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Construction of the first Malaysia's hybrid concrete pavement using jointed plain concrete pavement (JPCP) and roller compacted concrete (RCC)

S Sahari, B K Tan, S Shaharudin and M Bakar

Lafarge, Wisma Lafarge, 46050 Petaling Jaya, Selangor, Malaysia

E-mail: sahrusi.sahari@lafargeholcim.com & steven.tan@lafargeholcim.com

Abstract. Lafarge Infrastructure Team had constructed Malaysia's first hybrid concrete pavement using Jointed Plain Concrete Pavement (JPCP) and Roller Compacted Concrete (RCC) at Lafarge's Kanthan Cement Plant, Ipoh, Malaysia. The main purpose of the project is to showcase and study construction challenges in combining JPCP and RCC hybrid product for road solutions. The progress and pavement performance were monitored recorded and detailed through tests and site observation reports. JPCP pavement was constructed using two (2) type of construction methods; slip form and fixed form, while RCC pavement was laid and constructed using an asphalt paver set. The Quality Assurance & Control (QA/QC) monitored comprises of concrete design mix, concrete slump, concrete delivery, joints insertion, concrete curing, compaction, profile levels, saw cut and sequence of construction activities. Throughout the study, we have managed to table out the "Challenges and Best Practices" on the construction methods which mainly involves labours, machinery and material. All the information has been taken into consideration, to prepare a comprehensive report for the project. The study will enhance the knowledge and understanding for road owners, concrete suppliers, consultants and contractors in understanding the right application of JPCP and RCC in the future. We able to share and propose few best practices based on the challenges that we had face.

1. Introduction

Concrete roads have over 30-year history in Malaysia. Starting in 1988, first mega project using concrete pavement was built at the North-South Expressway (NSE) and New Klang Valley Expressway (NKVE). The concrete pavement was built using two different methods called Continuously Reinforced Concrete Pavement (CRCP) and Jointed Reinforced Concrete Pavement (JPCP). About twenty-two percent (22%) out of 846km Expressway network was constructed using concrete pavement methods [1].

These concrete roads have performed significantly much better than a conventional asphalt pavement in terms of durability. Projek Lebuhraya Utara Selatan (PLUS) concessionaire of the expressway, indicated that in general, the road stretches which were built using a conventional asphalt pavement need regular maintenance for every 7 years. It has been reported that PLUS is spending approximately RM740mil yearly on the maintenance and repair works for the whole stretch [2]. On the other hand, concrete pavement which required minimal maintenance would use only 1% of the budget. It is a proven testimonial on the durability and the superiority on the life cycle cost of concrete roads.



Despite the benefits of concrete pavement, the adoption rate in Malaysia is still low. Until today, Malaysia has only constructed 220km of concrete road. It consist less than 1% out of the total 144,403 km road networks in Malaysia. The most recent concrete road being built was a dual-lane 10km stretch of CRCP located at Raub, Pahang between Felda Telang to Kg Kechor. The road was part of the Central Spine Road (CSR) Project that had successfully completed in 2015 and had won the Second Runner-up for JKR Project Management Innovation Award 2015 [3].

Malaysia local authorities are facing challenges in increasing the adoption rate of concrete pavement. The benefits of concrete pavement are well recognized by the Kementerian Kerja Raya (KKR) and has set an ambition to build 5% of its new federal road using concrete in the '2013-2015 KKR's Strategy Plan' [4]. However, they face challenges in achieving its ambition to build concrete roads. There are limited roads network in Malaysia other than highway that being constructed using concrete. We reckoned one of the challenges is high initial construction cost; in relation of using a CRCP method is one of the key barriers; resulted in difficulty to justify concrete road adoption for rural roads. However, CRCP is not the only option in constructing concrete roads. Optimizing the design to suit with the needs and identifying the requirements based on different road categories could help in reducing the overall cost on the concrete road construction.

The objective of this paper is to determine the efficiency of alternative concrete pavements. By adopting to different concrete road construction methods, i.e. combination of Jointed Plain Concrete Pavement (JPCP) & Roller Compacted Concrete (RCC) as showcased in the reference project below (hereafter refer to as JPCP-RCC hybrid concrete pavement); can this be a good alternative with better efficiency comparing to CRCP? Meanwhile, at the same time looking at the anticipated challenges, as well as best practices of such hybrid concrete pavement as part of the road alternative and solution in Malaysia.

