

# Application of Advance Pavement Technology for Airfield, Field Experience at Kuala Lumpur International Airport (KLIA)

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**ABSTRACT:** The basic requirement for civil engineering materials construction usage is to use and optimise readily available materials nearest to the work site. Dependency on imported technology can sometimes limit the application of good engineering materials. Working from first engineering principles supported by research is a productive method to use non-standard materials confidently under known local environment. The pavement works at the KLIA underwent thorough studies working from basic principles. These principles are fully deployed during planning, design and construction in line with the available materials. Advanced technology was adopted for the design and construction while new materials were introduced for construction. This paper describes the historical and technical development of the pavement studies under local conditions, design and construction at KLIA. The pavement used stabilize meta-sandstone base as a structural bearing layer. The surfacing layers comprises of the bituminous crack relief layer (CRL) overlaid by polymer-modified asphalt (PMA). All these layers were newly introduced and were applied for the first time in large quantities in Malaysia. After five years the technology used had shown the expected performance even though the loading condition increased. The incorporation of a pavement management system in the monitoring exercise is also described. Valuable lessons learned from the starting point of investment up to maintenance management stage is described to guide investors on optimum use of pavement technology to benefit all stakeholders.

**KEY WORDS:** (Airfield, pavement, asphalt, polymer, optimisation)

## 1.0 INTRODUCTION

The runways and taxiways of KLIA were constructed and optimised both in engineering and economic perspective using a composite pavement structure. The asphalt surfacing was PMA and the structural base layer was a high strength cement treated base (CTB). Termed as a composite pavement, the development of the pavement have started earlier for more than ten years of research and development (R&D) works in pavement engineering sponsored by the Government of Malaysia.

At the time KLIA pavement under went preliminary studies, a team of pavement specialists, which consist of local engineers, and foreign experts sat down and plan the best strategy to build the pavement for highest quality, short construction period and highest achievable bearing capacity to reduce risk of early failure. Ten years local pavement R&D between the Government of Malaysia and the Transport Research Laboratory (TRL) United Kingdom, were made to full use. The results of the recently completed USD250 million Strategic Highway Research Program (SHRP, 1994) were also referred.

### 1.1 Preliminary Works

The designing team started experimenting on materials that were available near the site. It was found that about 5 million tons of meta-sandstone at a nearby hill is available 2 km form the project site. The sandstone hill was blocking the flight path and deemed to be removed. Instead of wasting, the team decided to use this material for the CTB and or other layers. The CTB is a mandatory stabilised layer to comply with International Civil Aviation Organization (ICAO) requirements for pavement to be used by jet aircrafts. The use of the meta-sandstone saves the estimated removal cost. The meta-sandstone was quarried and sold to contractors. A total estimated USD30 million saving is incurred on basic material cost for the construction of the CTB layer. This cheap material forms the strongest layer in the pavement. Thick stabilised base averaging 450 mm thickness, improved the overall pavement bearing capacity substantially.

The findings from local research had established the need for a durable, tough, and rough texture surfacing for the airfield pavement. Asphalt pavement was decided to be used for the runways and taxiway surfacing due to low initial investment cost. To meet the stringent ICAO requirements, application of “art of mix” design in accordance to the latest SHRP finding was applied. The team decided to use PMA to achieve durable and tough mix having rough texture. Three master-degree pavement specialists were sent for a two-week training in the United States to learn SHRP mix design approach to prepare for the design and supervision of the PMA works. At that juncture PMA is considered a new technology in Malaysia. The indirect bearing capacity of the pavement is improved in terms of durability of asphalt with high binder content and thick bitumen coating achievable only by using PMA.

## 2.0 PAVEMENT DESIGN

The use of high strength sandstone CTB base layer is not common in Malaysia. From literature review it was noted that cracking is a common failure mode of this layer. To avoid random cracking, this layer was pre-cracked in uniform pattern. In order to prevent reflective cracking of the pre-cracked CTB moving to the upper asphalt layer, a bituminous CRL interlayer is needed. Composite pavement structure is not common and standard design graphs provided by the Federal Aviation Authority (FAA) and ICAO did not cover this selection of pavement structure. Therefore the composite pavement requires a quasi-mechanistic design approach. For mechanistic calculation, the multi-layer analysis and theory were used. For verification, relevant overseas research and local research findings were referred inclusive of reference to any useful local pavement monitoring results.

