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Maintenance management of pavements for expressways in Malaysia

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Abstract. Pavements deteriorate over time due to traffic loading and environmental effects. The maintenance of pavements to improve the riding quality and level of service on major expressways, including the North-South Expressway (850 km in length), is a key challenge for the maintaining authorities and highway concessionaires. Pavement maintenance works not only incur high costs but also cause interruption to traffic flow resulting in complaints from the road users and the authorities. To maintain satisfactory condition of existing pavements, timely intervention is necessary which helps to minimise pavement deterioration and maintenance costs. Pavement condition assessment is required to determine the functional and structural condition which translate into service life. This paper describes an approach with case studies of pavement maintenance management for expressways in Malaysia.

1. Introduction

Pavement maintenance works form a major component of the annual expenditure. Appropriate intervention for maintenance and rehabilitation of existing pavements is necessary for asset preservation when signs of surface defects are observed. Such defects otherwise can affect the structural integrity of pavements and the level of service to the road users.

The maintenance management requires pavement condition assessment to be carried out at regular intervals. The data is used to determine the functional and structural condition. The data is also used to identify areas of poor condition pavements which are then followed by pavement treatment to be applied at the most appropriate time. The pavement treatment is determined using mechanistic design. The benefits of this design approach over empirical methods are that the in-situ material properties of pavement layers from a specific site can be modelled. The engineering properties of innovative materials can be incorporated into the design procedure. The mechanistic design also helps to ensure that pavements in different sections along the expressway are not over-designed or under-designed. This design approach therefore provides optimal and cost-effective maintenance solutions.

2. Pavement serviceability

Figure 1 shows conceptually how pavement serviceability changes with traffic loading over time [1]. Pavement deterioration starts off at an accelerated rate at a point known as the “critical or intervention level.” It is important to ensure that pavement strengthening is carried out at or before the critical/intervention level so that the structural integrity is largely retained. Before the intervention level, strengthening of pavements requires minimum treatment such as resurfacing or mill and pave in



localised areas followed by thin overlay to restore the pavement condition. This helps to minimise the maintenance costs. The serviceability of existing pavements is determined through pavement condition assessment which is discussed in the following sections.

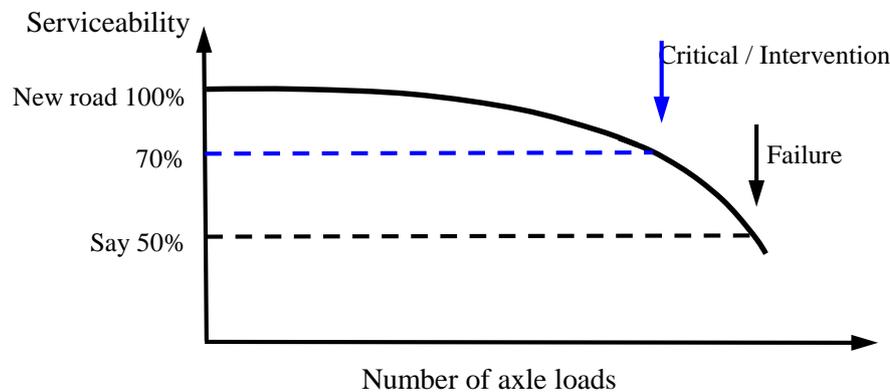


Figure 1. Pavement serviceability with traffic loading [1]

3. Pavement condition assessment

Pavement condition assessment (PCA) is carried out periodically for the whole expressway network. The purpose is to determine the functional and structural condition of existing pavements. A two-stage approach, termed as the network level PCA and project level investigation, is considered. The network level PCA provides an overall assessment of the performance condition of pavements which helps to identify sections of poor condition pavement. These sections are considered for project level pavement investigation. The PCA involves non-destructive testing techniques as described below.

3.1. Multi laser profiler (MLP) survey

The MLP survey is carried out annually to measure the surface properties which are directly related to the riding quality of pavements (figure 2). The survey is carried out at traffic speed of 70-90 km/hr. The data is recorded for every 25mm spacing and reported at 20m to 100m intervals based on the project requirements. The data is analyzed and processed to determine the following:

- Riding quality in terms of International Roughness Index (IRI) expressed in units of m/km.
- Transverse profile (rutting).
- Surface texture of pavements (macro texture).