2. Overview of different concrete road construction methods

2.1. CRCP – Continuously Reinforced Concrete Pavement

CRCP is a continues span of concrete pavement that without any transverse joints. The pavement contains continuous, longitudinal high tensile steel reinforcement. Most of the length of pavement is without any transverse joints, except for end-of-day header joints, transition between bridge approaches and other pavement structures. The highly heavily steel reinforcing in CRCP is to hold the concrete together and controlling all cracking especially transverse cracking caused by cement hydration, thermal effects and contraction/expansion of a concrete pavement [5].

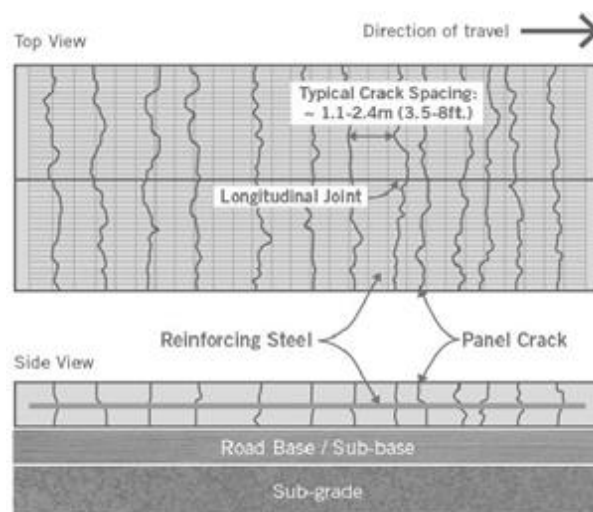


Figure 1. Continuously Reinforced Concrete Pavement (CRCP).

2.2. JPCP – Jointed Plain Concrete Pavement

JPCP is a concrete pavement that has transverse joints with panels. The pavement is constructed in a similar manner to CRCP, while the difference is that JPCP only introduces dowel & tie bars as compared to CRCP with fully reinforcing the pavement. The joints with dowel or tie bars have two important functions, i.e. inducing contraction & compression cracks and transferring loads to adjacent slabs. The bars also hold the slabs tightly closed to instill additional stiffness into the concrete slab in-between the panels [5].

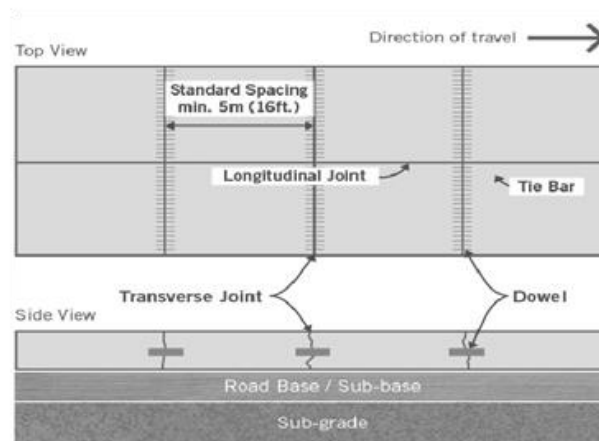


Figure 2. Jointed Plain Concrete Pavement (JPCP).

2.3. RCC – Roller Compacted Concrete

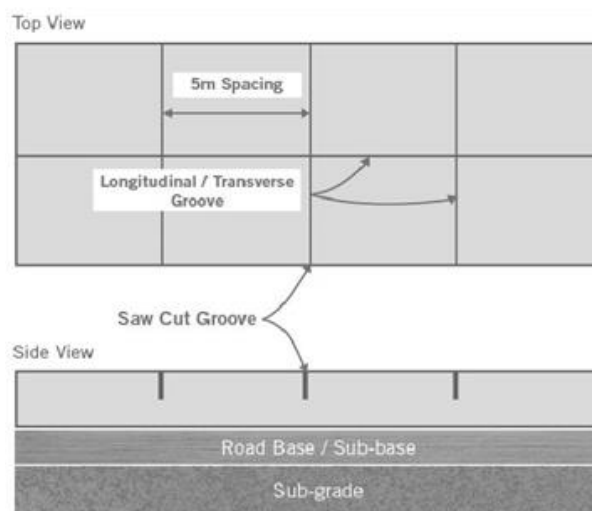


Figure 3. Roller Compacted Concrete (RCC).