Joint research in pavement materials conducted by Public Works Department (JKR) Malaysia and TRL for the previous 10 years had established many probable mode of failure for asphalt pavement under the local climate. The pavement for KLIA, having had to use the prescribed material composition was expected to fail by the following mode (see Figure 1): -

- 1) Traditional fatigue cracking due to repeated tensile strain at the bottom of asphalt
- 2) Deformation by subgrade strain
- 3) Cracking of the asphalt due to reflective cracking from the pre-cracked CTB
- 4) Top-down cracking due to aged asphalt by hardening of the binder

### 2.1 Traditional Fatigue Cracking due to Repeated Tensile Strain at the Bottom of Asphalt

The conventional fatigue theory of asphalt cracking due to repeated application of tensile strain at the bottom of the asphalt layer was an established fact. The multi-layer theory and analysis forms the basic approach to model this theory and was used to estimate the limiting thickness requirement for the asphalt to be loaded with the Mc Donald Douglas 11 (MD11) design aircraft. Total asphalt thickness of 250 mm on 450 CTB is a conservative choice to reduce conventional fatigue problem. Added granular drainage layer and improved subgrade layer below the CTB of 200 mm and 250 mm respectively further improve the bearing capacity of the pavement and reduce the risk of early failure.

### 2.2 Deformation by Subgrade Strain

The subgrade layer was prepared initially as a simple working platform compacted to 90% maximum dry density (MDD). To comply with ICAO guide that requires minimum 95 % MDD, 250mm of the subgrade was replaced with granular meta-sandstone that improves the bearing capacity and uniformity of the subgrade. The use of 450mm thick CTB further reduce the subgrade strain level to an almost insignificant level. The availability of the sandstone deposit was further exploited by incorporating 200 mm thick drainage layer. Results from the multi layer analysis showed that the use of high-strength, high E-modulus CTB on top of the above combined layer reduces subgrade strain to minimum level, as such conventional fatigue becomes a non-significant failure mode. Using the above layers and 250mm asphalt, the multi-layer analysis indicated that low strain is registered on the subgrade when loaded with MD11 loading system. Therefore, it is concluded that subgrade strain is not a critical failure mode.

2.3 Cracking due to Reflective Cracking from the Pre-Cracked CTB

Since conventional fatigue problem was almost eliminated, the pavement design model given below was assigned (See Figure 1). The pavement in principle was design to fail by functional mode rather than by structural mode provided the design aircraft load does not change.

There was a risk failure by reflecting cracking. Research in methods of mitigating reflective cracking by Hasim et al (1995) had studied and used several anti-reflective cracking strategies to mitigate reflective cracking. Bituminous CRL as an anti reflective cracking measure had performed well, proven by the research. This empirical finding is incorporate in the design approach. Standard design using CRL at that time is already available distributed by the Transportation Research Board (TRB). Similar specification and technical background from this report is another support on the basis of using the CRL.

