geobacillus stearothermophilus* and alginate gel beads provides an intriguing approach for crack remediation using the autogenous healing concept.

Keywords: *Geobacillus stearothermophilus*; Bacteria; Encapsulation; Alginate hydrogel; Crack repair; Autonomous healing

Introduction

Geobacillus stearothermophilus is high resistant and a thermophilic type of bacterium due to its capability of thriving high temperature (30°C to 75°C) which can be found in the geothermally heated region or high-temperature ambient such as hot spring [1, 2]. In a harsh environment, *Geobacillus stearothermophilus* can produce endospore [3]. *Geobacillus stearothermophilus* morphology and resistance properties allow it to be mobilised in the atmosphere and transported over long distances [4]. Furthermore, the longevity of *Geobacillus stearothermophilus* allows them to lie dormant but viable for long periods in extreme conditions, gradually accumulating over time to achieve surprisingly high population densities. The focus of this research was on two (2) main issues:

(1) The development of autonomous healing concrete using alginate encapsulated *Geobacillus stearothermophilus* (AE-GS), a bacteria species that has never been studied before.

(2) The suitability of AE-GS as a new smart material to be investigated for use in concrete repair and maintenance.

Conceptual of Autonomous Healing

In conventional concrete, a minor crack will allow water and harmful material to enter and propagate through the crack. The continuous ingress of water and chemicals in crack propagation would eventually cause premature matrix degradation and corrosion of embedded steel reinforcement if not properly treated [5]. The addition of the bacteria-based healing agent during the mixing process, on the other hand, would solve the problem. The crack and water entering the concrete would activate the bacteria-based healing agent. Bacterial activity causes abundant mineral precipitation, which aids in crack closure and prevents further entry of harmful materials, thereby protecting the reinforcement from corrosion. The concept of self-healing is illustrated as in Figure 1.

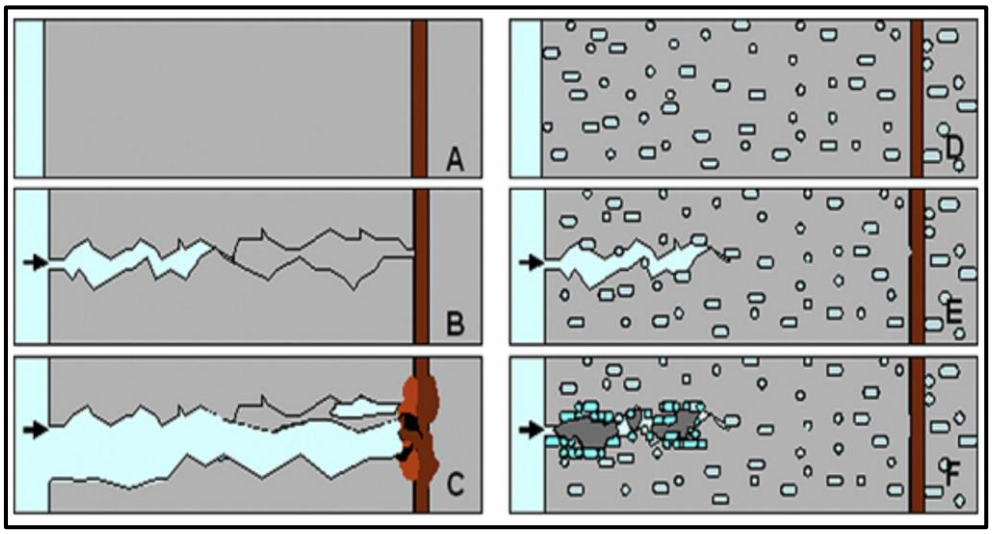

Fig. 1. Schematic drawing of conventional concrete (A-C) versus bacteria-based self-healing concrete (D-F) (courtesy of Jonkers) [9]

The most common and well-known pathways to precipitate calcium carbonate ($CaCO_3$) is by enzymatic hydrolysis of urea ($CO(NH_2)_2$ from bacteria through the biomineralization process [6] – [8]. Urea hydrolysis can produce high concentrations of carbonate within a short period and is the most easily controlled reaction to generate carbonate [10], [11]. The equation for this chemical reaction is shown in Equation 1.

$$(CO(NH_2)_2 + 2H_2O \rightarrow 2NH_4^+ + CO_3^{2-} \quad \text{(Equation 1)}$$

The combination of calcium (Ca^{2+}) from feeding solution or local environment with carbonate ions (CO_3^{2-}) resulting in the formation of calcium carbonate ($CaCO_3$) is as illustrated in Equation 2.

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3 \quad \text{(Equation 2)}$$

Materials and Methods

The materials used for producing alginate encapsulated *Geobacillus stearothermophilus* (AE-GS) mortar mixes are described in the following subsections.

Bacterial Strain

In this study, *Geobacillus stearothermophilus* (ATCC 12978) was used. Sterile nutrient broth (NB) containing beef extract (3.0 g/L) and peptone (5.0 g/L) was used to culture living cells. The medium's pH was adjusted to 7.0. For 24 hours, the culture was incubated at 65 °C and centrifuged at 110 rpm. The cells were harvested by centrifuging the culture for five (5) minutes at 8000 rpm and 4 °C. The pelleted centrifuged cells were washed twice with sterile distilled water before being used in the encapsulation process.

Encapsulation Process

The encapsulation processes were designed to keep the bacteria safe while it travelled through as inert material. Encapsulation occurs through a cross-linking process in which the calcium ion in the solution crosslinks the polymers in the alginate, resulting in gel beads. As a gelling agent, 15 g/l sodium alginate ($\boldsymbol{C_6H_9NaO_7}$) is required for each series of alginate beads. 33.3 g/l yeast extract, 33.3 g/l urea ($\boldsymbol{CH_4N_2O}$), and 20 g/l calcium lactate ($\boldsymbol{C_6H_{10}CaO_6}$) are required for the nutrient source of bacteria, with 11.1 g/l calcium chloride ($\boldsymbol{CaCl_2}$) for cross-linker.

Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy (SEM) was performed to learn more about the specimens. In this study, two (2) specimens were prepared for SEM testing. First, the *Geobacillus stearothermophilus* for its shape and morphology. Second, the state of *Geobacillus stearothermophilus* after being encapsulated and submerged in cement slurry for 28 days.

After preparing a 24-hour culture of *Geobacillus stearothermophilus*, the culture was aseptically transferred at 0.2 µl to the microscope slide. The smear is heat-fixed by passing it quickly over a flame and then using the bacterial staining method to fix the stain. The smear must be completely dry before being coated with gold sputter to improve image resolution when SEM is used. The AE-GS was removed from the cement slurry and rinsed before being allowed to air dry. A 10 % agarose consistency was also prepared. While the agarose temperature drops to 50 °C, the AE-GS is thoroughly mixed into the agarose.

The mixture was then poured into the small pan to harden the agarose. The hardened agarose with the AE-GS was thinly sliced and put on microscope slides using a sterilised scalpel. The slides surface with dry AE-GS sheet were then coated using a gold sputter machine before performing the SEM test.

Determination of mortar mix proportion and casting process

The mortar mix design was based on a cement-to-sand ratio of 1:3 and a water-to-cement ratio of 0.5. The chemical used for encapsulation (AE) was measured based on the weight of total replacement at 3%, 9%, and 15% by weight. Two (2) bacterial concentration (BC) were used namely $1x10^3$ cfu/ml and $1x10^{11}$ cfu/ml. Nine (9) batches of total mix designations were produced. There were three (3) batches of alginate-encapsulated without *Geobacillus stearothermophilus*, namely R (3%), R (9%), and R (15%), and six (6) batches of alginate-encapsulated *Geobacillus stearothermophilus* (AE-GS 1 to AE-GS 6). The R and AE-GS batches were mixed in the proportions shown in Table 1. Before the mixing phase, AE-GS was prepared. Cement and sand were mixed in a dry mix, then AE-GS was added. The bacterial work process is described in detail in previous sections.

Table 1. Mix proportion of mortar with alginate-encapsulated *Geobacillus stearothermophilus* (AE-GS)

Batch	AE (%)	BC (cfu/ml)	Alginate – Encapsulation [a]					Mortar [b]		
			dH^2O (ml)	Sodium Alginate (gram)	Calcium Lactate (ml)	Urea (ml)	Yeast Extract (ml)	Cement (kg)	Sand (kg)	Water (litre)
R (3%)	3	-	1039	20	80	80	133.2	10.8	32.3	5.4
R (9%)	9	-	3116	60	240	240	399.6	10.1	30.3	5.1
R (15%)	15	-	5194	100	400	400	666.0	9.4	28.3	4.7
AE-GS 1	3	1×10^3	1039	20	80	80	133.2	10.8	32.3	5.4
AE-GS 2	3	1×10^{11}	1039	20	80	80	133.2	10.8	32.3	5.4
AE-GS 3	9	1×10^3	3116	60	240	240	399.6	10.1	30.3	5.1
AE-GS 4	9	1×10^{11}	3116	60	240	240	399.6	10.1	30.3	5.1
AE-GS 5	15	1×10^3	5194	100	400	400	666.0	9.4	28.3	4.7
AE-GS 6	15	1×10^{11}	5194	100	400	400	666.0	9.4	28.3	4.7

[a] Encapsulation composition for each batch of alginate encapsulated without *Geobacillus Stearothermophilus* (R) and alginate encapsulated *Geobacillus stearothermophilus* (AE-GS)
[b] Material constituents for each batch of R and AE-GS

Experimental method

The experimental work on alginate-encapsulated *Geobacillus stearothermophilus* (AE-GS) is detailed in the following sub-sections:

Compressive strength

The mortar specimens were tested for compressive strength following BS EN 12390-3:2009. The compressive strength of the specimens was tested at 7 and 28 days of age. The dimensions of the specimens are 50 mm x 50 mm x 50 mm. The compressive machine was set to a pacing rate of 3.0 kN/sec, and the procedure followed BS EN 12390-4:2000.

Quantification of healing efficiency

The healing of the specimens was assessed by making realistic cracks on them. The self-healing evaluation was carried out using a 40 mm cylinder with a diameter of 100 mm. The realistic cracks were created using a Universal Testing Machine (UTM) Type 1000 and a controlled applied load. The specimen was placed between the grips of the unit, and a suitable jig for creating a crack was placed above the table load. To build several realistic crack widths, all specimens were subjected to a high pace rate of 15% and a compression load of 0.083 kN/s.

Visualization of crack filling

A portable stereomicroscope, the Dino-Lite Camera (Dino Capture 2.0, AnMo Electronics, Taiwan), was used to examine the crack filling. Following the formation of the cracks in the specimens, initial photographs of the cracks in the specimens were taken immediately after the cracking operation, and six (6) locations were marked on each of the crack on the specimens that were distributed uniformly along the crack length.

Initial and final image were taken after incubation under wet-dry cycles for 7, 28 and 60 days. The image of crack widths was taken at two locations for each sample. The level of healing properties for control specimens was measured using cracked specimens incorporated with alginate-hydrogel but without *Geobacillus stearothermophilus*. The healing ratio by the width

decrement are calculated using Equation 3 [12].

$$Healing\ (\%) = \frac{Cw_i - Cw_f}{Cw_t} \qquad \text{(Equation 3)}$$

where Cw_i is initial crack width, Cw_f is final crack width and Cw_t is a total initial crack width. The self-healing with the aid of bacteria is mainly due to microbial precipitation of calcium carbonate, the quantification of crack healed by the bacterial deposition will be an indicator for healing efficiency [13]. The data obtained was analysed and results taken by average.

Results and Discussion

Scanning Electron Microscopy (SEM)

Based on observation from the SEM image in Figure 2, the *Geobacillus stearothermophilus* is a rod-shaped cell as defined by Zeigler [4] and Nazina et al. [14]. *Geobacillus stearothermophilus* can be encapsulated in alginate hydrogel while retaining all of its incorporated nutrients (Figure 3). This shows that an alginate hydrogel can both protect bacteria and facilitate in a concrete environment.

Fig. 2. *Geobacillus stearothermophilus* (15000 x magnification, 200 nm)

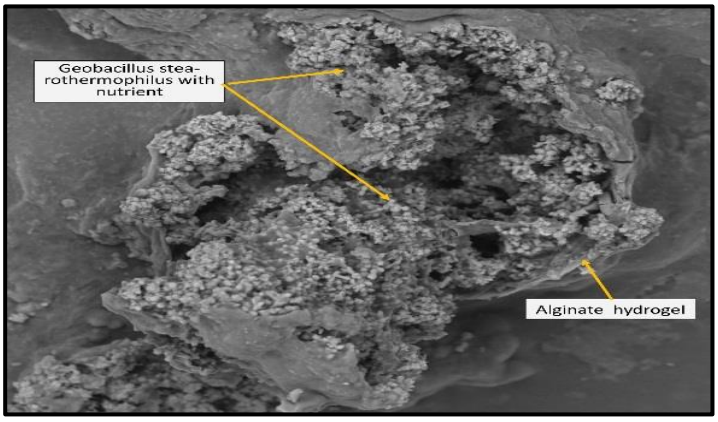

Fig. 3. *Geobacillus stearothermophilus* encapsulated in alginate-hydrogel (3000 × magnification, 30µm)

Experimental results

Compressive strength

The results in Figure 4 show that when AE-GS was used at a higher percentage, such as 15 %, the strength of the specimens was significantly reduced. In comparison to other batches, the lower percentage of AE-GS (3%) with a higher bacterial concentration ($1x10^{11}$ cfu/ml) had the highest compressive strength. A 15 % replacement of AE-GS in the mortar resulted in a significant decrease in compressive strength as opposed to a 9% replacement of AE-GS in the mortar.