RCC is concrete pavement that uses a zero-slump concrete, which can be laid using an asphalt paver. The RCC's material is designed much stiffer than a typical conventional concrete. The design mix has to remain stable under compaction operation using a vibratory roller but at the same time wet enough

to permit adequate mixing and distribution of paste of cement mortar without segregation. This product is purposely designed to provide road contractors a solution to construct concrete pavement without the need to invest in slip form concrete pavement machines. RCC is engineered to be place with asphalt-type pavers' followed by compaction by rollers. The RCC method of construction is without the need of any forms/formwork, dowels, or steel reinforcement. The proposed RCC material used in road pavement was a concrete that had a Compressive Strength of 40MPa with a Flexural Strength of 4.5MPa [6].

2.4. JPCP-RCC Hybrid Concept

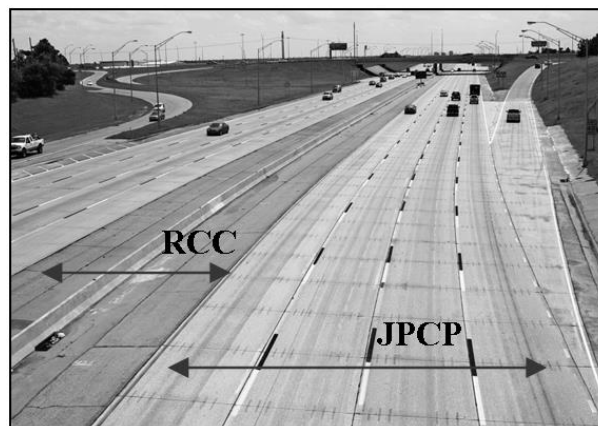


Figure 4. JPCP-RCC hybrid concept.

JPCP-RCC hybrid pavement is first of its kind in Malaysia. This hybrid design combining both JPCP and RCC construction techniques and is piloted by Lafarge Road Infrastructure team in Malaysia. The first hybrid pavement was successfully constructed and handed-over to Lafarge's Kanthan Cement Plant. The idea of the hybrid pavement is to optimize the pavement in relation to requirement, application and traffic flows to promote cost saving. This pavement is designed to use JPCP as the main driveway and RCC as the parking, lay-by and truck sheeting bay.

Upgrading existing rural asphalt roads to concrete become feasible with concept of JPCP-RCC hybrid pavement. One of the main challenges in upgrading existing rural asphalt roads into concrete roads is the long setting time of a normal concrete. Referring to the industry best practice, the concrete pavement must achieve minimum 20MPa in compressive strength before it can open to traffic. If the pavement is to be constructed with a normal G40 concrete, it will take a minimum 7 days for it to reach the desired strength. Hence, it is not feasible to close the roads for 7 days because it will cause significant nuisance to local communities that depend on it. However, with JPCP-RCC hybrid pavement help in resolving the challenges of long setting time. RCC material could achieve the desired strength and open to light traffic within 8 hours upon the compaction. The concept of the hybrid roads is to construct the RCC as permanent road shoulder but temporarily serve as diversion and access roads. Once the traffic has been diverted to shoulder/temporary access roads, JPCP can then be constructed as the main carriageway. With this approach, it makes upgrading existing rural asphalt roads feasible.

3. Project Background

3.1. General Overview

Lafarge Kanthan Cement Plant, Chemor, Perak, has planned to upgrade the existing crusher-run base to a reinforced concrete hardstand. Like most of the cement plants, dust pollution is always an environmental issue. By having an un-paved granular hardstand, it makes the issue of dust difficult to control. To reduce the dust, hence resolving environmental issues, the plant manager had decided to upgrade the un-paved hardstand by constructing a new reinforced concrete hardstand. The new concrete pavement is design to serve two main purposes. First, to address the environmental issue by reducing the dust pollution from the existing hardstand to an acceptable level, set by Department of Environment (DOE). Secondly, to address the increase number of traffic (trucks and plant vehicles), by adding in additional areas for driveway, sheeting bay and parking lots; this will allow the plant to have better management on the total traffic movement.



Figure 5. Aerial view of JPCP-RCC.

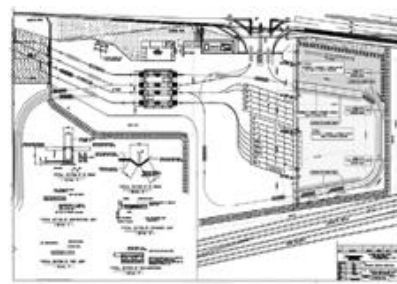


Figure 6. Original design pavement layout plan.