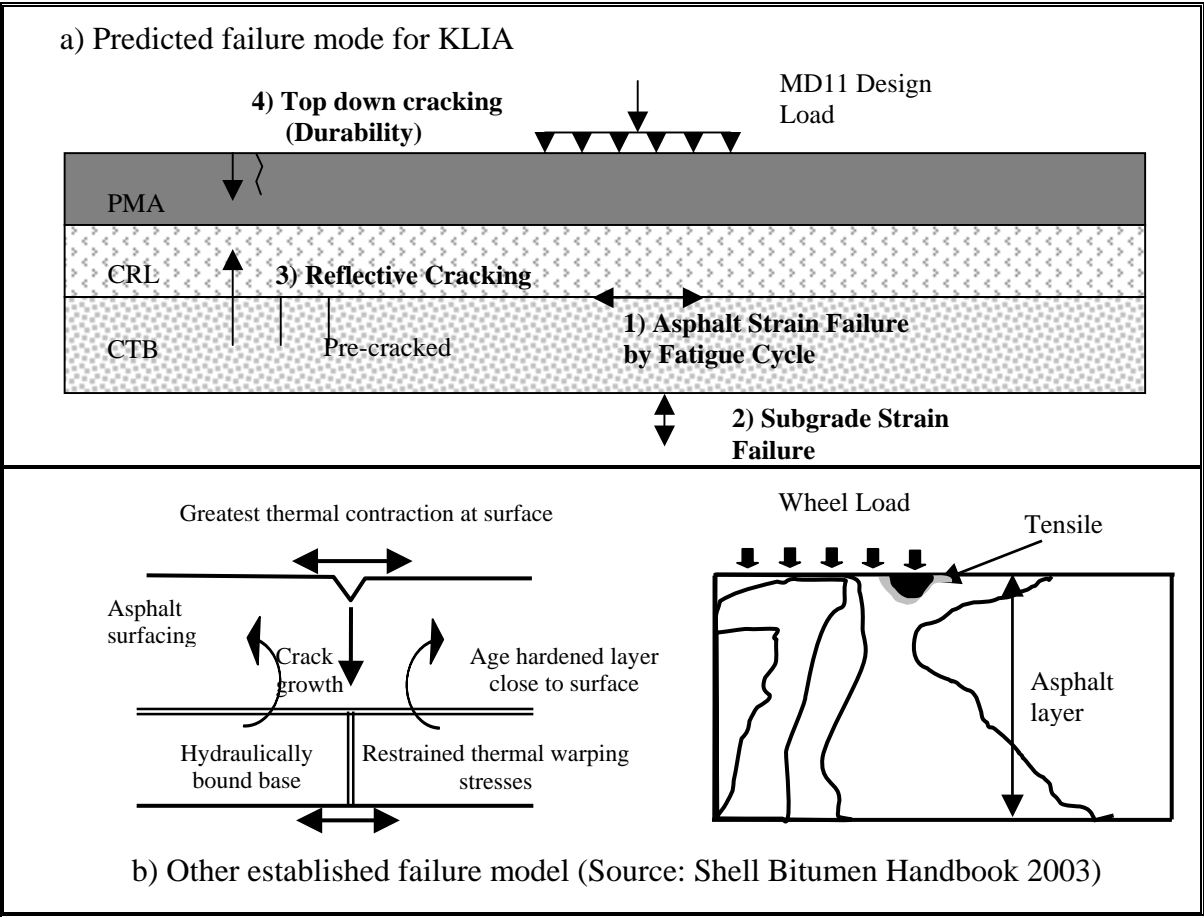


Figure 1: Pavement failure model for KLIA comparative to others

## 2.4 Top-Down Cracking due to Aged Asphalt

Top-down cracking is a complex mechanism in asphalt pavement behaviour. Pavement loading in the locality of the tyre is shown by Read et al (2003) to developed evidence of tensile stress on the asphalt surface. Local studies by Ismail (1992) also indicated that rapid hardening of the top i.e. 3 mm of the asphalt surface promotes top-down cracking. The use of polymer-modified bitumen was shown by Downes et al (1988) to be a cost effective means to improve asphalt properties in life cycle costing. These are among the support evidences to decide on the use of PMA for the asphalt binder and wearing courses in large volume for the first time in Malaysia. Introduction of the PMA at the moment is one of the approaches to reduce future problems related to asphalt ageing and to improve durability. At the same time, PMA have a higher Elastic (E) values compared to conventional asphalt also helps to reduce stress strain level in the asphalt system.

## 3.0 CONSTRUCTIONS AND SUPERVISION

The designing team was fully deployed to supervise the work. An independent testing team spent full time to supervise the construction works from subgrade to surfacing. A dedicated laboratory was set up at the project site equipped with an estimated USD 1 million worth of equipment to assist the supervision team. The test equipment includes those required by SHRP testing method for performance base or semi-performance base asphalt testing. Specialist asphalt quality assurance (QA) team was also deployed to ensure that the construction of the PMA was carried out correctly. A full QA test series and reports were produced during the supervision.

### 3.1 Improved Subgrade Layer

As mentioned earlier improved subgrade at average 250mm depth was constructed. Compliance to minimum insitu strength of 10% California Bearing Ratio (CBR) was tested using the Dynamic Cone Penetrometer Test (DCP) using established DCP-CBR relationship developed locally. The DCP test (See Figure 2) allows checking bearing capacity of the finished subgrade up to 1 meter thick by testing on top of the finished layer. It gives the Engineer a true sense of strength by insitu-penetration of a standard steel rod and cone into the subgrade to 1 metre depth. Falling Weight Deflectometer (FWD) test on the subgrade was also used to analyse the subgrade response and estimate its bearing capacity analytically (See Figure 2). Further application of proof rolling test at 1.4 Mega Pascal (Mpa) pressure were carried out. Direct soil strength achievement was visually assessed by observing soil movement under the roller load provides the high confidence level of compliance not only for subgrade strength but also uniformity of strength requirement meant for large aircraft heavier than the MD11 or Boeing 747. The long term bearing capacity of the improve subgrade is further enhance by applying a thin sand-emulsion blanket (see Figure 2) on the finishing layer. This layer serves as an impermeable separator to protect probable future water infiltration to the lower pavement layer. The lower soil is more sensitive to degradation of bearing strength by moisture penetration.