Results shown in Figure 4 indicate that with higher incorporation of AE-GS for instance at 15 % replacement, the strength decreased considerably. The lower percentage of AE-GS (3 %) with higher bacterial concentration ($1x10^{11}$ cfu/ml) recorded the highest compressive strength as compared to that in other batches. Major reduction of compressive strength was observed on a 15 % replacement of AE-GS in the mortar as compared to that on 9 % and 3 % replacement of AE-GS. In comparison to the direct incorporation of bacteria, which has a positive impact on compressive strength, the strength of the concrete decreased after the addition of AE-GS. Raden Maizatul Aimi et al. [15] found that a higher concentration of *Geobacillus stearothermophilus* has a direct impact on early strength as early as three (3) days when compared to that in a control mortar.

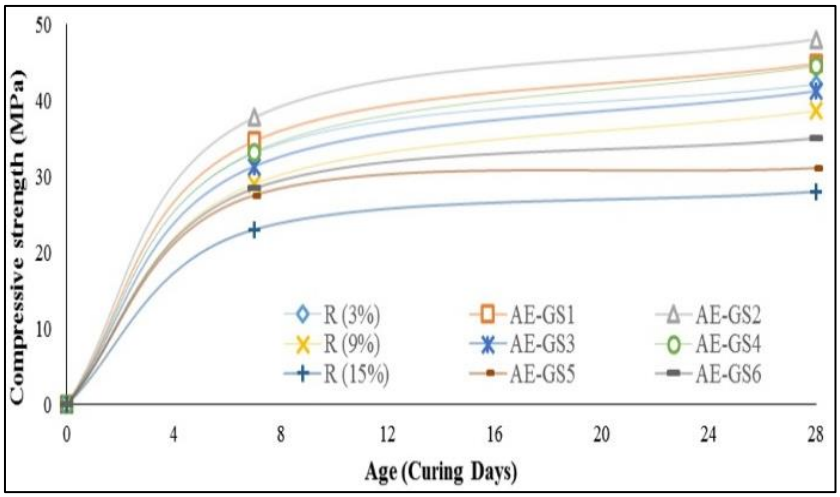

Fig. 4. Compressive strength for the mortar cubes

Quantification of crack healing

The reference was made by combining alginate-hydrogel with no bacteria (R). The incorporation of AE-GS improved the autogenous healing of mortar specimens (Figure 5). The progression of the crack healing process can be seen in stereomicroscopic images of cracks taken at regular intervals (0, 7 and 28 days). The cracks were observed to gradually heal over time (Figure 6). By 28 days, cracked mortar with a higher replacement of AE-GS and a higher concentration of bacteria had healed completely. On the reference mortar, no deposition of calcium carbonate due to bacterial precipitation was observed.

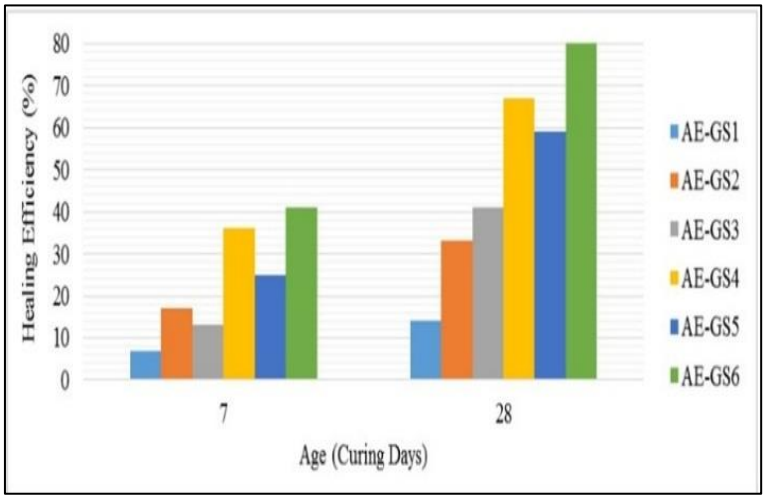

Fig. 5. Cracks healing percentage at 7 and 28 days. No healing was observed for reference samples

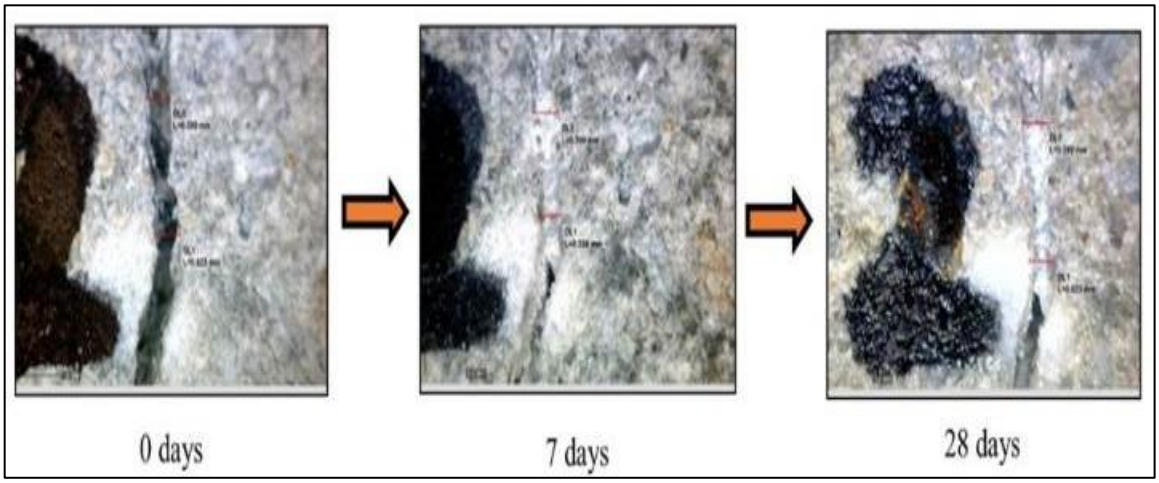

Fig. 6. Crack filling with whitish precipitation by *Geobacillus stearothermophilus* (specimen in series AE-GS2)

Conclusions

The incorporation of AE-GS had two effects on the mortar matrix. First, AE-GS has a negative effect on compressive strength by incorporation of more than 9 % in the mortar. Second, higher AE-GS replacement (15 %) and higher bacterial concentration ($1x10^{11}$ cfu/ml) in mortar resulted in higher healing efficiency. Higher bacterial concentrations indicate that more calcium carbonate precipitation will occur as compared to a lower bacterial concentration ($1x10^{3}$ cfu/ml). The incorporation of AE-GS in mortar mix evidenced the occurrence of self-healing based on stereomicroscope images. The maximum healing was achieved at 80 % on the 28th day of observation. When 15 % of the AE-GS is replaced as in AE-GS5 and AE-GS6, the strength dropped between 17 % and 24 %; compared to AE-GS replacement at 3 % and 9 %. This study demonstrated the ability of alginate-hydrogel to encapsulate *Geobacillus stearothermophilus* and act as a vehicle protector. *Geobacillus stearothermophilus* biomineralisation also implies the bacteria's success in the potential repair and maintenance of cracks.

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Project Management with *Maslahah* from the Technical Departments Approach

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Abstract

Public projects implementation in Malaysia, led by the two (2) technical agencies i.e. Jabatan Kerja Raya (JKR) and Jabatan Pengairan dan Saliran (JPS), is significant to the Government as well as to the people as it is an important instrument to create economic growth with multilevels effect, bridging the gap between urban and rural folks, the rich and the poor, to distribute wealth, building the infrastructure for social wellbeing, to spur upstream and downstream from low to medium scales businesses. However, its delivery is continuously confronting issues and challenges in an increasingly stringent, dynamic, complex business requirements, processes and demanding environment. With continuous project delays, cost overruns and also issues relating to ethics, integrity, the effective governance of public projects are questionable. On the other hand, the persistent efforts by the Government of Malaysia towards the practice of Islamic principles are prominent. Indeed, Islam is a way of life than merely a religion that covers all facets of affairs and life. It provides the most comprehensive guidance in all spheres including project management. Project management needs a new approach, other than merely technical competencies, enriched with extra dimension of spiritual, *tauhid*, human driven to give 'soul', aims not only achieving the worldly project objectives and success but the ultimate success in the Hereafter. Hence, this paper proposes the application of Project Management with *Maslahah*. The methodology employs multiple approaches; literature review, presentation of the preliminary concept in a conference, a webinar and a workshop session.

Keywords: Public projects; Project management; Islamic principles; *Maslahah*; Project success

Introduction

Project management (PM) for public projects in Malaysia is best represented by Jabatan Kerja Raya (JKR) or the Public Works Department of Malaysia and and Jabatan Pengairan dan Saliran (JPS) or the Department of Irrigation and Drainage as the main technical departments for implementing physical and infrastructure projects [16, 17, 21]. In this respect, JKR has long been leading other government agencies on technical guidelines for building, road, and maintenance projects, construction contracts and PM whereas JPS is the expert for irrigation, drainage, water resources and dams, river and coastal related projects.

Despite many developments and tremendous changes that have taken place in the construction industry and PM such as Green Buildings, energy efficiency, IBS (Industrialised Building System), LCC (Life Cycle Costing), Total Asset Management, as well the move towards digitalisation in line with Industrial Revolution (IR) 4.0, government projects are still

confronting common issues such as project delays, cost overruns, completion beyond original schedules, quality issues, dissatisfied clients etc. [38, 39]. Apart from that technical and physical in nature issues, it is also smeared by ethical and moral related issues such as bribery and corruptions that are intangible, indirectly measurable and even hard to prove, but what is more alarming is that recent reports in the media have shown escalating cases. Malaysia's position among countries on The Corruption Perception Index (CPI) for 2020 has dropped from ranking 51 to 57 as compared to the previous year of 2019 [46, 56]. Thus, these highlighted issues need to be addressed.

PM is a combination of both the science and the art, the term 'project' reflects technical knowledge, skills and competencies while 'management' refers to human-related components such as interpersonal and leadership capabilities [50, 57]. PM comprises both the 'hard' part and the 'soft' part. The former refers to the well-defined technical and mechanistic procedures and guidelines whereas the latter concerns about the people related, project leadership and interpersonal skills [38]. While much emphasis has been given to the well established technical part, less effort is contributed to the people part in PM that is equally important. Stephen R. Covey (2013), the famous author of the over 25 million copies book sold worldwide; 'The 7 Habits of The Highly Effective People' told in his book that a person has four dimensions i.e. Physical, Mental, Social/ Emotional and Spiritual that need to be balanced. Typical and traditional project management has probably been too much devoting to the first two i.e. Physical and Mental that are associated with the technical competencies and is lacking on Social/ Emotional and Spiritual dimensions that are equally important.

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 PM which is part of *muamalat* (transactions or dealings according to Islam) [26, 35].

The completeness and comprehensiveness of Islam that provides the best guidance and as a way of life, to regulate the whole life of mankind and to resolve and fulfil all the needs of men and women, in totality is also confirmed in the following verse of the Qur'an: In *Surah al-An'am* 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" (Qur'an, *al-An'am*: 38, translation of Tafsir Ar-Rahman, JAKIM, 2007).

This commandment is all-encompassing to all human affairs and not to exclude matters pertaining to PM. Moreover, it is obligatory (for Muslims) as part of obligations towards Allah to identify the lawful (*halal*), in accordance with *Shari'ah* and otherwise those prohibited in our daily dealings [8, 26]. For non-Muslims, although it is not obligatory, Islamic system, values and principles, that it 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 that is currently well in place. 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" (Qur'an, *al-Anbya'*: 107, translation of Tafsir Ar-Rahman, JAKIM, 2007). In this regard, the success of Islamic finance and banking system as well as Islamic insurance (*takaful*) has provided sufficient proof that Islam benefits all and brings the best to mankind and their life affairs.

In fact, the positive impacts of Islamic leadership in various organisational types and settings have been proven empirically in various researches such as [1](value-based corporate management); [33](banking); [42](business effectiveness); [13](social organisation); [14](social organisation); [15](quality management); [59](takaful industry); [29](social and religious perspective organization); and [25](academic institution). Recent research with empirical evidence shows that Islamic leadership principles can have positive outcome on PM and enhance the likelihood of project success [38].

Therefore, principles that bring elements of faith and religion of Islam would have positive impacts because it strives for true purpose of life, 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 that it will have positive impacts on projects as it has been demonstrated in previous researches. They have internal control mechanism that can influence their ways and behaviour towards their projects and the people involved, which is oftenly neglected in the vast majority of PM literature. Malaysian Anti Corruption Agency (MACC) reported that one of the root causes of committing corruptions was weaknessess internal control of individuals involved [60]. In light of the issues that have been discussed in the previous paragraphs, this paper will discuss; PM with *Maslahah* to enhance the chances of project success and to improve ethical practices.

Research Methodology

This paper has employed the followings:

i. Literature review from the previous studies in the relevant fields i.e. project management, Islamic leadership, *Shari'ah*, *Maqasid Shari'ah* and common themes.
ii. A Preliminary agenda of this paper has been presented as a conference paper in Persidangan Juruukur Bahan Sektor Awam 2019, 29 September – 1 October 2019, CREaTE, Melaka and in SiBE Live Webinar Series: *Islamic Leadership Principles In Project Management* (Webex Video Link), 25 November 2020.
iii. A workshop presentation was conducted involving panellists consisted of Quantity Surveyors from Bahagian Ukur Bahan dan Pengurusan Kontrak (BUBPK), JPS Malaysia on 7 April 2021 for feedbacks and comments. All panellists had vast working experience in project management for more than ten (10) years. Two (2) panellists whom were very senior Quantity Surveyors had more than twenty (20) years working experience in project management and public projects implementation.