The concrete pavement is designed for 20 years with 20 million of Rigid Equivalent Standard Axle Load (ESAL). The daily traffic volumes for the cement plant can reach up to 200 numbers of cement tankers per day transporting its daily production of 8,000 metric tonne (mt) cement to clients. Each cement tankers can weigh up to 60 mt on full load of delivery. The design ESAL have to be minimum of 0.64 Million per year to support the number of truckload going through the pavement. Hence, for a 20 years design, the pavement has to be designed with 12.8mil flexible ESAL or 19.2mil rigid ESAL [7].

3.2. Project objective

JPCP and RCC hybrid pavement was introduced to reduce the overall construction cost and at the same time shorten the completion period. In optimizing the overall design of the plant hardstand, combination of JPCP and RCC hybrid construction technique has been proposed to the plant. The proposal will help in reducing the overall construction cost and completion period. On the other hand, this proposal will also provide a training ground to gain on-site experiences on the construction of the hybrid concrete road design.

The ultimate goal is to study the concept of constructing the road pavement with JPCP as carriageway and RCC as road shoulders. This project will allow us to understand the best and workable concrete mix design, practical construction method statements, pre, during and post construction testing for the construction of JPCP and RCC hybrid pavement works.

4. The optimized JPCP-RCC hybrid design

4.1. Original design

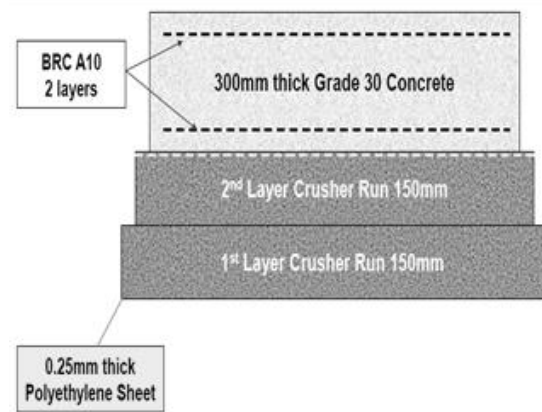


Figure 7. Cross section of original design.

The pavement was originally designed with conventional reinforced concrete pavement. The original design of the concrete pavement is made up of a 300mm thick G30 concrete pavement, reinforced with two layers of BRC A10. The concrete surface course is to be supported with two layers of 150mm thick of crusher run and separated with a layer of 0.25mm thick polyethylene sheet lay under the concrete. The details are referred to Figure 7.

4.2. The optimized design

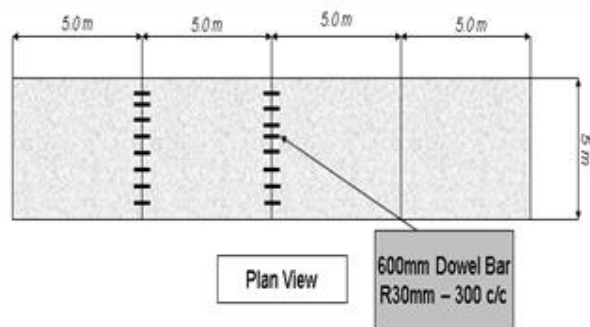


Figure 8. Joints and saw cut for JPCP.

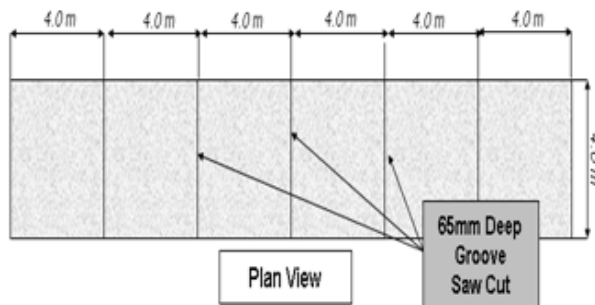


Figure 9. Joints and saw cut for RCC.