### 3.2 Granular Drainage Layer

On top of the improve subgrade that was designed as impermeable layer, a permeable layer called the drainage layer was laid in average thickness of 200mm. This layer serves to allow proper drainage of excess moisture in the upper pavement layer. From previous experience this layer will help maintain equilibrium moisture level of the subgrade as such the bearing capacity of the subgrade shall maintain uniform for a long period of time probably surpasses the design life of the pavement.

### 3.3 Pre-cracked CTB and Bituminous CRL

The CTB layer was constructed with three lifts, each 150mm in thickness. Each layer was pre-cracked at 5 m by 5 m panel size. On top of the CTB, 100mm thick asphalt CRL was constructed using conventional asphalt paver. Completed CTB layer was finished and primed with bituminous emulsion (See Figure 2). The production of bituminous CRL material makes use of continuous asphalt plant.

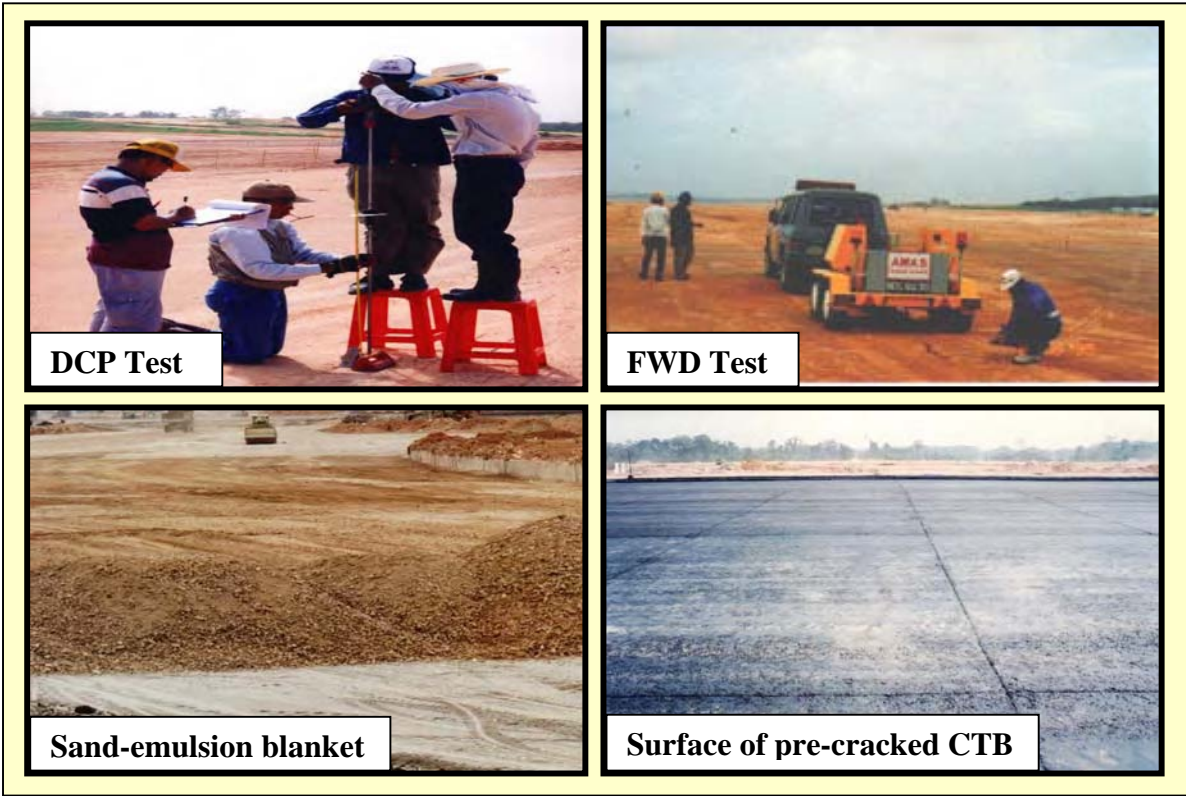


Figure 2: DCP and FWD tests. Sand-emulsion blanket, granular drainage layer and finished surface of pre-cracked CTB.