Project Management (PM) In Islam

Project management is not new for it had been in existence and applied in the modern context ever since people started erecting buildings and bridges [9, 44]. Project management has been defined as a temporary endeavour that has a starting and ending dates towards achieving certain objectives. As a matter of fact, Islam has pioneered with great leadership qualities in the past. Construction marvels include the construction of pyramids during the Pharaoh (Fir'aun) periods of ancient Egypt, the construction of Sultan Suleiman mosque in Istanbul during the Ottoman reign (that took more than five (5) years to complete), the Taj Mahal in India that was built by Shah Jahan in memory of his true love for his wife, Mumtaz Mahal, (that took 21 years and more than 20,000 workers, craftsmen to complete in 1653).

Other great PM examples are derived from the stories of the life of the Prophet S.A.W. during his prophet hood times. Allah describes the best leadership qualities of the Prophet S.A.W. in the Qur'an as 'Uswatun hasanah' which means good example (Surah *al-Ahzab*: 21) and

'Khuluqin azim' which means the best character (Surah *al-Qalam*: 4). It is narrated that the Prophet S.A.W. led the *Muhajirins* (the immigrants) from Mecca to Medina during the time of *Hijra*. Before arriving in Medina, they stopped at a place called Quba', where the Prophet S.A.W. initiated the construction of the first ever mosque there named Masjid Quba'. During the construction, the Prophet S.A.W. exemplified the noblest qualities of Islamic leadership when he himself participated in the dirt, dust and dangerous processes of the construction works of the mosque. Therefore, modern PM could certainly emulate the noble leadership of the Prophet S.A.W. to lead projects that are both successful worldly i.e. project success as well as in the Herefater i.e. to get rewards and the blessings from Allah S.W.T. (*mardhatillah*).

Project Management (PM) with *Maslahah*

The purpose of PM with *Maslahah* is to create and to have *tauhidic* consciousness plus *Shari'ah* mindset and practice that view PM in both worldly and the Hereaftter dimensions while implementing projects. Ultimately, Project Managers and project team members would be striking to optimise the best performance i.e. project success while at the same time eradicating any vulnerability to such unethical practices. While *Shari'ah* literally means the road to the watering place, the straight path to be followed and it is the total Islamic teaching and system, it is not a set of Islamic law as it is normally translated but *Shari'ah* is a combination of a comprehensive code of moral norms, ethical conduct as well as a body of divinely ordained religious law [34]. *Shari'ah* was revealed to the Prophet S.A.W. and written in the Qur'an, *Maslahah* is protecting the interests and safeguarding benefits for the people (*ummah*) that it is the main objective of *Shari'ah* [35, 47]. *Maslahah* is also protecting people against harm, evil or corruption that is called *Mafsadah*. Generally, this is the reason why *Shari'ah* is sent down to mankind (*ummah*).

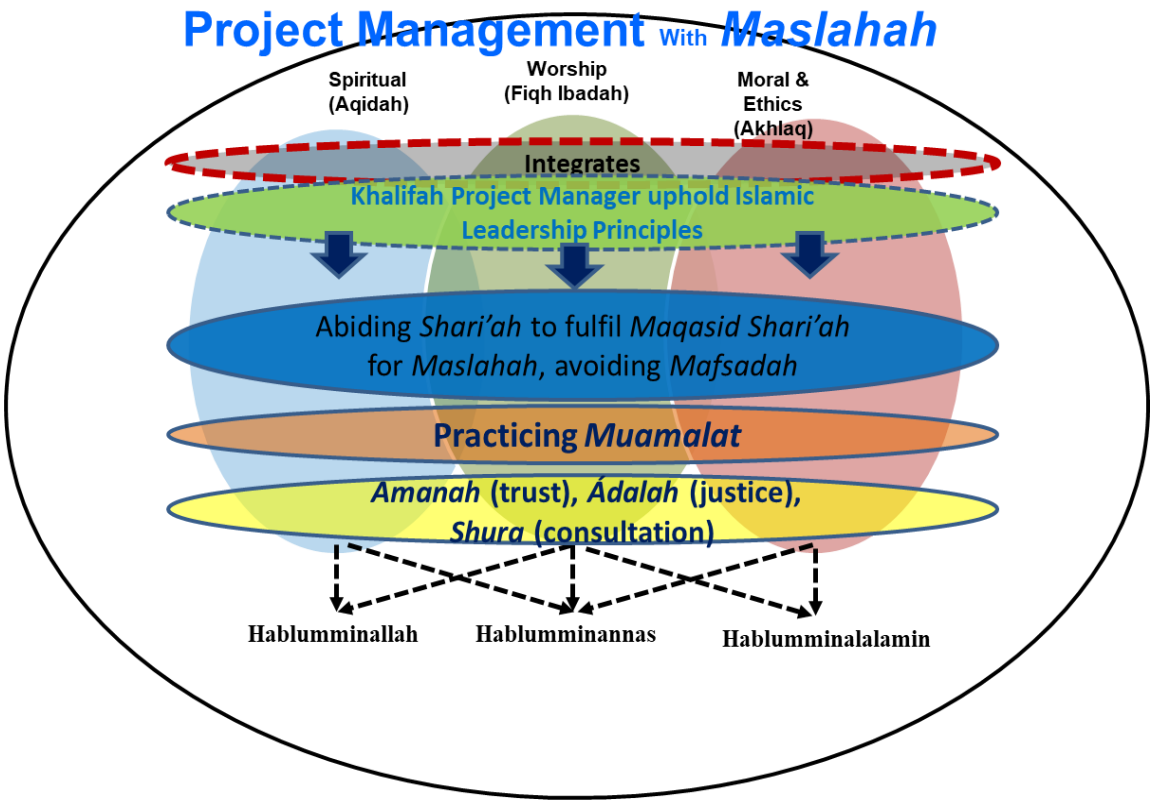

Fig. 1: Project Management with *Maslahah*

The following discussions will be referring to Figure 1. Before discussing on PM with *Maslahah* further, Islam from the very fundamental is founded upon three (3) elements namely *aqidah, ibadah* and *akhlaq* [4, 18, 19, 28, 29, 32, 35, 36, 53]. Thus, any model or framework from Islamic perspective is in line, consistent and grounded upon the foundation of the religion of Islam i.e. these three (3).

Islam begins with the establishment of the belief system in Allah and the concept of *tauhid* (the Oneness of Allah), that is referred as *aqidah* and *iman* and the people are known as *mukminun* (the believers) [4, 18, 19, 36]. Without such faith in Allah as God and tauhid, an individual is not a Muslim. *Aqidah* and the *tauhid* give men and women the meaning and purpose of their lives and why they are created. Secondly, upon such *aqidah* being founded in the heart and mind, Muslims are commanded to perform actions of worshipping Allah and this is *ibadah*. This is clearly stated in the Qur'an *Surah al-Jinn*, verse 56 that He Created men and jins with the purpose only to worship Him.

The performance of worship (*ibadah*) is not only performing the specific Five Pillars of Islam that are obligatory upon all Muslims consisting of *syahadah* (declaration of faith), *solat* (prayers), giving *zakat* (alms-tax), fasting and pilgrimage to Mecca but also including the general worship as in accordance with verse 162 of Surah *al-An'am* stated above is to include all activities and affairs of Muslims' lives such as economy, social, politics, business etc. In this regard PM that are rewardable actions if they are done faithfully according to Islam with the intention (*niat*) to get His pleasure or otherwise can become sinful actions if one transgressed and performed what is prohibited [6, 7, 19, 20, 36, 37].

Thirdly, as the development of Muslim to the third stage of Islamic core components, that is *akhlaq*, Islam sets the highest and noblest characters to be embraced and practised by the believers. *Khuluq* (*akhlaq* for plural) in Arabic term means character', which can be acquired through custom, habit and education by properly emulating the model of the Prophet S.A.W. or moral and ethics in modern literature [6, 7, 19, 20, 36, 37]. The fundamentals of Islam of *aqidah, ibadah* and *akhlaq* also reflect the three (3) relationships role as a *Khalifah* and His servant to bear, to take care of, to practice at all times i.e. *hablumminallah* (relationship with Allah), *hablumminannas* (relationship with men) and *hablumminalalamin* (relationship with alam (environment and other creations). These relationships complete the comprehensiveness and inclusiveness of divine dimensions for all mankind to live in accordance with *Shari'ah*, with *Maslahah*, in harmony and co-exist with all other creatures (*makhluk*).

Having these three (3) fundamentals of Islam as foundation, PM with *Maslahah* expands to embrace and practice four components; Islamic Leadership Principles, *Maqasid Shariah*, *Muamalat* and principles of *Amanah* (trust), *Ádl* (justice) and *Shura* (consultation). The first component is Islamic Leadership Principles. Leadership is identified as central and core to successful business outcomes and constitute as crucial in any group or collective tasks. Leadership is crucial in determining the fate of any organisation, in other words it dictates the success or failure of an entity whether missions and visions are achieved or not. Literature also revealed that for any initiatives or changes to be roled out in an organisation, it depends very much on the strong support and commitment from leaders.

Literature in PM has widely discussed and revealed the many success and failure factors in project delivery. One of those factors is leadership because leadership can harness the heterogeneous composition of people in the project team, influence them in the most effective manner, bring out the best talent from them, continuously build and maintain team

cohesiveness towards achieving the same project goals [3, 12, 30, 43, 45, 50, 52, 55, 58]. From the Islamic perspective, leaders and leadership are given even more great emphasis, from the very beginning of the creation of every man in this world i.e. as His *Khalifah* (Vicegerent) on earth.

Islamic leadership is an integral part of a Muslim life and part of Islam itself unlike the separation between religion and private matters or other life affairs in the West and conventional system [32, 41, 54]. Thus, leadership in Islam exists and it is dominant in every aspects of lives starting from leading oneself as individual to leading everything else. The strong element of God belief system in Islam that is called the *tauhidic* dimension that every Muslim leader possesses or the presence of spirituality of God-consciousness is the fundamental feature of Islamic leadership [2, 20, 24, 41].

Due to the establishment of the *tauhid*, leadership in Islam is a divine trust or *amanah* and focuses to serve people i.e. to promote doing good deeds, prevent wrongdoings and provide social justice. Leaders are to demonstrate characters that are in line with Islam or known as *akhlaq* and all actions are regarded as worship or *ibadah*. Leaders are to exercise their leadership with the primary guidance of the Qur'an and exemplary Sunnah of the Prophet S.A.W. [6, 7, 19, 20, 53]. This principle of the crucial role of Islamic leadership applies to all affairs and facets of lives including project management.

Islamic leadership principles (ILP) are discussed in literature of Islamic studies for example in [11, 19, 20, 27, 36, 48]. In this paper, the six (6) ILP that have been appraised, identified and subsequently validated by expert Muhamad Rosdi (2019a) are referred. In his research, empirical evidence shows that Islamic leadership principles can have positive outcome on project management and enhanced the likelihood of project success.

The ILP is a Manifestation of Human role as His *Khalifah*; Leadership is a Knowledge Acquisition and Translation-leading With Knowledge; Leadership is a Responsibility; Leadership is a Team Working; Leadership by Example and lastly, Leadership is Vision and The Will to Achieve The Vision. The ILP are applicable to be the leading and guiding principles for Project Managers, Project team members in JKR and JPS project implementation. Being *Khalifah* with ILP is to lead projects by upholding *Shari'ah* and performing good deeds and preventing from wrongdoings (*amal maaruf wahna anil munkar*) and among fellow men, taking care of other creations, in all aspects of life including matters relating to works, in this regard, project management. Realising this principle, all activities are indeed 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. Allah Says in *Surah al-An'am* of the Qur'an that some people will be appointed to be leaders to lead others and *Surah al-Hajj* reminds leaders are to lead themselves and to serve and guide followers to do good deeds and prevent from committing things that are prohibited.

The next paragraphs will discuss the second component of PM with *Maslahah*. As stated in the previous paragraph, *Maslahah* is the main objective of *Shari'ah* and to realise it, or to implement it, *Maqasid Shari'ah* is the ultimate aim of *Shari'ah* to be the guiding principles as to what are the essentials that need to be protected, preserved against any harmful or evil actions for the welfare, safety, interest, benefits of human beings. There are five elements of *Maqasid Shari'ah*; Preservation of Religion (*ad-din*), Life (*al-nafs*), Dignity or Lineage (*al-nasf*), Intellect (*al-'aql*) and Property (*mal*) [26, 34, 35]. These are also applicable and should be the

guiding principles for PM in all stages i.e. from Planning, Design, Procurement, Construction until Handover to ensure that the projects that are implemented meet their full potentials technically, engineering sound as well as bring the most benefits and *Maslahah* to people and community who are affected by the projects and which the projects are meant for, and most importantly also are counted as good deeds (*amal maaruf, soleh*), free from any unethical behaviours, malpractices such as corruptions. In the end, both the worldly and the Hereafter objectives are fulfilled.

Project managers possess the given and gifted leadership quality from the divine to lead projects while protecting the *maslahah* of other people and environment. With the commissioning of the principle of *Khalifatullah* (His vicegerent) into PM, it gives the perspective of the project managers and the team leadership role to be 'immense and big'. It changes the view by 360 degrees. For example, project managers are also to protect the other creatures of God and the environment that He has commanded so while implementing projects to minimise destructions and wastages on people, environment and others.