3.2. Falling weight deflectometer (FWD) testing

The FWD testing is carried out to determine the structural condition of pavement (figure 3). The testing is carried out along left wheel-path of slow lane and right wheel-path of fast lane. The test spacing is generally 200m for network level PCA depending on the size of road network and 25m to 50m for project level investigation.

The FWD contact pressure is around 0.7 MPa for flexible pavement and 1.0 MPa for rigid pavement which produces a load pulse similar to that from an axle load of heavy vehicle. Pavement and air temperatures are recorded during testing and used in the subsequent analysis. The FWD data is analysed to determine the stiffness moduli of pavement layers and subgrade.



Figure 2. Multi Laser Profiler



Figure 3. Falling Weight Deflectometer

3.3. Automated crack detection (ACD)

The ACD survey is carried out using the Hawkeye (2000) system developed by ARRB, Australia. The Hawkeye system comes with a software which allows reporting of the type, severity and extent of cracks. It also allows reporting of wide cracks and percentage of all cracks over a specified length. The system uses the latest digital camera technology to record high resolution video images of the pavement surface condition.

All images are recorded using four channel digital cameras from different views such as vertical (down-facing to pavement surface), front view, right side and left side views. The cameras can log these images against other parameters such as distance and GPS coordinates. The cameras can also record roadside furniture such as guardrails, kilometer markers, signboards and road marking.

3.4. Visual condition survey

A detailed visual condition survey is carried out for project level investigation. The sections with different types of surface defects are identified and recorded following the procedures given in the JKR Guidelines on visual assessment of flexible pavement surface condition [2] and Transport Research Laboratory (TRL) Overseas Road Note 18 [3].

All types of pavement defects such as cracking, rutting, potholes, patching, bleeding and raveling as applicable are recorded. The data is reported at 100m intervals. The defects are characterised in terms of their type, severity and intensity. The severity of longitudinal, transverse, crocodile and/or block cracks is recorded as follows:

- Hairline crack - Very Low (VL)
- Crack width up to 1mm - Low (L)
- Crack width 1mm to 3mm - Medium (M)
- Crack width greater than 3mm - High (H)
- Crack width greater than 3mm with spalling - Very High (VH)

Rutting along wheel-path is measured at regular intervals using a 3m straight-edge. The severity of rutting is reported as follows:

- Rutting < 5mm: Low (L)
- Rutting 5mm to 15mm: Medium (M)
- Rutting 15mm to 20mm: High (H)
- Rutting > 20mm: Very High (VH)

3.5. Coring and dynamic cone penetrometer test

Cores (150mm diameter) are taken through asphalt layers to determine the thickness of asphalt and assess materials condition. Cores are taken from areas of good and poor pavement condition. A dynamic cone penetrometer (DCP) test is carried out through coreholes. The coreholes are then reinstated using

suitable materials. The DCP data is analysed and interpreted to determine the thickness of granular materials for roadbase, sub-base and capping (if any) and the in-situ CBR of subgrade.

3.6. Skid resistance survey

Skid resistance survey is carried out using a Grip-Tester. It involves measurements which represent friction force on a test wheel operated at constant load and longitudinal reference slip. Water is sprayed ahead of the reference tyre by a self-watering system to produce 0.25mm thick water film and the test wheel is brought to the road surface by means of a hydraulic actuation system. The data is analysed to derive a Grip-Number (GN) which represents the skid resistance of pavement surface. The GN values are then used to determine pavement sections which fall under acceptable or investigatory level as per UK Highways Agency guidelines [4].

3.7. Traffic volume and axle load survey

Axle load survey is carried out using portable weigh pads or Weigh-in-Motion (WIM) system. The survey sites are selected to represent the axle load spectrum from commercial vehicles along the expressway network. The axle load data is used to determine Equivalence Factor (EF) values which are then used to calculate the design traffic loading in millions of equivalent standard axles [5].