### 3.4 Surfacing: Asphalt

PMA were approved for construction. The Runway 1 was constructed using Low Density Polyethylene (LDPE) modified asphalt, the Runway 2 used Ethyl Methyl Arcylate (EMA) modified asphalt and the taxiway mainly use Styrene Butadiene Styrene (SBS) added with a proprietary resin modified asphalt. Both the binder course and the wearing course used polymer modified bitumen. Both runways were grooved using purpose built transverse saw cutter producing grooves measuring 6 mm wide by 6 mm deep at 35 mm apart. The grooves were meant to improve the macro-texture of the asphalt surfacing. The productions of the PMA make use of Batch Plant type asphalt plant that was made compulsory for the productions of the PMA. The various pavement constructions for the asphalt pavement are given in Table 1. The Runway pavement was designed to be properly restraint at the edge with the presence of slotted drains at 1m thick (See Figure 3).

Table 1: Various location and constructed asphalt pavement at KLIA (all numbers in mm)

Slotted Drain	Location	Pavement Composition					Grooving
		PMA	CRL	CTB	Drainage Layer	Improved Subgrade	
Yes	Runway 1	150 (LDPE)	100	450	200	250	Yes
Yes	Runway 2	150 (EMA)	100	450	200	250	Yes
No	Taxiways	150 (SBS)	100	450	200	250	No

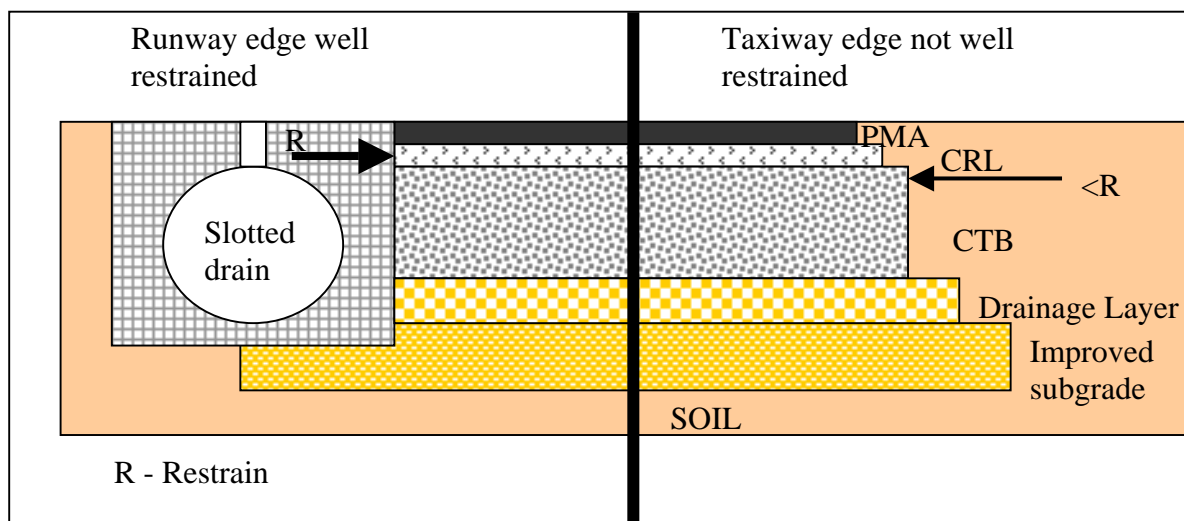


Figure 3: Runway edge restrained with slotted drain.

The Taxiway pavement was not properly restrained at the edges with only compacted soil to restrain any horizontal movement. The restrained condition is perfect for the Runway since the slotted drain was a rigid concrete reinforced structure that will restrain any possible horizontal movement of any layer in the pavement especially the CRL. The taxiway may not perform well without proper restraint at the edges. However this assumption required further proves and site monitoring data collection. Theoretically the taxiway can also performs poorly compared to the runway since it was also subjected to slow moving taxiing aircraft imposing low loading time although the aircraft were similar.