As for the general worship (*ibadah*), *Shari'ah* has laid down certain principles for the conduct of daily business transactions involving people which is *muamalat* [22, 26]. The principles of muamalat are applicable for PM as it involves transactions and dealings among people. Therefore, this is the third component i.e. *muamalat*. Muhammad Rawwas (2005) quoted the principles of *muamalat* that can be summarised as the followings; transactions are not containing elements or products that are prohibited by the *Shari'ah* such as *riba* (interest charges), alcohol, gambling, prostitution, etc.; facilitating people in conducting daily personal and business lives transaction (*maslahah*), *iktinaz* (hoarding, black marketeering), *talaqqi al-rukban* (middle person; not *al-ijarah* or one who serves others) leading to inflated prices, *gharar* (uncertainty) and *maysir* (gambling) such as market manipulation and harmful speculation are forbidden; *al-ihtikar* (monopoly) must be avoided; transactions are conducted with patience, tolerance, truthfulness, ethics, integrity and accountability that must be held at all times; the parties in transactions must fulfil their respective obligations diligently and persevere to one's best ability [22]. These principles could certainly ensure our PM to be clean and transparent, following the path of *Shari'ah*.

Allah Says in the Qur'an that those who choose to follow the correct path of Islam will get assistance from Allah for example, even in marital affairs when a marriage is about to be dissolved, likewise in other affairs, Allah Provides His guidance as stated in the following verse: "And those who no longer expect menstruation among your women - if you doubt, then their period is three months, and [also for] those who have not menstruated. And for those who are pregnant, their term is until they give birth. **And whoever fears Allah (taqwa) - He will make for him of his matter ease**" (Qur'an, *al-Talaq*: 4, translation of Tafsir Ar-Rahman, JAKIM, 2007).

The fourth component of PM with *Maslahah* is *Amanah* (trust), *Ádl* (justice) and *Shura* (consultation). These three (3) are the common and famous traditions in Islam, mostly referred to, exhibited, demonstrated and exemplified of the Prophet S.A.W. in many occasions and mentioned in many places in the Qur'an and *Hadith* [26, 31, 39]. For example, *'adl* is referred to on at least fifty three (53) instances in various verses of the Qur'an that believers are urged to be just in all affairs and dealings [26]. *'Adl* is placing things in the right place where they belong [26].

Trust is placed right from the very beginning of the creation of men i.e. as His *Khalifah* to take care of fellow mankind, other creatures and do not cause destruction on earth. This is the number one (1) the utmost trust for every individual. It is well reflected to PM as if every task in PM we carry out diligently but excellently on the principle of divine trust, then everything must be right. Thus, it becomes a religious duty to accomplish in one's best ability, manner and in fullest commitment.

In *Surah an-Nisa',* Allah reminds the believers to assign trust to the people who are qualified and to be just and fair in dealings; "Truly, Allah Commands you to hand back your trust to their (rightful) owners, and (Allah commands you) whenever you have to judge between people, to pass judgment with fairness. Indeed, the most excellent is that which Allah exhorts you to do. Truly, Allah is All-Hearing, All-Seeing" (Qur'an, *an-Nisa'*: 58, translation of Tafsir Ar-Rahman, JAKIM, 2007). Islam indeed promotes a well-balanced society, sets a high priority on the principle of justice that eliminates elements of manipulation, fraudulence, favouritism, depression, leading to corruption etc. This is practical and very much relevant to PM, Project Managers and project team to improve the transparency and efficiency of every single process involved especially in dealing with people.

The Prophet S.A.W. after resorted consultation, had accepted the view from Salman al-Farisi to dig trenches to defend Medina in the battle of *Khandaq* that took place in the 5th *Hijrah* although it was not the original plan is one of the great examples of the common practice of the principle of consultation [39]. The practice of consultation with sincerity to follow the tradition of Islam will uplift the openness in PM for better ideas, creativities, avoiding conflicts and concurrently receive the rewards from Allah. The core components for the application of PM with *Maslahah* is presented in Table 1.

Table 1: The core components for the application of Project Management with *Maslahah*

Components	Details
Islamic Leadership Principles	Leadership is a Manifestation of Human role as His *Khalifah*; Leadership is a Knowledge Acquisition and Translation-leading With Knowledge; Leadership is a Responsibility; Leadership is a Team Working; Leadership by Example; Leadership is Vision and The Will to Achieve The Vision.
Maqasid Shari'ah	Preservation of Religion (*ad-din*); Life (*al-nafs*); Dignity or Lineage (*al-nasf*); Intellect (*al-'aql*) and Property (*mal*).
Muamalat	Transactions are not containing elements or products that are prohibited by the *Shari'ah* such as *riba* (interest charges), alcohol, gambling, prostitution, etc.; facilitating people in conducting daily personal and business lives transaction (*maslahah*), *iktinaz* (hoarding, black marketeering), *talaqqi al-rukban* (middle person; not *al-ijarah* or one who serves others) leading to inflated prices, *gharar* (uncertainty) and *maysir* (gambling) such as market manipulation and harmful speculation are forbidden; *al-ihtikar* (monopoly) must be avoided; transactions are conducted with patience, tolerance, truthfulness, ethics, integrity and accountability that must be held at all times; the parties in transactions must fulfil their respective obligations diligently and persevere to one's best ability.
Amanah (trust), *Ádl* (justice) and *Shura* (consultation)	The three (3) principles are common and famous traditions in Islam, mostly referred to, exhibited, demonstrated and exemplified of the Prophet S.A.W. in many occasions and mentioned in many places in the Qur'an and *Hadith*.

Discussions

The presence of elements of God-consciousness for project managers to lead and to make sure that the practice of promoting doing good deeds and prohibiting the wrongdoings are in place. This is paramount because it will guide the project managers and the project team to steer their project activities and PM on the correct path as commanded by Allah and not commit any actions that are contrary with what Islam has permitted. When everything in the project is conducted correctly and perfectly in accordance to Islam, success prevails. Success here means in both dimensions in the project success and worldly context as well as in the spiritual, religious and in the Hereafter. This is so because following and conforming to the *Shari'ah* as the divine guidance as a way of life in total, in all affairs, in PM as discussed in this paper, also results in PM excellence and free from moral degradation or unethical practices such as corruption since Islamic principles promotes best performance, one's best ability, highest achievement with the most benefits (*Maslahah*) to people and minimum wastage, resources i.e. achieving good outcomes and project success.

Conclusions

Project Management with *Maslahah* that proposes the application of principles of Islamic leadership, *Maqasid Shari'ah*, *muamalat* and *amanah* (trust), *a'dl* (justice) and shura (consultation) in project management demonstrates Islam as a way of life in totality that it is not confined only to spiritual, ritual or religious matters but is comprehensive for all facets, all affairs and everything we do including project management. This is to ensure that we achieve project objectives and project success technically, tangibly with ethical virtues and received the rewards and ultimate success in the Hereafter. It strives for technical excellence and maintains relationship with Allah, fellow men and other creations.

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A Case Study of Rail and Bus Transit Services between KLIA and Kuala Lumpur

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Abstract

Effective and efficient public transportation from city to airport and vice versa is important as airport is the gateway to a country or a city. Thus, establishing a transit service with good reputation will enhance not only travelling time of passengers from airport to the city centres but, it will have direct impacts on economic growth and business prosperity by tourists and businessman alike from airports and city centres. In this paper, perception on the effectiveness level of rail and bus are carried out based on findings by the researchers focusing on passenger's safety and accessibility with time travelled from KL Sentral and Kuala Lumpur International Airport (KLIA). Furthermore, the level of passenger satisfaction in the decision-making tendency of transit services based on the parameters set are analysed and evaluated before the comparison between the two transport systems is examined. Statistically, rail services received better passenger satisfaction level than bus services at 75.5% as compared to 56.5% based on the parameters studied. It is hoped that with these findings, further enhancement initiatives to both the airport-city transit services will be seriously considered by the relevant authorities to promote public transit services as an attractive mode of transport.

Keywords: Airport transit; Public transport system; Train transit; Bus transit; Transportation engineering

Introduction

Public transportations are shared and often operated with designated routes and fixed scheduled. Public transport system consists of various sub-systems on land, water and air systems including various vehicles or rail coach system, track and signalling system, route and scheduling system, fare and ticketing system, switch and transfer system and integrated information services. Land public transport transit systems depend on the government's ability to provide a convenient transit mechanism for a community moving from one place to another easily, safely, efficiently and effectively [1].

In Malaysia, the public transport system is the most important aspect of the connection system for both urban and rural communities. As an increasingly developed country, the connection system in Malaysia should have efficiency and progress in terms of services as well as the technology used. Therefore, the Malaysian government has taken various reforms and new strategies to further improve the quality of public transport services to attract public interest.In order to attract prospect passengers, public transport operators must improve their services to accommodate a wide range of customer's need and expectation [2]. Although much effort has been made to analyze passenger attribution towards vehicles and public transportation in general, only a few studies have distinguished between different modes of public transportation [3]. Studies involving differences between two modes of public transport with the same origin

and destination has been scarcely studied. Thus, this study was conducted to provide benchmarking information involving several parameters of land public transit systems used in urban areas.

Problem Statement

Perceptions about the quality of public transport services and the attribution of public transport have been important issues in some transport research, especially research that drives the promotion of public transport [3]. The problem of ridership attraction of rail and bus has been discussed mostly in qualitative terms. The only quantitative statement about this issue relates to the alternative specific constants in models of passenger's choice of modes which capture the effects of excluded factors from the model. If a model includes only quantifiable attributes such as travel time and cost, the alternative specific constants must capture the less tangible attributes mentioned earlier [4].

Based on the above issues, some of the parameters involved in passenger behavior during the operation of the public transport system of rail and bus types have been identified to highlight the issues of accessibility, comfort and safety in the use of the mode of transport in urban areas namely rail and bus. This issue of accessibility, comfort and safety when not addressed in the early stages can make people in the city feel difficult, frustrated and tired of meeting with people [5].

The current status of the land public transport system between the KL Sentral and KLIA stations indicates that the diversity of transit systems will contribute towards the effectiveness and efficiency of different passenger mobility [6]. These factors are important to ensure that public land transport will make passengers feel more comfortable with the services provided and the related service providers can offer more friendly services. It is important to learn the tendency of passengers to use rail and bus to reduce congestion and support the operation of the public transport system in the Klang Valley.

This paper aims to analyze and evaluate the passenger's level of satisfaction in making decisions to use rail and bus services in terms of accessibility, safety and onboard facilities from the same origin and destination to obtain a fair comparative result.

Methodology

This study involves two types of public transport service system, namely rail and bus that connect between KL Sentral station and KLIA station. KL Sentral Station and KLIA Station were chosen because of their suitability having the same start and end locations for survey and data collection. Qualitative and quantitative methods were used through passenger feedback surveys. Parameters that affect passengers are identified and analyzed to determine the level of accessibility, safety and onboard facilities of the rail and bus systems towards passengers between the two transit stations.

The research instrument is in the form of filling in survey data and feedback form. A pilot study was conducted by constructing a five section questionnaire to test the research instrument developed based on literature review, surveys and third-party feedback. The fractional distribution of such sections are demographics of respondents, respondent's experience, accessibility, safety services and onboard service facilities of the transportation system involved. The study required feedback from 500 passengers for each rail and bus between KL

Sentral and KLIA based on scientific study to determine the sample size using a table to facilitate population sampling [7].

SPSS software was used for data input and analysis. Correlation analysis was performed to measure the linear correlation between the variables and regression analysis was performed to assess the contribution of each factor to overall passenger satisfaction [2].

Results and Discussion

The results obtained in this study consist of responses from passengers who use rail or bus or both to travel from KLIA to KL Sentral. A total of 500 passengers each were approached to provide feedback on the questionnaire that has been prepared. Passenger group covers a wide range of different ages and social backgrounds. A total of 399 rail and 447 bus passsenger who answered the questionnaire are Malaysian citizens. Female passengers are the largest group participating in the rail survey with a percentage of 57% while male passengers are the largest group participating in the bus survey with a percentage of 57.8%. In terms of age, it was found that the highest respondents 301 people with 60.2% consisted of rail passengers aged between 26 to 40 years as shown in Table 1. The highest respondents of 52.4% consisted of bus passengers aged between 26 to 40 years, which is a total of 262 people as is shown in Table 2.

Table 1 Rail passenger demographic data

Citizenship			Gender		Total
			Male	Female	
Malaysian Citizen	Age	18 years and below	9	23	32
		19 – 25 years	6	74	80
		26 – 40 years	110	143	253
		41 – 59 years	4	6	10
		60 years and above	18	6	24
		Total	147	252	399
Non-Malaysian Citizen	Age	18 years and below	11	0	11
		19 – 25 years	21	27	48
		26 – 40 years	19	6	25
		41 – 59 years	17	0	17
		Total	68	33	101

Table 2 Bus passenger demographic data

Citizenship			Gender		Total
			Male	Female	
Malaysian Citizen	Age	18 years and below	0	5	5
		19 – 25 years	79	60	139
		26 – 40 years	104	133	237
		41 – 59 years	48	0	48
		60 years and above	10	8	18
		Total	241	206	447
Non-Malaysian Citizen	Age	18 years and below	15	5	20
		19 – 25 years	25	0	25
		26 – 40 years	8	0	8
		41 – 59 years	0	0	0
		Total	48	5	53

Accessibility

From the distribution of accessibility parameter data that has been collected, a summary of the number and number of passenger's responses to each item for accessibility parameters has been compiled as per Table 3 and Table 4. Overall, most rail passengers are very satisfied with accessibility of rail services; RA_1 to RA_5 with the percentage exceeded 50% at 'Excellent' scale making it accomplished the criteria of a good public transport [8]. A feedback from bus passengers shows that RA_2, RA_3, RA_4 and RA_5 received a 'Poor' scale with 6%, 7%, 4.2% and 5.4% respectively that need critical improvements and consideration on pedestrian walkway, design space in rail, ample space for luggage and facilities appropriate to the needs of the elderly and the disabled. This shows that the accesibility to public transit station can be a factor in determining passenger's selection and their overall satisfaction with the public transport journey [9].