3.8. Trial pit investigation

Trial pit investigation is carried out only in selected areas of existing pavements. The trial pit locations are based on the analysis of FWD deflection data and site conditions. Trial pits allow a more detailed visual inspection of pavement layer thicknesses and materials condition including the presence of water. It also allows to take bulk samples of granular materials and subgrade for laboratory testing.

3.9. Equipment calibration

The calibration of all survey equipment is necessary to ensure the accuracy of PCA data. The equipment shall be capable of providing satisfactory data with repeatability. All equipment is calibrated as per manufacturer's recommendation.

The FWD and MLP require annual calibration carried out by the manufacturer and a relative or reference calibration prior to the commencement of any survey. The FWD relative calibration involves stacking tower test for deflection sensors. This helps to compare and verify deflection measurements from all deflection sensors. Any sensors with inconsistent readings are removed and replaced prior to commencement of data collection.

4. Analysis and interpretation

4.1. Functional and structural condition

The PCA data is analysed to determine the functional and structural condition of pavements. The pavement condition is classified as good, fair, poor or bad with respect to the Key Pavement Performance Indicators (KPPI) established by the Malaysian Highway Authority. The structural condition is represented by Pavement Condition Index (PCI) and FWD deflections. The pavement assessment criteria with respect to roughness, rutting, surface texture and PCI are shown in table 1.

Table 1. Pavement Condition Assessment Criteria

Pavement Condition	Roughness IRI (m/km)	Rutting (mm)	Texture Depth (mm)	Pavement Condition Index (PCI)
Good	< 2	< 5	> 0.5	< 2
Fair	2 - 3	5 - 10	0.3 - 0.5	2 - 3.9
Poor	3 - 3.8	10 - 20	< 0.3	≥ 4
Bad	≥ 3.8	≥ 20	-	-

Pavement Condition Index (PCI) = CI + RI, where:

CI = Crack Index

0 = No crack

1 = Single crack

2 = More than one crack (not connected)

3 = Inter-connected cracks

4 = Crocodile cracks/block cracking

5 = Complete disintegrating or potholing

RI = Rut Index (derived from the MLP survey)

0 = 0 - 5 mm

1 = 6 - 10 mm

2 = 11 - 15 mm

3 = 16 - 20 mm

4 = > 20 mm

Figures 4 and 5 show typical example of the structural and functional condition of pavements with respect to PCI and surface roughness (IRI) respectively. The percentage of good, fair and poor condition areas indicate performance of pavements over the expressway network.

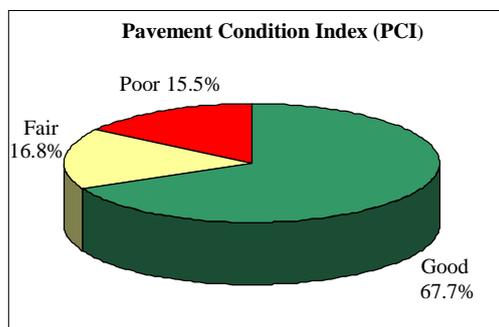


Figure 4. Pavement Condition based on PCI

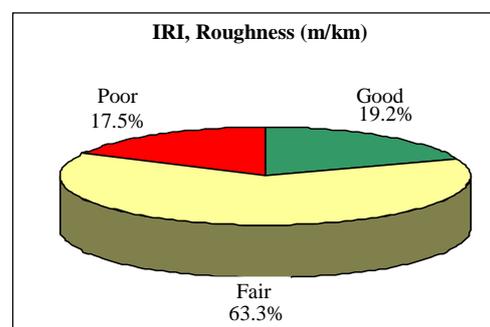


Figure 5. Pavement Condition based on IRI

4.2. HDM4 analysis

The highway development and management model (HDM4) has been used for planning of maintenance budgets for road projects in many countries. The HDM4 analysis is carried out to provide maintenance strategies which allow monitoring of pavement performance with respect to the level of service based on different financial budgets. The HDM4 model has been calibrated for local conditions in Malaysia. This had involved setting up and performance monitoring of long-term pavement performance (LTPP) sites over 10 years. The input data for HDM4 analysis includes the following:

- Pavement condition assessment data
- Pavement construction details and age
- Traffic volume data
- Axle load data with Equivalence Factors (E.F.) of commercial vehicles
- Pavement maintenance record and treatment options
- Unit rates for the treatment options

HDM4 analysis produces a long-term rolling programme (LTRP) which shows medium to long-term maintenance works and expenditure profile. It provides different maintenance scenarios which can be analysed over a period of 5, 10, 20 or 30 years. This scenario analysis is particularly useful for the financial planning of maintenance budgets in order to achieve target key performance indicators for the expressway network. Figure 6 shows a flow chart of HDM4 analysis.

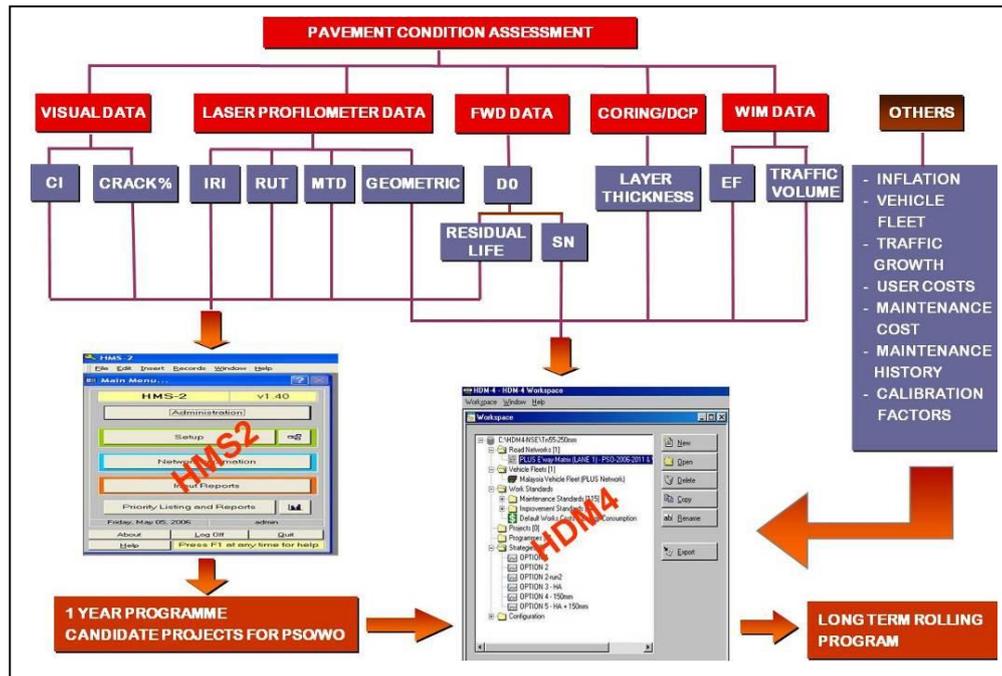


Figure 6. Flow chart of input data for HDM4 Analysis

4.3. Pavement sections for maintenance

The PCA results in terms of surface rutting and cracking can be presented on a strip-map as shown in figure 7. This gives an idea of the extent and location of good, fair and poor condition pavements along the expressway network. The strip-map is used to identify sections of poor pavement condition which require attention for pavement maintenance and rehabilitation works.