## 4.0 PAVEMENT MAINTENANCE AND MONITORING

### 4.1 Maintenance

Runway 2 experienced minor maintenance by applying crack sealing technique to cold joint cracks that occur at random during the early period after opening. Minor cut and patch repair technique were also carried out mainly on taxiways. No major repairs were undertaken.

### 4.2 Monitoring

In 2003 about six years after construction, a full-fledge network level data collection on the pavement was carried out. Although a different team was assigned to carry out the post construction monitoring data, similar personnel involved during the design and construction stage were employed by the airport owner to ensure continuity of the evaluation process so the best maintenance investment planning can be formulated.

Network level data collections were carried out in line with the FAA guide using the appropriate information quality level. A pavement management system tool recommended by the FAA was also used. Pavement Condition Index (PCI) approach was used to define the condition of the pavement that can also be used to assess the performance of the pavement.

The pavement inventory was first set up where 8 branches and 302 sections were registered. The monitoring includes the concrete pavement that was reported separately. Historical data were made available by having similar personnel involved during the design and supervision exercise. Historical data including present (year 2003) bearing capacity data were gathered using the Heavy Weight Deflectometer (HWD) tested at 1.44MPa load similar to the original multi layer design load of the MD11 tyre pressure (See Figure 4). Other structurally related data such as cracking were also recorded. The pavement roughness was also measured using laser method (See Figure 4).



Figure 4: Bearing Capacity Data collection using the HWD and Multi Laser Profilometer



For each branch and section the functional and structural data we compiled together into a single performance parameter termed as the pavement condition index (PCI). The performance of the pavement was rated using percentage rating, 100 per cent indicate perfect condition and the condition rating decreased as the percentage number reduced. The performance rating were then transferred the sections in graphical format as shown in Figure 5. Each branch and section is colour coded to show the current PCI.

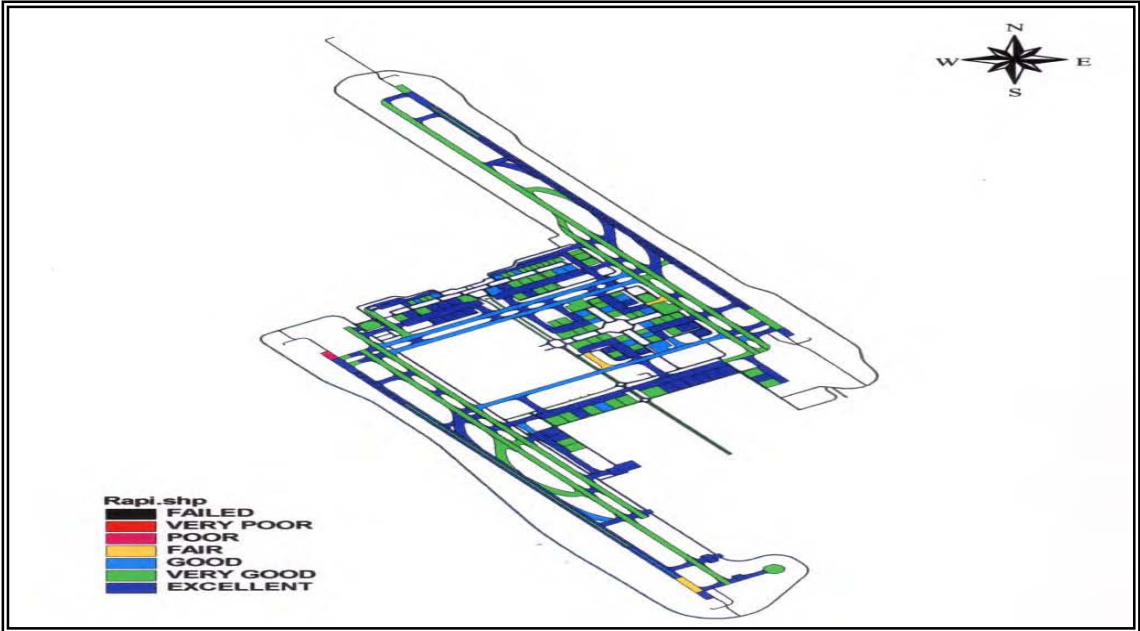


Figure 5: Graphical presentation of pavement condition

## 5.0 PAVEMENT PERFORMANCE

### 5.1 General

The composite pavement had been in service more than six years. In normal circumstances conventional asphalt could have indicated evidence of top down cracking to occur. From the PCI data, both runways did not indicate evidence of cracking, however one of the PMA location had shown evidence of poor cold joint performance whereby many cold joint had open up and form longitudinal cracks. Other forms of failure predicted by the design model did not occur.