Table 3 Distribution of passenger feedback for rail accessibility parameter

Rail Accessibility	Very Poor	Poor	Fair	Good	Excellent	Mean
Rail network coverage (RA_1)	0	0	60	136	304	4.49
Provision of pedestrian walkway to the Rail platform (RA_2)	0	30	30	136	304	4.43
Convenient space to move in the Rail (RA_3)	0	35	24	123	318	4.45
Convenience of luggage space inside the Rail (RA_4)	0	21	30	169	280	4.42
Convenient route for disabled persons, senior citizens and person of special needs (RA_5)	0	27	54	125	294	4.37

Table 4 Distribution of passenger feedback for bus accessibility parameter

Bus Accessibility	Very Poor	Poor	Fair	Good	Excellent	Mean
Bus network coverage (BA_1)	0	5	15	400	80	4.11
Provision of pedestrian walkway to the Bus platform (BA_2)	14	42	21	330	93	3.89
Convenient space to move in the Bus (BA_3)	0	0	80	291	129	4.10
Convenience of luggage space inside the Bus (BA_4)	11	14	21	319	135	4.11
Convenient route for disabled persons, senior citizens and person of special needs (BA_5)	1	41	13	347	98	4.0

Safety

Rail safety with label RS_2, RS_3 and RS_4 earned a majority percentage of 'Excellent' scale over 50% with 57.2%, 60.8% and 50.6% respectively. For RS_1 and RS_5, the percentage of 'Excellent' scale was low with 45.6% and 20% respectively. However, RS_5 got the highest percentage on the 'Good' scale with a value of 69.8% as shown in Table 5. Table 6 shows the importance outcomes related to bus passenger evaluation of safety services from BS_1 to BS_5. Safety items BS_1 to BS_4 earned a 'Good' scale percentage of more than 60% with 71%, 72.4%, 85% and 84.4% respectively. Item BS_5 gained most of the Poor scale of value at 64%. Safety and security were two important aspects perceived by the rail and bus users [10]. Most

passengers were satisfied with the safety and security aspects of rail and bus service except for matters related to the provision of emergency and safety equipment; RS_5 and BS_5 which were not visible to the passengers along the journey.

Table 5 Distribution of passenger feedback for rail safety parameter

Rail Safety	Very Poor	Poor	Fair	Good	Excellent	Mean
Safety level on the Rail platform is sufficient (RS_1)	0	17	30	225	228	4.33
Safety level of seats in Rail are appropriate (RS_2)	0	0	30	184	286	4.51
Cautious, efficient and secure Rail driving trip (RS_3)	0	0	54	142	304	4.50
Warning signs / safety instructions displayed in Rail (RS_4)	0	21	54	172	253	4.31
Emergency / safety equipment is available in Rail (RS_5)	0	21	30	349	100	4.06

Table 6 Distribution of passenger feedback for bus safety parameter

Bus Safety	Very Poor	Poor	Fair	Good	Excellent	Mean
Safety level on the Bus platform is sufficient (BS_1)	0	0	18	355	127	4.22
Safety level of seats in Bus are appropriate (BS_2)	0	0	11	362	127	4.23
Cautious, efficient and secure Bus driving trip (BS_3)	0	0	0	425	75	4.15
Warning signs / safety instructions displayed in Bus (BS_4)	0	0	77	422	1	3.85
Emergency / safety equipment is available in Bus (BS_5)	0	320	180	0	0	2.36

Onboard Facilities

Table 7 and Table 8 show passenger feedback about onboard facilities for rail and bus. These tables show the important assessments related to passenger's evaluation of onboard facilities services in rail and bus. Only one item of RO_2 got a majority percentage of 'Excellent' scale exceeding 50% which is 67.6%. Based on the feedback, all rail passengers agreed that the level of rail service was at 'Good' scale level respectively for RO_1 = 42.4%, RO_3 = 56.5%, RO_4 = 63.6% and RO_5 = 55.8%. For bus services, onboard facility items BO_1 and BO_2 earned a good scale percentage of more than 60% with 85.4% and 84.2%, respectively. Only 13.8% of passengers were very satisfied and rated 'Excellent' scale for BO_1 and 15% of respondents were very satisfied and rated 'Excellent' scale for BO_2. Items BO_3 to BO_5 did not reach the level of passenger's satisfaction. This indicates that travelling with high level of facilities, convenience and quality are significant for passengers [2].

Table 7 Distribution of passenger feedback for rail onboard facilities parameter

Rail Onboard Facilities	Very Poor	Poor	Fair	Good	Excellent	Mean
Provision of suitable and adequate seating in the Rail (RO_1)	0	27	54	212	207	4.20
Comfort of air conditioning along the way (RO_2)	0	21	24	117	338	4.54
Wireless internet setup (WiFi) are available during the trip (RO_3)	6	30	36	283	145	4.06
Digital visual telecommunication media displaying travel information is provided in Rail (RO_4)	30	6	24	318	122	3.99
Provision of facilities for disabled persons, senior citizens and person of special needs (RO_5)	0	6	24	279	191	4.31

Table 8 Distribution of passenger feedback for bus onboard facilities parameter

Bus Onboard Facilities	Very Poor	Poor	Fair	Good	Excellent	Mean
Provision of suitable and adequate seating in the Bus (BO_1)	0	0	4	427	69	4.13
Comfort of air conditioning along the way (BO_2)	0	0	4	421	75	4.14
Wireless internet setup (WiFi) are available during the trip (BO_3)	0	375	125	0	0	2.25
Digital visual telecommunication media displaying travel information is provided in Bus (BO_4)	0	375	125	0	0	2.25
Provision of facilities for disabled persons, senior citizens and person of special needs (BO_5)	0	375	125	0	0	2.25

Correlation Analysis

Table 9 and Table 10 show the results of mean correlation analysis from three main parameters namely accessibility, safety and onboard facilities in determining passenger's level of satisfaction of rail and bus services provided between KL Sentral and KLIA. For obtaining an overall analysis of the rail services between these three parameters, the mean values of 'μ' for accessibility, safety and onboard facilities are obtained by computing the sum of the values of each parameter item involved. The significant relationship between each parameter can be seen based on the Pearson correlation test. The table show a strong relationship between mean accessibility ($C\mu_R$) with safety ($D\mu_R$) and onboard facilities ($E\mu_R$) with a value of $r = 0.955$ and $r = 0.878$. The relationship between $D\mu_R$ and $E\mu_R$ also showed a strong value of $r = 0.887$.

The results of passenger's level of satisfaction for bus services show that mean correlation analysis and significant relationship between each parameter can be seen based on the Pearson correlation test. When referring to the relationship between each parameter, the mean safety ($D\mu_B$) and the mean onboard facilities ($E\mu_B$) show a strong correlation with mean accessibility ($C\mu_B$) with a value of $r = 0.609$ and $r = 0.472$. The relationship between $D\mu_B$ and $E\mu_B$ also shows a strong value of $r = 0.563$. Overall, the relation values for each parameter are still in the range 0 - 1 and indicate that each parameter has a significant and strong relationship to each other.

Table 9 Correlation analysis of rail parameters

Category		$C\mu_R$	$D\mu_R$	$E\mu_R$
Accessibility, $C\mu_R$	Pearson Correlation	1	0.955**	0.878**
	Sig. (2-tailed)	-	0.000	0.000
	N	500	500	500
Safety, $D\mu_R$	Pearson Correlation	0.955**	1	0.887**
	Sig. (2-tailed)	0.000	-	0.000
	N	500	500	500
Onboard Facilities, $E\mu_R$	Pearson Correlation	0.878**	0.887**	1
	Sig. (2-tailed)	0.000	0.000	-
	N	500	500	500

** The correlation is significant at the 0.01 level.

Table 10 Correlation analysis of bus parameters

Category		$C\mu_B$	$D\mu_B$	$E\mu_B$
Accessibility, $C\mu_B$	Pearson Correlation	1	0.609**	0.472**
	Sig. (2-tailed)		0.000	0.000
	N	500	500	500
Safety, $D\mu_B$	Pearson Correlation	0.609**	1	0.563**
	Sig. (2-tailed)	0.000		0.000
	N	500	500	500
Onboard Facilities, $E\mu_B$	Pearson Correlation	0.472**	0.563**	1
	Sig. (2-tailed)	0.000	0.000	
	N	500	500	500

** The correlation is significant at the 0.01 level.

Regression Analysis

Regression analysis of the rail service was performed to identify which variables had an effect on the parameters studied. The process of regression can determine which factors are important, which factors can be ignored and how these factors influence each other. A summary model of the relationships between variables is given in Table 11. The table shows the value of the coefficient R of 0.869 and also the value of the coefficient R-squared (R^2) = 0.755. R^2 known as coefficient of determination values range from 0 to 1 and are commonly stated as percentages from 0% to 100%. An R^2 of 100% means that all dependent variables (DV) are completely explained by movements of the independent variables (IV).

Thus, the value represents the joint effect of the three independent variables on the dependent variable, namely the level of passenger satisfaction of 75.5%. The regression analysis for the bus service using the model of the relationship between the variables is shown in Table 12. The table shows the value of the coefficient R of 0.752 and the value of the coefficient R-squared (R^2) = 0.565. The value indicates that the three main parameters namely accessibility, safety and onboard facilities moves relatively in line with the level of passenger satisfaction of bus services of 56.5%. The results of regression analysis in this study show that the variables that have the most positive influences on passenger satisfaction with rail and bus services is accessibility based on the highest coefficient (beta) value (B_{rail} = 1.305) and (B_{bus} = 0.747)

Table 11 Rail satisfaction coefficient regression model coefficients

Model		Non-standardized coefficients		Standardized coefficients	t	Sig.	R^2
		B	Standard Error	Beta (β)			
Rail	(Constant)	2.377	0.107		22.266	0.000	0.755
	Accessibility (X_1)	0.971	0.057	1.305	17.009	0.000	
	Safety (X_2)	-0.747	0.76	-0.780	9.793	0.000	
	Onboard Facilities (X_3)	0.280	0.044	0.317	6.412	0.000	

Table 12 Bus satisfaction coefficient regression model coefficients

Model		Non-standardized coefficients		Standardized coefficients	t	Sig.	R^2
		B	Standard Error	Beta (β)			
Bus	(Constant)	0.088	0.233		0.379	0.000	0.565
	Accessibility (X_1)	0.947	0.048	0.747	19.627	0.000	
	Safety (X_2)	0.029	0.083	0.014	2.349	0.000	
	Onboard Facilities (X_3)	- 0.017	0.068	0.009	2.244	0.000	

Conclusions

The study of rail and bus transit system with related parameters is a study to improve existing public transport services and facilities especially in Kuala Lumpur and Klang Valley area connecting to KLIA airport. Overall, there is a positive effect influencing the overall variable with the level of passenger satisfaction with rail and bus transport services. In this study, the safety aspect also affects the reliability and dependability of the public service. The provision of comfortable and attractive interior rail and bus facilities will also attract various ages to make this public transportation system a top choice.

To conclude, all the parameters discussed have a significant impact on the needs and satisfaction of passengers towards public transport services. It is hoped that with these findings, further improvement initiatives to both KL Sentral and KLIA transit services will be seriously considered by the relevant authorities to ensure effectiveness and efficiency of the services to the public.

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Enhancing Energy Performance in Existing Government High-rise Office Building in Malaysia through Building Envelope Retrofit

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Abstract

The optimum design of building envelope plays a leading role in the energy efficiency of a building and can improve the existing building's energy-related performance. This study revealed that existing typical government high-rise office buildings in Malaysia have a higher Building Energy Intensity (BEI) of 161 kWh/m^2/year than the recommended value in Green Building Index (GBI) for commercial office buildings (150 kWh/m^2/year), and the Economic Planning Unit (EPU) standard for public buildings (140 kWh/m^2/year). Therefore, this study presents a report of a case study approach combined with calibrated building energy simulation to determine the optimal building envelope retrofit strategies in relation to their energy reduction designed for three levels of intervention (minor, moderate, and major level). The effectiveness of each level of retrofit interventions and its individual ERMs were evaluated by comparing the simulated space cooling and annual energy consumption between the validated base case model of typical government high-rise office building (before any intervention) and after the retrofit interventions' implementation. The results showed that all levels of intervention provided between 3% and 9% savings in annual energy consumption. The proposed interventions demonstrated compliance with the BEI benchmark margins of the GBI and EPU standard, namely 116 kWh/m^2/year (minor intervention level), 113 kWh/m^2/year (moderate intervention level), and 110 kWh/m^2/year (major intervention level). This study demonstrates the validity of the applied approach and provides a methodological framework for optimising building envelope retrofit interventions that can be applied by the local building sector and the Government of Malaysia.

Keywords: Building envelope retrofit; Building energy simulation; Office buildings; Energy savings; Retrofit interventions

Introduction

In most countries, office buildings make up the largest energy-consuming building type within the commercial sector due to their high operating energy requirements for lighting and air-conditioning systems [1, 2]. Retrofit forms a key part of mitigation strategy to decarbonise the global building stock and improve their energy efficiency [3, 4]. Appropriate energy retrofit interventions rely not solely on energy savings but also on providing opportunities for improving thermal and visual comfort, air quality, and maintenance cost reduction [2, 5-7]. However, many energy-related retrofitting projects conducted globally, including in Malaysia, are mainly concerned with active building system interventions such as air-conditioning and mechanical ventilation (ACMV), and lighting systems [8]. Building envelope design is one of the vital factors affecting building energy consumption for heating and cooling [7, 9, 10]. In hot and humid climate countries, 10% to 50% energy reductions can potentially be achieved

by reducing energy consumption for space cooling via building envelope retrofit [11]. A high-performance building envelope optimization in hot climate integrates optimum window-to-wall ratio (WWR), advanced glazing technologies, insulations, good airtightness, along with efficient reflective surface usage [10, 11].