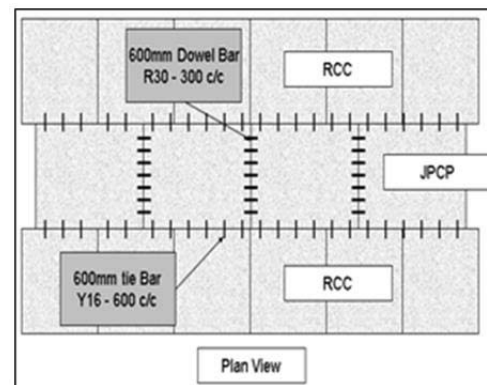


Figure 10. Joints and saw cut for JPCP-RCC hybrid.

The hybrid pavement is designed according to traffic movement to bring better efficiency in saving cost and time. Not all concrete panels are subject to the same loading, the pavement can be optimized by combined JPCP and RCC pavement. By understanding tankers and trucks movement, the pavement can be designed to provide a better cost effective and easy to be constructed by reducing the need to install steel reinforcement and formworks. The optimized design decided to construct the driveway using JPCP with broom finishing texture to cater for cement tankers and trucks movement. While area that have longer vehicles stoppage time and lower movement like parking lot and sheathing bay were design to construct using RCC. The specifications for the pavements are as follow:

- Surface course, 200mm thick G40 Concrete for both JPCP and RCC
- Joints, JPCP pavements are joint with steel basket consist of 600mm R30, 300mm c/c Dowels and 600mm Y16, 600mm c/c tie bars.
- Panel, JPCP is saw cut into a 5m x 5m panel' size while RCC is saw cut into a 4m x 4m panel size.
- Tie bars between JPCP and RCC, 600mm Y16- 600mm c/c tie bars are inserted at conjunction area of JPCP and RCC.

4.3. Benefit of the optimized design

The optimized hybrid pavement is proven in reducing overall construction cost and faster completion. The outcome of the hybrid design is promising, as it has managed to reduce the overall construction cost by 30%. The project has registered saving from concrete, steel reinforcement, formwork and overhead cost. The major material saving came from the reduced quantity of reinforcement steel bar, whereby the hybrid design has managed to reduce 70% reinforcement steels needed to construct the pavement. Beside cost saving, the JPCP-RCC hybrid pavement was completed within 13 days.

5. Challenges in constructing concrete pavement

Table 1. Challenges in JPCP and RCC construction.

No	Challenges	Best Practice
1	Concrete Delivery	
(i)	<u>Poor mixing</u> Maximum loading of mixer trucks to speed up delivery could result in poor mixing due to limited space inside the mixer drum to thoroughly mix low slump concrete creating a non-homogeneous mix.	To load only 80 % of mixer drum capacity to allow adequate space inside the mixer drum to mix and create a homogeneous mix.
(ii)	<u>Waiting time</u> Too many trucks being used for concreting will result in extended waiting time and will cause rapid slump loss.	Proper tracking and scheduling of mixer trucks need to be done by the plant and site personnel to ensure on time delivery is maintained during concreting work.
(iii)	<u>Travel time</u> Concrete being delivered from batching plants located more than 10 km away from the construction site. Due to extended travel time and over mixing during long hauls, excess heat is generated due to friction causing the concrete to lose water rapidly thru evaporation process resulting serious slump drop.	To identify suitable batching plants which are located much nearer or less than 10 km away from the project site. Lesser travel time will enable us to maintain a consistent concrete slump.
2	Inexperience road contractor An incompetent contractor with poor or limited knowledge and experience in RCC paving work will impact the overall operations and product performance.	Competent contractors with the relevant knowledge and experience in paving work must be selected for each job to ascertain the desired results are achieved. Additional class room or on the job trainings can be conducted to further enhance the contractor's knowledge.

Table 1. Challenges in JPCP and RCC construction (continued)

3	Weather	
	(i) <u>Rain</u> Concreting in bad weather.	Proper canopy need to be in place to protect freshly casted pavement from being exposed to the rain water. Mixer trucks for JPCP need to have proper hopper covers and tipper truck for RCC need to have proper tarpaulin to prevent rain water entry into the concrete drum resulting in high slump.
	(ii) <u>Hot weather</u> Working in ambient temperatures above 34degree Celsius will lead to concrete drying up much quicker due to rapid evaporation of water. This dry concrete would result in poor pavement finishing.	To provide proper shade and to arrange adequate manpower and equipment to commence pavement finishing work immediately upon paving.
4	Joint/ Connection	
	(i) <u>Improper installation of bars</u> Improper installation of the tie bar and dowel bar between the JPCP - RCC pavement and JPCP - JPCP pavement will affect the overall levelness of pavement. Besides, it will also result in mid-panel crack or another pavement defect.	Contractor to properly install tie bar and dowel bar into the JPCP pavement according to the design and specification. Installment of the tie bar into the JPCP pavement shall be perpendicular to the concrete edge.
	(ii) <u>Delay in saw cut</u> Delay in saw-cutting the JPCP/RCC pavement will result in uncontrolled cracking.	Contractor to saw cut the pavement in a straight line and saw cut shall be done within eleven (11) hours of casting. The timing of saw cut is essential to avoid cracks in concrete.