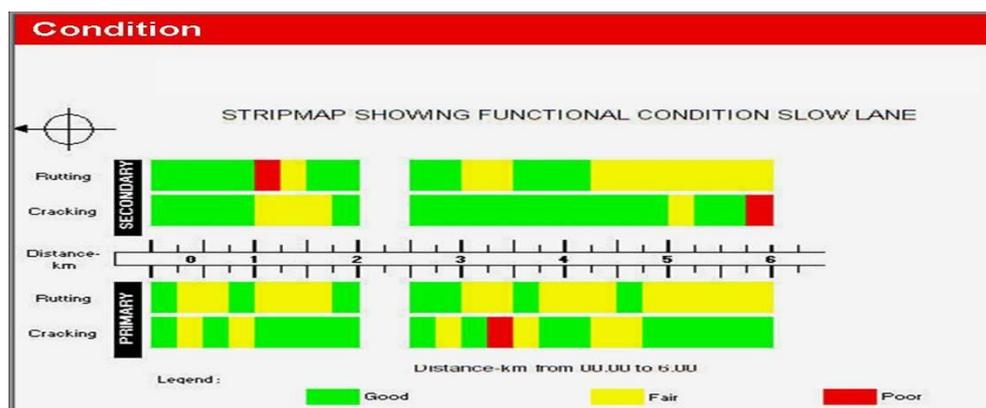


Figure 7. Strip-map of pavement surface condition

5. Pavement rehabilitation design

5.1. Design approach

Pavement rehabilitation design is carried out using a mechanistic approach [6, 7]. The mechanistic design offers several advantages over empirical methods such as:

- The engineering properties of each pavement layer and subgrade can be modelled.
- Temperature and environmental data specific to a particular site can be considered.

- Sensitivity of design thickness to changes in data can be assessed.
- Pavement design for extra heavy and unusual vehicles loading can be carried out.
- Design options for alternative pavement structures can be determined.
- Innovative materials can be incorporated into the design procedure.

Pavement rehabilitation design based on mechanistic approach has been applied to major expressways in Malaysia over several years. The objective of the design procedure has been to retain as far as possible the existing pavement materials and obtain optimal maintenance solutions.

5.2. Design procedure

The design procedure requires computation of strains at the base of asphaltic layers and on top of subgrade [8]. These strains are related to fatigue cracking in asphalt and permanent deformation (rutting) of subgrade. Computation of tensile stresses in cement treated base (where applicable) is also carried out. The critical strains in the asphaltic layers and subgrade are compared to the permissible strains based on traffic loading. Figure 8 shows a flow chart of the design procedure for fatigue cracking. A similar approach is adopted to determine strains for subgrade permanent deformation.

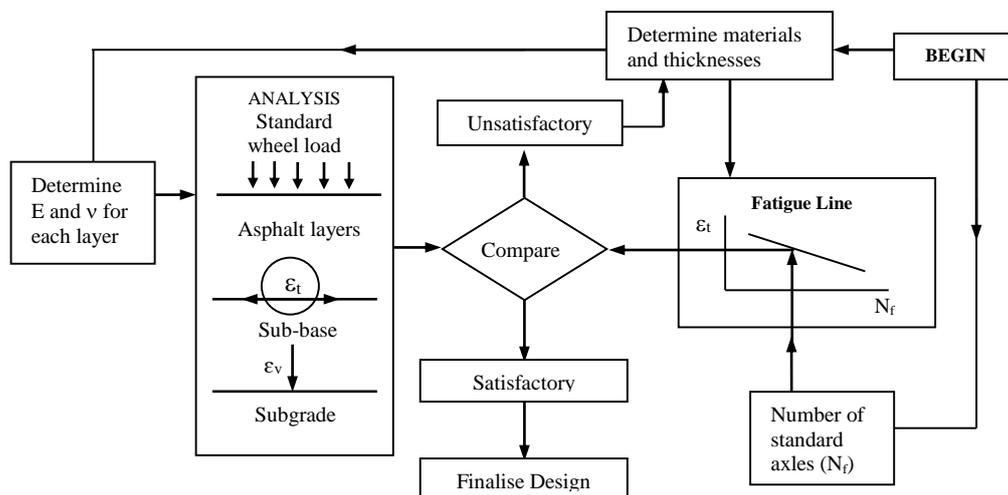


Figure 8. Flow chart of design procedure for fatigue cracking

The above design process considers conventional failure mechanism of asphalt cracking and rutting in flexible pavement. Other failure modes such as reflection cracking, surface initiated (top-down) cracking, poor drainage, poor asphalt mix and workmanship are also considered. Depending on the structural condition of existing pavement layers (i.e. granular roadbase, sub-base and subgrade), pavement rehabilitation design would generally involve asphalt overlay with partial reconstruction of slow lane. Full reconstruction may also be required in some localised areas with contaminated granular layers and poor subgrade. The overall objective of the design procedure is to preserve the asset with optimised treatment. This helps to minimise the maintenance costs.