Malaysia's present lack of policy and financing framework for greening existing buildings where the collected energy-related data from the building stock are not properly coordinated or sycronized to meet the national sustainability goals [12]. As a result, conducting case studies to showcase the potential energy savings by retrofitting existing buildings in Malaysia are considered rare. Surprisingly, most of the existing government office building designs have not optimized passive design strategies [12]. This indicates that there is a great necessity to quantify the desirable energy savings and identify suitable retrofit measures. Currently, 105 government office buildings are using equal to or more than 3 million kWh of electricity [13]. Therefore, this study was conducted to develop an understanding of how interventions in building envelope components could improve energy performance, particularly in existing government high-rise office buildings in Malaysia. Its objective is to develop a validated model for building envelope retrofit that can contribute to annual energy savings of existing government high-rise office buildings in Malaysia.

In order to achieve the stated objective, this study implemented a case study combined with calibrated simulation approach to establish a validated case model of a typical government high-rise analyse and calibrate the case models. The calibrated simulation approach is an approach for measuring savings that uses computer simulation software and calibrating the various inputs to the program so that predictions match closely with the measured energy data [14]. The levels of interventions (minor, moderate and major) are defined according to selected pre-defined quantitative criteria of Energy Retrofit Measures (ERMs) thermal characteristic aiming solely on building envelope improvement. These ERMs include WWR reductions, external insulation, high-performance glazing and the existing external shading devices. The determined levels of three retrofit interventions were intended to identify the optimal order in which a range of retrofit options should be prioritised and implemented to reduce the building's energy consumption, taking into account the efficiency, cost and the technology availability in the local market. It was conducted in two phases: 1) identification of a case study and extraction of its actual energy-related data to facilitate a simulation study; and 2) simulation of the energy performance of each level of interventions and individual ERMs to determine an optimised retrofit intervention strategies.

Methodology

Phase 1 - Case Study Building of Wisma Persekutuan Seremban and Extraction of Energy-related Data

No guideline defines a high rise building in Malaysia [22]; thus, this study referred to the definition by the National Fire Protection Association (NFPA) Code, namely a building with a total height exceeding 75 feet (22.9 meters), or about seven storeys above the ground level. As such, the 8 to 17 storey Wisma Persekutuan buildings, which were built in the 1970s or 1980s, were deemed qualify. The buildings take a form of a hermetically sealed box, totally depending on artificial lightings and ACMV systems for space cooling. They had high WWR values, repetitive and monotonous geometrical patterns on the facades, and glazing with low visible light transmission values. To date, only some of these buildings had their ACMV systems upgraded to improve the buildings' energy performance and reduce the electricity costs. Data from the Ministry of Works Malaysia showed that these buildings still maintained almost 90%

of their original building forms and façade designs. These buildings were established as the typical government high-rise office building models for this study.

Wisma Persekutuan Seremban located in Seremban, Negeri Sembilan was chosen as the case building for the simulation studies. It had linear facades with almost identical designs with no history of modifications made to its original façades. The original external shading devices were still intact. They consisted of concrete ledge shadings (890 mm wide and 825 mm high) and polycarbonate horizontal shadings fixed at the edge of the concrete ledge (Figure 1). To date, this building had carried out energy retrofits on ACMV system (completed in 2018), the energy-efficient lighting system (on-going in 2020), and an energy management program.

This study opted to follow the recommendation in the ASHRAE 90.1 Standards, i.e. to use two years of monthly utility bills to analyse the previous building energy consumption and simulation study. In general, the extracted data from the documents and site visits to the case building covered the building's general information, construction details, electrical system, ACMV systems, and architectural geometrical characteristics to establish the case building model (Table 1). It was notable that the case building had a high overall WWR, i.e. approximately 42.2% of the total gross wall area. Also, it was observed that the infiltration of outdoor air into air-conditioned spaces mostly came from the operable windows.

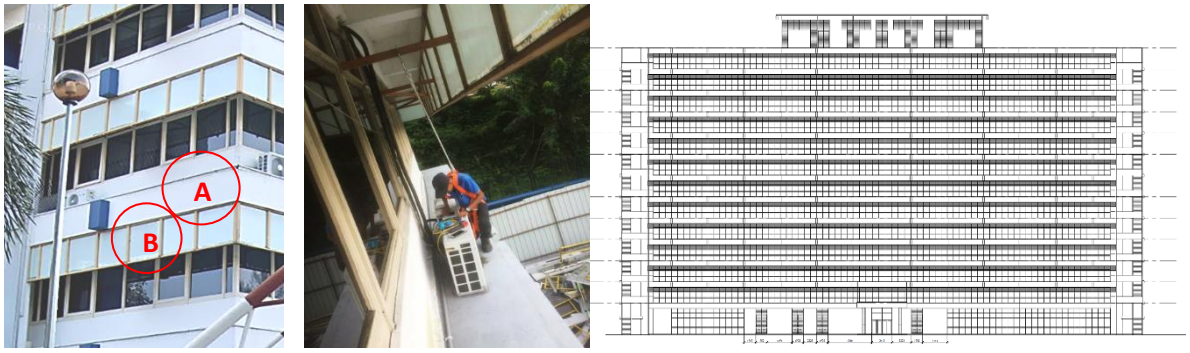


Fig. 1. Case building of Wisma Persekutuan Seremban: a) Existing shading devices, A-concrete ledge, B-polycarbonate horizontal shading, b) Concrete ledge shading; and s) Front elevation drawing.

The BEI of the case building was calculated by using the annual electricity bills (in kilowatt-hour, kWh) from the previous years of 2017, 2018, and 2019. From the data in Table 2, it is apparent that the BEI in 2017, which was before the ACMV up-grading works were completed, was the highest (161.63 kWh/m^2/year), followed by the BEI in 2018 and 2019 with the values of 134.0 kWh/m^2/year and 126.31 kWh/m^2/year, respectively. These BEI results exceed the recommended BEI in the GBI (150 kWh/m^2/year for commercial office buildings) and EPU standards (140 kWh/m^2/year for government/public buildings). It should be noted that the building has started to undergo lighting retrofit in 2019, and since then, the energy consumption has started to reduce. This work is expected to complete by the end of 2020. The energy-saving percentage via ACMV up-grading works and lighting retrofit was in a range of 13.23% to 18.70% in comparison to 2017 annual energy consumption. These results were compared with the results from the proposed building envelope retrofit interventions conducted in this study. The case building's OTTV value was 61.75 W/m^2 indicating a non-compliance with MS1525: 2014 that recommends the OTTV for the building envelope not to exceed 50 W/m^2.

Table 1 Detail technical information of Wisma Persekutuan Seremban

General Data and Geometrical Characteristic
Location: Seremban, Malaysia (latitude 2°43'31.1"N, longitude 101°56"E)
Building type: Office building, 13 storey above ground
Floor area: Total gross floor area: 17,044.9 m^2
Air-conditioned floor area: 13,877.35 m^2
Dimension and height: 76.81 m x 17.07 m (rectangular); floor-to-floor height = 3.275 m
Operating hours: Monday to Friday – 7.30 am – 5.30 pm; Saturday & Sunday – closed
Building Envelope Components Specifications
Opaque walls: Wood frame (50mm x 100mm, 400mm c/c), 9.5mm plywood + 50mm air space (ASHRAE U-value = 2.12 W/m2K)
Glazing walls: 6mm reflective glass with tinted film (shading coefficient = 0.76, U-value = 5.7 W/m2K, SHGC = 0.659)
Roof: 150mm thick concrete flat roof (ASHRAE U-value = 0.23 W/m2K)
Main operative parameters of ACMV
ACMV system type: Central – water-cooled chilled system
Air-conditioned space: o\Office space and lift lobby
Un-conditioned space: Stairs & Toilets
Occupancy density: 20m^2/person
Lighting load & type: 11.70 W/m^2, fluorescent lighting
Computers load: 4.10 W/ m^2
Infiltration rate: 1.65 AC/h
Space design temperature & humidity: 24° Celsius

Table 2 BEI calculation from annual electricity bills (2017, 2018 and 2019)

Year	Annual Electricity Consumption (kWh)	BEI calculation: Annual Electricity Consumption (kWh)/Total Air-conditioned Area (m^2)
2017	2,156,032.00	2,156,032.00 / 13,877.35 m^2 = 161.63 kWh/m^2/year
2018	1,870,893.00	1,870,893.00 / 13,877.35 m^2 = 134.0 kWh/m^2/year*
2019	1,752,816.00	1,752,816.00 / 13,877.35 m^2 = 126.31 kWh/m^2/year*

*BEI level after the completion of ACMV refurbishment works

Phase 2 - Energy Performance Simulation using IES<VE>

This study opted for IES<VE> simulation software to conduct the energy analysis due to its comprehensiveness, reliability and accuracy that satisfies the simulation program requirements as stipulated in the Malaysian Standard MS1525:2014. By using the software's thermal simulation package, the program analyses the performance of different types of opaque and glazing wall materials using real climate data, in response to various variables for each of the 8760 hours in a year. The model must be developed as precisely as possible to increase the accuracy of the simulation results. The process began by modelling its architectural geometrical characteristic and inputs of the building components and materials using the ModelIT module. The layout plan was divided into two thermal zones: non-air-conditioned and air-conditioned spaces. The ACMV and electrical systems, operating times and occupancy patterns were based on actual building operational data extracted from Phase 1. This study utilised the readily available hourly weather data of Subang, Kuala Lumpur for the simulations. The design temperature was 24°C with the operating time from 7.30 am to 5.30 pm on working days

(Monday to Friday). ApacheSim module was opted for the dynamic thermal simulation of the case model. The established model is shown in Figure 2.

The calibrated simulation approach in this study was based on several previous studies as there is no methodology standard available in Malaysia. Next, the validation of the calibrated model was based on a statistical indices approach to evaluate the accuracy of the simulated model. Essentially, each ERM is a component of the building envelope but with different performance values to differentiate the levels of intervention. Table 3 presents the different levels of retrofit intervention and their respective ERMs. Subsequently, by using the validated case model, retrofit strategies were simulated by integrating the proposed ERMs to the envelope components. The impact of these ERMs on the overall energy and space cooling annual consumptions were evaluated and analysed by comparing the results of the simulated model and original case model.

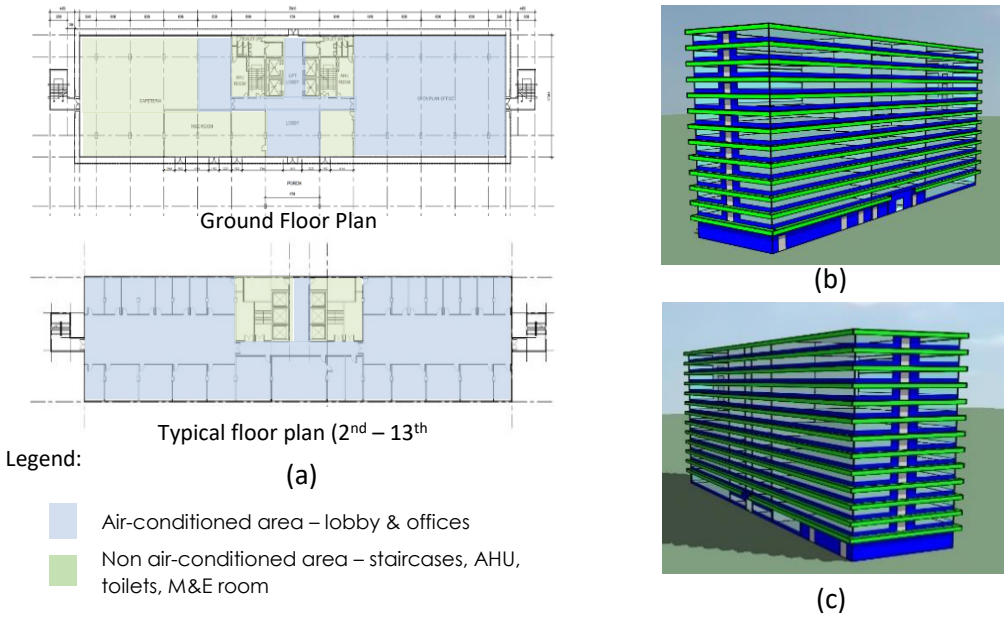
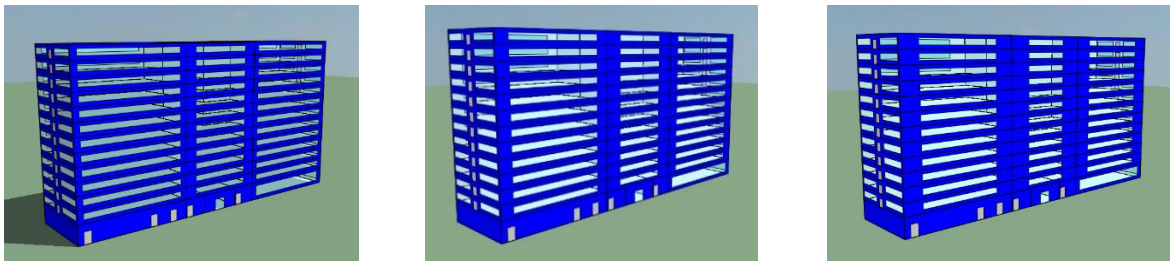


Fig. 2. Case building of Wisma Persekutuan Seremban: a) Thermal zones and usages of case building, b) Concrete ledge shading; and s) Front elevation drawing.