Table 2. Challenges in JPCP construction using slip form.

No	Challenges	Best Practice
1	Slump	
	(i) <u>Slump non-conformance (too wet) - Slump above 60 mm.</u> When concrete above the specified slump is delivered to the site, it will be difficult to pave platform edges/sides. The concrete basically tend to sag and collapse due to its diluted state.	Compliance to specified slump range. Based on practical experience, it is best to use concrete which is within the specified slump range; 50 mm to 60 mm.
	(ii) <u>Slump non-conformance (too dry) - Slump below 50 mm.</u> When concrete below the specified slump is delivered to the site, it will have poor workability which will be an issue during placement of concrete. We'll also face difficulty unloading the concrete from the mixer truck onto the road base, etc.	Compliance to specified slump range. Based on practical experience, it is best to use concrete which is within the specified slump range; 50 mm to 60 mm.
2	Improper Concrete Placement Insufficient concrete in the paver during paving resulting in honeycomb or cavity on the paved pavement.	To keep the paver's receiving hopper fully loaded during paving process.
3	Poor Surface Finishing Delay in bull floating, troweling and broom finishing work resulting in poor pavement finishing.	To arrange adequate manpower and equipment to commence finishing work immediately upon paving.

Table 3. Challenges in JPCP construction using fixed form.

No	Challenges	Best Practice
1	<p>Slump</p> <p><u>Slump non-conformance (too wet) - Slump above 85 mm.</u></p> <p>When concrete above the specified slump is delivered to the site, slurry loss occurs resulting in work delayed, concrete bleeding and poor finishing work.</p> <p><u>Slump non-conformance (too dry) - Slump below 75 mm.</u></p> <p>When concrete below the specified slump is delivered to the site, manual handling by workers during casting will be difficult and prolonged resulting in honeycomb and cavities.</p>	<p>Compliance to specified slump range. Based on practical experience, it is best to use concrete which is within the specified slump range; 75 mm to 85 mm.</p> <p>Compliance to specified slump range. Based on practical experience, it is best to use concrete which is within the specified slump range; 75 mm to 85 mm.</p>
2	<p>Uneven/Dented Formwork</p> <p>Using dented or damaged steel form will cause uneven pavement surface finishing.</p>	<p>To check accuracy and straightness of the steel form using thread alignment method or using dumpy level.</p>

Table 4. Challenges in RCC construction using asphalt paver.

No	Challenges	Best Practice
1	<p>Paver and Equipment</p> <p>(i) <u>Asphalt Paver</u></p> <p>Paver breakdown during paving and sensor string line not functioning.</p> <p>(ii) <u>Compactor & Water Truck</u></p> <p>Compaction non-conformance – Compaction value < 90 %</p>	<p>Site personnel need to control and monitor site situation and to communicate with plant people consistently on the concrete delivery if any emergency and machinery breakdown happened.</p> <p>Contractor to use High Density Paver to pave the pavement in order to achieve initial compaction value more than 80 % with an additional tandem & tire roller.</p>

6. Observed performances

6.1. Pre-construction testing and trial

Before the actual site construction work started, preliminary study on the existing platform has been conducted to understand the overall condition of the site. The tests involved for the preliminary study were Dynamic Cone Penetration (DCP) complying to ASTM Code D6951/D6951M-18 [9] and In-situ California Bearing Test (In-situ CBR) complying to BS Code 1377:Part9:1990 [10].

The DCP was conducted to measure the in-situ strength and the thickness of underlying soil layers. Five (5) numbers of tests (Refer Appendix A) have been conducted at different areas, with a total depth of 1.0 meter from the existing surface. Two (2) areas have been found having average CBR value less than 40%. As for these findings, we have decided to excavate these 2 critical areas to a depth of 500mm and replace it with crushed aggregate/crusher run to ensure the concrete pavement have better subgrade to support the pavement.