### 5.2 Changes in Design Load

Before the fifth year Boeing 777 (B777) airplane was introduce into the fleet. The B777 was fitted with two triple tandem landing gear configurations. The FAA recommended a different and more specific approach to cater the triple tandem landing gear arrangement that may cause more damage to the pavement. Pavement response to the B777 airplane is currently being evaluated for future maintenance and upgrading strategy. The bearing capacity analysis is currently being reviewed using the FAA circular and the LEDFAA analysis system.

### 5.3 Pavement Performance

During the data collection exercise for the 1<sup>st</sup> phase Pavement Management System (PMS), the PCI performance indicator was used as a single indicator to define the condition of the pavement at each divided section or branch. The PCI guide recommended by Shahin (1994) was used since it provides a logical, simple and succinct performance indicator for budget planning purposes. At this juncture this indicator is sufficient to evaluate the performance of the pavement designed to the MD11 aircraft load. The majority of the pavement registered PCI greater than 75 per cent in the year 2003.

From the monitoring data it was noted that 2 of the parallel taxiways recorded lower condition index compared to other locations. It was noted that the B777 airplane traversed the two taxiways. It was believed that the lower condition index is due to this added loading factor. The pavement was originally designed only up to MD11 aircraft load. The extra damaging effect of the triple tandem landing gear may affect the fatigue performance for the taxiway pavement. The effect of B777 rolling speed to the composite pavement is currently being studied along with the FAA specialized analysis for this type of airplane.

To date there is no indication of probable failure due to lack of bearing capacity requirement base on the original design load, the MD11 aircraft. However a general functional failure pattern on the parallel taxiway suggest that the introduction of the B777 airplane may affect the performance of the asphalt pavement. Total pavement thickness for the runways and taxiway are the same, however the runways edge is fully restraint by the existence of slotted drains parallel the edge of the runways. Low restraint could be a contribution to the functional deterioration of the taxiway. It was also noted that the large aircraft normally taxi at low speed along the taxiway thus exerting different and more damaging 'long loading time' effect to the asphalt. This phenomenon is also being studied.

Both runways did not show any significant distress indicator to suggest critical or failed pavement condition due to poor pavement performance. After more than six years of trafficking some of the forecasted failure mode described in Para 2.0 does not happen.

Other possible suspected failures were also thought but did not occur such as: -

- 1) Closing up of grooved asphalt surface
- 2) Hydraulic pumping failure due to saturation of asphaltic CRL
- 3) Rapid or exaggerated hardening of PMA
- 4) Failure due to unknown chemical or physical reaction of polymer to the environment.
- 5) Deterioration of asphalt due to fuel spillage

## 6.0 CONCLUSIONS AND RECOMMENDATION

Pavement is a costly investment and the full application of basic civil engineering principle like the full use of readily available material should be deployed whenever possible. The science of pavement engineering has advance and the use of untested materials but having superior engineering properties should be applied where applicable. The basic probable advantage such as time saving, cost and added strength should be evaluated scientifically. KLIA airfield pavement used advanced pavement technology whereby at that point of time very limited application of the said technology was seen. Research and development works in a more coordinated and focus manner can help gathered the technical benefit obtained from the performance of the airfield pavement. At this juncture the investment of KLIA pavement initially worth more than USD 1 billion (inclusive of associated works) was one of the highest in Malaysia. The government R & D spent on this subject has shown fruitful results where the following recommendation should be carried out when investing on heavy duty and expensive pavement investment: -

- 1) The use of cheap locally available material carried at improving the bearing capacity of heavy duty pavement must be given top priority
- 2) Local knowledge on pavement materials, pavement behaviour and failure characteristics are important for long term and heavy pavement investment
- 3) Spending money on Research and Development is the way forward and proven beneficial in many angles
- 4) Monitoring pavement performance is beneficial for objective and strategic pavement investment cost benefit analysis, which include maintenance cost
- 5) Transparency is resolving issue either managerial or technical is a key towards successful implementation of high investment project
- 6) Qualified personnel with the correct experience and knowledge cannot be compromised for successful mission
- 7) Partnering concept is an effective way toward the implementation of a successful investment project drawing clearly all stakeholder role, responsibility and liability with a positive win-win mission statement

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