Table 3 Description of the proposed interventions and individual ERMs

Retrofit Intervention	ERMs	Code for individual ERMs	U-value (W/m^2K) of overall assembly		Simulation strategy
			Existing	Proposed	
Initially established 3 case models	40% reduction of WWR for Southwest (front) and Northeast (rear) façade orientations	A1	NA	NA	ERMs combination
	35% reduction of WWR for Southwest (front) and Northeast (rear) façade orientations	A2	NA	NA	ERMs combination
	30% reduction of WWR for Southwest (front) and Northeast (rear) façade orientations	A3	NA	NA	ERMs combination
A -Minor level of intervention	Reduction of WWR	A1, A2 & A3	NA	NA	S1: A1+B1+B2+B3
	Glazing replacement with low-e tinted single glass panes (SHGC 0.75) and metal frames	B1	5.7	2.63	S2: A2+B1+B2+B3
	Exterior wood panel wall (existing) + external cement board (40mm) + insulation board (12mm)	B2	1.03	0.68	S3: A3+B1+B2+B3
	Existing concrete balcony and polycarbonate shading	B3	NA	NA	S3A: A3+B1+B2+B4
	Without existing concrete balcony and polycarbonate shading	B4	NA	NA	
B - Moderate level of intervention	Reduction of WWR	A1, A2 & A3	NA	NA	S4: A1+C1+C2+B3
	Glazing replacement with double low-e glass panes - Double Low-E (Argon fill, SHGC 0.44)	C1	5.7	1.97	S5: A2+C1+C2+B3
	Lightweight concrete block (100mm) + polyurethane board (50mm) + gypsum plasterboard (12.5mm)	C2	1.03	0.36	S6: A3+C1+C2+B3
	Existing concrete balcony and polycarbonate shading	B3	NA	NA	S6A: A3+C1+C2+B4
	Without existing concrete balcony and polycarbonate shading	B4	NA	NA	
C - Major level of intervention	Reduction of WWR	A1, A2 & A3	NA	NA	S7: A1+D1+D2+B3
	Glazing replacement with double low-e glass panes - Double Low-E (Argon fill, SHGC 0.35)	D1	5.7	1.47	S8: A2+D1+D2+B3
	Lightweight concrete block (100mm) + polyurethane board (75mm) + gypsum plasterboard (12.5mm)	D2	5.7	0.26	S9: A3+D1+D2+B3
	Existing concrete balcony and polycarbonate shading	B3	NA	NA	S9A: A3+D1+D2+B4
	Without existing concrete balcony and polycarbonate shading	B4	NA	NA	

Subsequently, modifications were made to the validated case model, and three modified case models were produced. These modified case models were designed according to the proposed WWR reductions from the original WWR of the front and rear façades: 40% (A1), 35% (A2) and 30% (A3) (Figure 3). Initially, the total energy consumption and cooling load of the original case model were simulated. Later, the modified case models were simulated using twelve (12) simulation strategies (as listed in Table 3) from three retrofit intervention levels.



(a) Southwest facade – 40% (b) Southwest facade – 35% (A2) (c) Southwest facade – 30% (A3)

Fig. 3. The modified case models according to the proposed WWR reductions.

Results and Analysis

The initial simulation revealed that the annual energy consumption and the annual space cooling load of the original case model were 1679.94 MWh and 1147.03 MWh, respectively. In terms of annual energy reduction from the three modified models in comparison with the original model, the result revealed that case model A3 had the highest reduction percentage of -2.87%, followed by A2 (-2.14%) and A1 (-1.57%). Table 4 shows the total annual energy consumptions and cooling loads after applying all ERMs within the three levels of retrofit intervention as well as their differences in comparison with the original case model. The table indicates a clear trend of decreasing annual energy consumption from simulation strategy S1 until S9, or from minor to major level of intervention, with S1 having the most energy consumption of 1630.38 MWh and S9 the least (1527.34 MWh).

For retrofit intervention A (minor level), simulation strategies S1, S2, and S3 produced an annual energy reduction of -2.95% (1630.38 MWh), -3.55% (1620.26 MWh) and -4.78% (159.58 MWh), respectively. Interestingly, however, the energy reduction of S6 (-6.09%) in the moderate level is slightly higher than S7 (-6.07%) in the major level intervention. However, when existing shading devices were excluded as part of the retrofit strategies (represented by simulation strategies S3A, S6A and S9A), no energy reduction was produced (i.e., all values were positive). The highest increment in total energy consumption was 7.94% for S3A (minor intervention), followed by 4.67% for S6A (moderate intervention) and 1.64% for S9A (major intervention).

Retrofit intervention B (moderate level) simulation strategies generally had higher energy savings than retrofit intervention A (minor level). The energy-saving percentages for S4, S5, and S6 were -4.03% (1612.27 MWh), -4.59% (1608.88 MWh), and -6.90% (1577.68 MWh), respectively. Retrofit intervention C (major level) offered the highest level of energy efficiency improvement among all three levels of intervention. Among all simulation strategies within this level, S9 produced the highest energy saving of -9.08% (1527.34 MWh). Besides, there was a trend of increasing annual cooling load savings from minor to moderate and major levels of intervention (A, B and C), with S1 (minor level) having the least savings (-4.32%) and S9 (major level) having the greatest savings (-13.30%). Notably, the strategy using the modified case model of WWR 30% reduction within all levels of intervention provided the highest annual cooling loads reductions: -7.00% (S3 of minor level), -10.66% (S6 of moderate level), and -13.30% (S9 of major level).

Table 4 Simulation results for all simulation strategies in comparison with the original case model

Retrofit Intervention	Simulation strategy: individual ERMs	Annual energy consumption (MWh)	The difference in annual energy consumption (%)	Annual cooling load (MWh)	The difference in cooling load (%)
A – Minor level of intervention	S1: A1+B1+B2+B3	1630.38	-2.95	1097.46	-4.32
	S2: A2+B1+B2+B3	1620.26	-3.55	1087.34	-5.20
	S3: A3+B1+B2+B3	1599.58	-4.78	1066.66	-7.00
	S3A: A3+B1+B2+B4	1813.39	7.94	1031.59	-11.63
B - Moderate level of intervention	S4: A1+C1+C2+B3	1612.27	-4.03	1079.35	-5.90
	S5: A2+C1+C2+B3	1608.88	-4.59	1069.97	-6.72
	S6: A3+C1+C2+B3	1577.68	-6.09	1024.76	-10.66
	S6A: A3+C1+C2+B4	1758.37	4.67	1225.45	6.84
C - Major level of intervention	S7: A1+D1+D2+B3	1577.95	-6.07	1045.03	-8.89
	S8: A2+D1+D2+B3	1569.39	-6.58	1036.47	-9.64
	S9: A3+D1+D2+B3	1527.34	-9.08	994.42	-13.30
	S9A: A3+D1+D2+B4	1707.42	1.64	1174.50	2.39

Notes:
i. The original case model's annual energy consumption: 1679.94 MWh
ii. The original case model's annual space cooling consumption: 1147.03 MWh
iii. The code of individual ERMs – refer to Table 3.

Similarly, it is apparent from Figure 3 that the highest energy savings were obtained from all strategies using the similar modified model of WWR 30% reduction, namely S3 (minor level), S6 (moderate), and S9 (major level) with the values of -4.78%, -6.09% and -9.08%, respectively. Overall, the evidence gathered here is sufficient to assert that the major level of intervention C was the most effective retrofit intervention proposed for the case building. The BEI and OTTV of this modified case model using simulation strategies S3 (minor level), S6 (moderate level) and S9 (major level) were calculated. The BEIs for S3, S6 and S9 were 115.63 kWh/m^2/year, 113.00 kWh/m^2/year and 110.06 kWh/m^2/year, respectively. These values were lower than the GBI benchmark of 150 kWh/m^2/year (refer to Table 11). Additionally, the OTTV results were 40.94 W/m^2, 39.06 W/m^2 and 37.90 W/m^2 for S3 (minor), S6 (moderate) and S9 (major), respectively, which were lower than the MS1525: 2014 recommended value of 50 W/m^2.

Findings

This study suggests that it is very crucial to identify the scope and level of detail energy efficiency in stages, with the possibility of conducting one ERM within one level of retrofit intervention at a time. This approach offers a systematic framework to identify the potential ERMs that optimise the building envelope design with better opaque and glazing wall properties. The study has determined that an optimised retrofit intervention with combined ERMs provided a notable decrease in annual energy consumption. The effectiveness of the combined ERMs for opaque wall and glazing in reducing the overall energy usage by 3% to 9% has successfully been demonstrated by enhancing the thermal efficiency of the building envelope. Substantially, all selected ERMs directly reduced the building energy consumption through savings in the space cooling load except for S3A, S6A and S9A simulation strategies. The existing concrete balcony and polycarbonate shading were used omitted in their proposed combination of ERMs. In other words, these strategies resulted in higher annual energy consumption and cooling loads, which indicate that the existing external shading design is efficient for the case building. Individual ERMs of B2, C2 and D2 produced lower annual energy consumption than ERMs B1, C1 and D1. This finding is consistent with the increased thermal mass of the selected wall insulation specification with a lower u-value, combined with

either existing opaque wall or new wall assembly. As such, insulation specifications outlined in all levels of intervention are considered to be sufficient and practical.

Lastly, the study revealed that a glazing improvement combined with the existing shading devices (S3A, S6A and S9A) provided better energy efficiency in the building compared with ERM S3A, S6A and S9A. Among the selected glazing ERMs, ERM D1, described as high-performance low-e double glazing (argon gas fill) with SHGC value of 0.35, was the most effective individual ERM as there was up to a 1.41% reduction in the building's total energy consumption. No energy reduction value was observed for other glazing ERMs, namely B1 and C1. The study also found that the energy savings expected from installing better glazing properties alone (at all levels of retrofit intervention) were insignificant. Given the findings from this research, it can be argued that for a building envelope retrofit to result in total building energy reduction, it should involve a combination of excellent glazing properties, optimum insulated opaque wall interventions, and appropriate external shading device.

The calculated BEI and OTTV for energy benchmarking of all retrofit intervention levels showed that all values were within the benchmark margin of the GBI and EPU standards: 115.63 kWh/m^2/year, 113.00 kWh/m^2/year and 110.06 kWh/m^2/year for minor, moderate and major intervention levels, respectively. The average BEI reduction for all retrofit intervention levels in comparison with the GBI standard was between 23% (minor level) and 27% (major level), and between 18% (minor level) and 21% (major level) compared with the EPU standard. In the same vein, all retrofit intervention levels resulted in lower OTTV values than the MS1525:2014 benchmark of 50 W/m^2.

Conclusions

This study was set out to explore how the energy consumption of existing office buildings could be reduced through building envelope retrofit interventions. As such, typical existing government office buildings in Malaysia were selected as case studies. The study also sought to identify how much energy reduction could be realised through different building envelope retrofit strategies. Findings from the study reveal that the implementations of identified building envelope retrofit strategies result in lower BEI. In this case, retrofit strategies that focus on improving building envelope thermal performance need to be based on Malaysia's climatic condition, material, and feasibility in the local market. The approach adopted in this study demonstrates the application of the whole-building calibrated simulation approach in establishing and evaluating the potential ERMs and their energy savings.

Additionally, the calculated BEIs of all case models in this study are essential information for building energy benchmarking. They also help provide reference points for energy performance, energy saving strategies assessment and goals setting to improve buildings' energy efficiency. The methodology adopted in this study involves simulation model calibration and validation processes with prescribed ERMs selections that can be customised to the needs of typical government office buildings and other similar types of office buildings in Malaysia. Also, the pre-defined retrofit interventions have the potential to assist building owners and stakeholders to at least consider implementing different levels of measure that could reduce the cooling loads and overall energy consumptions before embarking on a large scale of major retrofit involving active measures such as ACMV system retrofit. If the methodology is followed in retrofitting existing buildings, the government would strengthen their existing slogan of leading by example in energy efficiency. Furthermore, the models or ERMs can be customised to meet the needs of not only typical government high-rise office

buildings but also private-owned high rise office buildings in Malaysia.

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Best Management Practice on the Implementation of Bio-Ecological Drainage System at JKR Pilot Projects

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Abstract

A best management practices (BMPs) manual is developed based on the lesson learnt during design and construction stages of Bio-Ecological Drainage System (BIOECODS) at two JKR Pilot Projects since 2017. BIOECODS at the District Police Headquarters (IPD) Pasir Mas, Kelantan was planned based on on-site level and mid terrain gradient development site, has outlined the issues concerning high water table, saturated sandy ground, site constraints, disposal of grease and oil, as well as swale alignment clashes with utility cable ducting and pipes. On the other side, the BIOECODS at Civil Defence Department Southern Training Centre (PULAPAS) deals with the challenges of design and construction on terraneous site at community scale, outlined the issues concerning high velocity runoff, excessive overland flows and sediment from hill side, site constraints, discharge of pumped water from existing pool insufficient outside drain capacity, siltation, and backflow issues at the detention pond due to blocked outside drain. The developed BMPs reviewed the practicality of the provision in Second Edition of the Urban Stormwater Management Manual for Malaysia (MSMA 2ed) and highlighted the best management practices of both site conditions with respect to construction and maintenance.

Keywords: Swale; On site detention; Sustainable; Bioecological; Siltation; Backflow

Introduction

The Public Works Department of Malaysia (PWD), as the leading technical agency in developing infrastructure projects in Malaysia has adopted a more sustainable drainage system in support of the Sustainable Development Goals 2030. One of the initiatives taken towards improving water quantity and quality control in an environmentally friendly manner was incorporating a green and sustainable drainage system pioneered by Universiti Sains Malaysia (USM) and the Department of Irrigation and Drainage Malaysia (DID), which is Bio-Ecological Drainage System (BIOECODS) [1]. This drainage system combines infiltration, delayed flow, storage and purification as pre-treatment of stormwater before discharging it to constructed wetlands. In addition to source control, these measures include integrating large-scale landscapes into the development as a major element in the stormwater management system. The concept of the BIOECODS is to integrate drainage system with the Ecological Ponds for further treatment of the stormwater runoff. The integration of the two components will increase runoffs lag time, allows pollutant removal through settling and biofiltration, and

reduces the peak hydrograph. BIOECODS fully complies with the Urban Stormwater Management Manual for Malaysia (MSMA) [2]. BIOECODS comprises of a series of components namely, ecological swale, in-line underground storage, and dry ponds as shown in Figure 1.