To further determine the strength of the base, three (3) 'In-situ CBR' using a test method called Load Penetration Test, have been conducted along the alignment of the main road of proposed JPCP. We find out that one area have the lowest CBR value between 19% to 35% at a penetration of 2.50mm and 5.00mm relatively (Refer Appendix B). The others are having a CBR value between 49% and 81%. We found that the area was not properly compacted and additional compaction has resolved the problem area.

The other testing that were done before the construction was designing the JPCP and RCC material at the plant. The plant trial was conducted to ensure that the value of concrete strength conforming to the pavement design. Full scale plant trial mix was conducted at the concrete batching plant that was selected to supply the material to the project. All of the information above is vital to make sure that the alternative proposed design is conforming to the client requirement.

6.2. Testing during construction

Upon confirming the CBR value of the base, profile levels and compaction, trial lay of the JPCP and RCC were conducted at site to verify the concrete performance and to identify the method, labor, machinery and work sequence confirming with the Method Statement submitted by the contractor.

Slump tests and Vebe' test were conducted on every delivery of concrete supply to the site. Slump tests were conducted for JPCP and Vebe' test for RCC works for every batch of product produced. The purpose of the tests is to ensure the workability of the material when arrived at the site.

Samples of concrete will also be taken on every batch to prepare cubes to run through compression tests for 7 and 28 days (Refer Appendix C). Although only 75% has achieved the targeted strength for 7 days, it was found that for the overall 28 days we had achieved 130% compression strength more than the design. There is no single cube fail for 28 days compression tests. Upon completion of the work for RCC, Nuclear Density Test (NDT) was conducted at 3 location every 100 meter length of works (Refer Appendix D). Although a small number of the NDT tests failed to achieve 98 % compaction as per target, we managed to achieve a minimum compaction of 95% which are acceptable. Re-compaction of the areas have improved the initial compaction.

6.3. Post construction testing

Upon completion of the overall project, before handing over the site to the client, several subsequent tests have been conducted to measure the performance of the pavement. Tests such as Sand Patch, International Roughness Index (IRI) and Skid Resistance Test were conducted.

The sand patch was conducted, conforming to BS 598 Part 105: ASTM E965, to determine the average texture depth of a selected portion of a concrete pavement surface [11,12]. From the test conducted, the results (Refer Appendix E) were accepted within tolerance, which is, in the range of 1.50mm to 2.91mm in thickness.

Road roughness, or smoothness, was inspected with IRI method. Conforming to ASTM E1364-95(2017), the tests were conducted to monitor the pavement conditions and to evaluate the riding quality of new the pavements. From the tests (Refer Appendix F) we concluded that the range 1.52m/km to 11.01m/km is not smooth enough for traffic traveling above 50km/hr.

The other test that was conducted after the construction was skid resistant. The purpose of the test is to measure the force of skid resistance of a tire is prevented from rotating slides along the pavement surface. Inadequate skid resistance on the pavement will lead to higher skid which could cause accidents. Seventy (70) numbers of tests had been conducted for the whole area (Refer Appendix G). From the results, we found that 46% of the test results fall in category A, 47% in category B and 7% in category C (refer to Appendix Table 1).

7. Conclusion

From the project, we can confirmed that different methods of concrete pavement have its own advantages and disadvantages. By using more than one method of concrete pavement, we could optimize the overall design based on its application and usage. The disadvantages of a concrete pavement, such as initial cost and difficulties to construct, can be overcome by exploiting the advantages at the right application. Understanding the right method for the right application is the key for optimization of design and construction.

In order to construct a concrete pavement, you must do it right for the first time. Experience is very vital to run a concrete pavement project. The right equipment used during the construction is essential to deliver a good concrete pavement job. Observing performance and testing; before, during and after the construction are tools for better understanding to improve the delivering to a good

concrete pavement job. Finding and experiences should be shared among clients, consultants and contractors to ensure we continue learning the secret of better concrete pavement.

To ensure concrete pavement to become a desired option when building road, bad impression and experiences from the user should be overcome. Delivering a good concrete pavement project that shall be accepted by the user is another challenge. Concrete pavement construction in Malaysia is still young. Road users need to give some time to allow the local road industry to become matured in delivering a superb concrete pavement for Malaysian road network.

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