Fig. 1. The objective, principle and the components of BIOECODS

The BIOECODS has been implemented in several government projects namely Tanjung Rambutan Hospital [12], Taiping Town Clinic, Universiti Tun Hussein Onn, etc. The decision to implement BIOECODS in PWD projects calls for a research and development initiative to further assess the effectiveness of this green technology in terms of best construction material to be used and identification of the best management practices for ecological drainage system construction. For this purpose, two pilot projects were implemented at the Pasir Mas District Police Headquarters (IPD Pasir Mas), Kelantan (Figure 2.2) and the Southern Civil Defence Training Centre (PULAPAS) at Kluang, Johor (Figure 2.3). The selection of these projects was made based on the level of facilities namely, *on-site* and *community.* The development at IPD Pasir Mas covers a catchment area of 4.5 hectares on medium soil type. This area was originaly an oil palm plantation. More than 75% of the total area has been developed into an impervious area such as paved road, car park, playground and utilities other than buildings. The development of this project took 152 weeks which started in June 2016. The construction of BIOECODS started in early March 2019 and ended in August 2019.

Fig. 2. Pasir Mas District Police Headquarters (IPD Pasir Mas), Kelantan

The development of PULAPAS covers a catchment area of 8.126 hectares on terraneous area. The area was surrounded by oil palm plantations. More than 42% of the total area is impervious with the construction of an Assembly Hall, musolla, paved roads, car parks, other buildings and utilities, in addition to existing buildings. The duration of this project was 152 weeks which started in October 2017. The construction of BIOECODS started in early 2019 and ended in September 2020.

Fig. 3. Southern Civil Defence Training Centre (PULAPAS) at Kluang, Johor

Construction Issues

The construction of BIOECODS has posed several challenges to the supervision teams in term of striking a balance between the department's green policy and minimum design as per guideline and the local authority's requirement, modification due to site constraints and best management practice. General challenges in constructing BIOECODS would be the alignment control, which was different than that of the conventional drain alignment control. During

setting out, the location and the alignment of the swale will be determined followed by levelling survey to avoid misalignment to the connecting downstream swale. The invert level of the swale will be marked along the drainage alignment so that the excavation work will be properly done. The alignment control is important as improper alignment will increase the construction and maintenance cost of other infrastructure or utilities at adjoining land. Without proper alignment, preferred shapes of swale cannot be appropriately constructed. The work sequence, best management practice, and maintenance procedure need to be clarified to the contractor. The alignment of the swale must be coordinated with platform level, road level, road crossing, sewerage system alignment (sewer pipe and manhole location), domestic and hydrant pipe alignment, etc. The alignment must also consider the landscape requirement in terms of open space and green area. Therefore, the site supervision team must ensure that the swale is not turned into a dumpsite during or after the construction stage. The alignment of the swale must be marked clearly before work commences and must be protected with signboards and a silt fence. The contractor shall also submit a method statement on the construction process of swale and obtain material approval before the construction of BIOECODS.

The determination of the swale alignment must account for possible clashes of modules with utility cables or pipes i.e. high voltage cables, water reticulation pipes, sewerage pipes, street lighting cables, feeder pillar, ducting, telephone cables, etc. For each case, pre-consultation between the designer or site representatives and the local authority or service provider is highly advisable. The cables or pipes may have to be realigned, bent, crossed over, run beneath or aligned parallel to the swale alignment or laid through, subjected to the recommendation of the approving bodies. In the case of invert level, in BIOECODS the concerned invert level is the subsurface module compared to the base of concrete drain as in conventional drain.Figure 4 shows the clashes observed between the TNB power supply cable ducting and the swale sub-surface module at IPD Pasir Mas in which the cable is laid at 10.11m and the invert level of the swale sub-surface module is at 10.50m. The clash is resolved by laying the cable beneath the module.

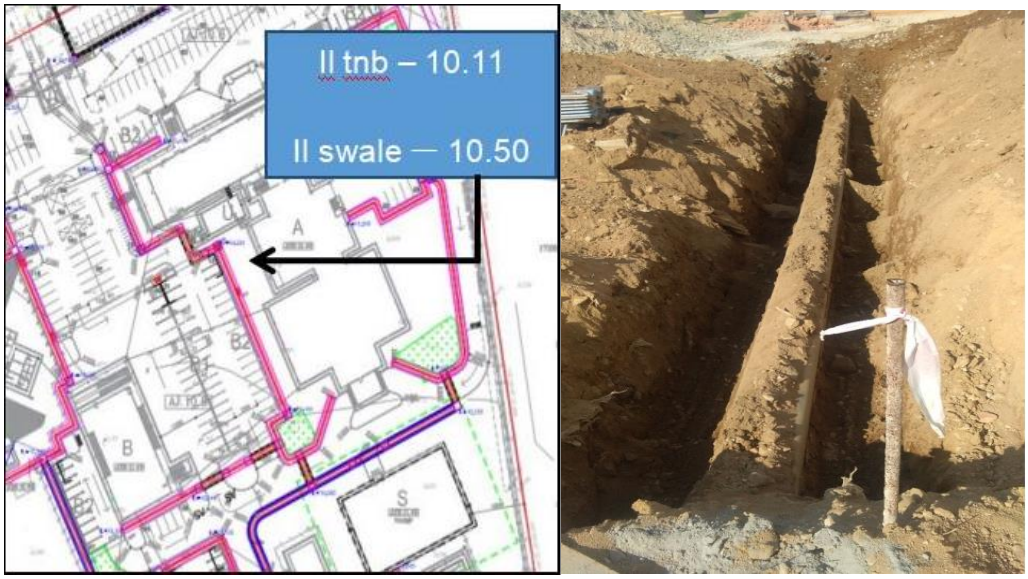

Fig. 4. Clashes between TNB power supply cable and swale

The clashes observed between Telecom cable and the swale sub-surface module at three different locations at IPD Pasir Mas were resolved by laying the Telecom cable between the surface of the swale and module. Other possible options are the cable could be laid through the sub-surface module, or design modification can be carried out by turning the swale alignment into a detention storage.

At the site in which the swale is designed with subsurface module but the water table is deemed to be high (i.e. less than 1 m from the designed depth of subsurface module), it is advisable for the designer to design this system as a *conveyor*, in which a geotextile module is laid as separator thus, the infiltration of stormwater into the ground beneath the subsurface module is not encouraged. The seasonally underground water i.e. high water table may lead to saturated sandy ground causing uplift force to the subsurface module. It is also recommended that each unit of the module be tied to one another, preventing the alignment to be disrupted.

The direct disposal of overflow from grease and oil interceptors and sewerage system into BIOECODS is prohibited. This may affect the cow grass and also the final discharge quality. A brief revision of the MSMA Chapter 14 has shown that there was no provision as to how the grease and oil should be disposed. It is thus recommended that provision of separate channel (i.e. lined drain) to be included for disposal of grease, oil and sewerage system overflow.

The swale alignment or the swale invert level may have to be modified with respect to the invert level of the inspection chamber. Similarly, the invert level of the swale sub-surface module will have to be compared to the depth of the water reticulation pipes and electrical power supply cable. As both the cable and pipe were laid beneath the module, the swale invert level is then raised, and the depth of the swale reduced. Normally, the clash analysis conducted before construction focuses mainly on the clashes between the utility cable and the swale sub-surface module. Another option which can be considered by the designer is to modify the design of the module from a single or double module to a half module to avoid discontinuity of the swale alignment. Clashes have also been resolved by combining concrete drain with swale due to site constraint. For example, the width required for swale may lead to insufficient design requirements for other infrastructures. At PULAPAS, the designed swale of type A with an overall width of 2.0m led to insufficient width required for parking lots and road width adjacent to the Assembly Hall. Design modification was done by replacing the BIOECODS swale with a 300mm box culvert beneath parking lots.

Similar solution was identified at the Male Hostel at PULAPAS. The swale designed as perimeter drain at the courtyard area has resulted in a deep invert level, which could further lead into a deeper invert level and an increase in the swale width for the main drain. The provision of road crossing will require designers to check on the final invert level of the corresponding module before the crossing and the invert level under the crossing becomes much deeper. (Note: Swale module could sustain up to 20 T/m2). For a crossing with an opening or width lesser than the width of the swale, which may lead to reduced capacity, modification of the road layers may be carried out by reducing the thickness of the binder course. The supervision team must also consider the required 1% gradient for marching field, hardscape or parking area which will discharge into the swale. The location and type of road curbs and scupper drain must be coordinated with the corresponding internal road and drainage plan.

The grassed swale is suitable to be used in urban drainage system to convey water in a non erosive manner [13]. The construction of BIOECODS at terraneous area, where the swale

functions as toe drain, must be considered with extra care as the stormwater velocity may be erosive. High-velocity stormwater calls for the provision of rock check dams or reinforcement matting along the swale as an energy dissipator, as per detail in Clause 14.3.4.3 of MSMA [2]. High velocity runoff, leading to excessive overland flow was also recorded at PULAPAS. According to the provision of MSMA, the longitudinal terrain slope shall not exceed 2% as low runoff velocity is required for pollutant removal and to prevent erosion. The use of chipping/ gravels/ boulders to replace the sand layer as the straining layer could be considered to increase the infiltration rate as shown in Figure 5. The supervision team must also ensure that all the erosion and sediment control methods were commenced according to the approved plan and general desiltation process is carried out according to the approved frequency as per proposed by the Enviromental Officer. It is proposed that permanent desiltation structure be incorporated in the design to facilitate maintenance.

Fig. 5. Use of chipping to replace sand layer

In PULAPAS, the issue of pumped chlorinated water from the swimming pool outlet has also been discussed, since there was no provision in MSMA [2] as to how the high-velocity water (i.e. more than 2m/s) should be discharged. Direct discharge of high velocity pumped water into the drain may affect the side slopes, hence, design modification was carried out in which a separate drain pipe was installed to the final discharge point, i.e. concrete roadside drain. It is also proposed that the existing guideline could be improved by incorporating the maximum concentration of common disinfectant (chlorine, pesticide, etc) which can be discharged into the BIOECODS, for example chlorine concentration (2-5 ppm).

The BIOECODS performance was very much influenced by the outside drain capacity or the maintenance of the existing discharge facility. Upgrading of the existing drainage and regular maintenance of the whole alignment up to the Drainage and Irrigation Department (DID) flood basin is required to avoid backflow issues of the detention pond.

Best Management Practice

The best management practice of BIOECODS construction includes initiatives prior to construction stage, during construction and general maintenance with respect to the site. The method statement for BIOECODS construction has been discussed by Yusof et al. (2004) [10]. Prior construction, the swale alignment must be marked clearly and protected with signboards and silt fence. No traffic should be allowed nearby swale alignment during construction. The excavator should operate from the sides of the swale, and not on the base (Figure 6).

Fig. 6. Excavator during swale construction at PULAPAS

Grass planting and protective lining installation should be carried out according to the approved plan and method statement. The best planting period would be in the dry season and immediately after laying of the sub-surface module and sand filling to avoid erosion and scouring (Figure 7). Immediate watering of the grass is required to stabilize the grass and the watering should be done twice a day, as per suggested by Yusof et al. (2004) [10]. If excavation is carried out during rainy season, covering using plastic sheets must be provided by the builder (Figure 8). The grass planting commenced until the grass is stabilized by watering and utilizing erosion control methods such as check dam and reinforcement matting onto newly planted grass.

Fig. 7. Grass planting during dry season

Fig. 8. Protective plastic covering during grass planting at IPD Pasir Mas

The accuracy of the utility mapping is very important to ensure that the clashes or design modification is fully resolved before the works commences at site. Proper access into the site and exit route must also planned properly to avoid damage to the subsurface module.If the clashes are unavoidable, the corresponding subsurface module alignment could be modified into detention storage.

The provision of road crossing will require designers to check on the final invert level of the corresponding module before the crossing and the invert level under the crossing becomes much deeper. For a crossing with an opening or width lesser than the width of the swale, which may lead to reduced capacity, modification of the road layers may be carried out by reducing the thickness of the binder course. Designers must also consider the required 1% gradient for marching field, hardscape or parking area which will discharge into the swale. The location and type of road curbs and scupper drain must be coordinated with the corresponding internal road and drainage plan.

Conclusions

BIOECODS has shown great potential as an innovative and effective system towards better stormwater quantity and quality control [11]. However, several issues pertaining to construction call for improvement of the system design, efficient procurement, and good coordination at the site. This study has illustrated the issues faced at PWD pilot projects in the its construction stage of BIOECODS. The experience, lessons learnt and the best management practices outlined in this study aim to give an insight into the significant parameters to be taken into account in designing, supervising and managing issues in the construction of BIOECODS

Despite facing challenges during the BIOECODS construction, this innovative system, developed to manage water quantity and water quality in an environmentally friendly manner, has shown great potential in supporting Sustainable development initiative pushed forward by the government. While the construction method was not complicated, detail monitoring and control throughout construction period is extremely important to ensure successful execution. Thus, it is highly recommended that the expertise and experience of both designers and builders be integrated and contracted under the Prime Cost Sum. As such, collaborative practices

between designers and builders can be established effectively because requirements for successful construction of BIOECODS can be set out at the very early stage of the construction.

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