5.3. Case studies

Pavement maintenance and rehabilitation works along the North-South Expressway (NSE) have been carried out on a yearly basis. The works have been completed in several areas along the NSE. These areas were identified with poor functional and structural condition. Pavement condition has been monitored based on the PCA data. The results have indicated improved functional and structural condition of pavements where rehabilitation works have been completed. Case studies for two sites along the NSE, referred to as Site A and Site B, are discussed below.

5.3.1. Site A - NSE Section S3 (KM 72.0 - 79.13) Northbound. Total length of this site was 7.13 km comprising a two-lane carriageway plus hard shoulder. This site involved flexible pavement with 50% of the pavements constructed on embankment (fill areas) and 50% in cut sections. PCA 2008 results showed poor functional and structural condition with poor IRI, high defections and high crack index (Figure 9a).

Project level pavement investigation was carried out between Nov 2008 and Feb 2009. This involved FWD testing, detailed visual condition survey, coring through asphaltic layers, in-situ DCP test, trial pit investigation and laboratory tests. The visual condition survey showed medium to high severity cracks on 70% of the slow lane. Rutting of medium to high severity (15-20 mm) along wheel-paths was observed over the entire length of slow lane. The fast lane pavements were generally in good condition with low severity cracks and low severity rutting (less than 5mm). The asphalt thickness was around 180mm to 220mm. A number of cores taken from slow lane showed cracked and broken asphalt material. The average thickness of granular materials (wet mix roadbase and sub-base) was 400-500 mm. A capping layer of 600-800 mm thickness was found underneath of sub-base. The in-situ subgrade CBR was generally 6% and higher.

The design traffic was calculated based on the traffic volume and axle load data from Weigh-in-Motion stations. The 10-year design traffic was found to be 48.6msa for slow lane and 12.2msa for fast lane. The pavement residual life was found to be less than 1 year for slow lane and 4-6 years for fast lane.

5.3.2. Site B - NSE Section N2 (KM 90.0 - 93.0) Northbound. Total length of this site was 3.0 km comprising a two-lane carriageway plus hard shoulder. This site involved flexible pavement with 10% of the pavements constructed on embankment (fill areas) and 90% in cut sections. PCA 2010 results showed poor functional and structural condition of pavements with poor IRI, high crack index and high rut index (Figure 10a).

Project level pavement investigation was carried out between Oct 2010 and Jan 2011. This involved FWD testing, detailed visual condition survey, coring through asphaltic layers, in-situ DCP test, trial pit investigation and laboratory tests. The visual condition survey showed medium to high severity cracks on 80% of the slow lane. Rutting of medium severity (5-15 mm) along wheel-paths was observed on slow lane. The fast lane pavements were generally in good condition with low severity cracks and low severity rutting (less than 5mm). The asphalt thickness was around 180mm to 200mm. The average thickness of granular materials (wet mix roadbase and sub-base) was generally between 500-600 mm. A capping layer of 400-600 mm thickness was found underneath of sub-base. The in-situ subgrade CBR was generally 5% and higher.

The design traffic was calculated based on the traffic volume and axle load data from Weigh-in-Motion stations. The 10-year design traffic was found to be 38msa for slow lane and 10msa for fast lane. The pavement residual life was found to be less than 1 year for slow lane and 3-5 years for fast lane.

5.3.3. Pavement performance. Pavement rehabilitation designs were carried out using mechanistic approach for 10-year design life. The treatment involved mill and pave existing pavement on slow lane (to varying depth) then followed by asphalt overlay on full width of carriageway. The pavement rehabilitation works were implemented and completed in Year 2009 for Site A and in Year 2011 for Site B. The performance of these sites has been monitored since completion of pavement works and is described below.

Site A - NSE Section S3 (KM 72.0 - 79.13) Northbound

- Figure 9a shows PCA 2008 data which is before the rehabilitation works. The results indicate poor condition of pavements with poor IRI, high defections and high crack index.
- Pavement rehabilitation works were completed in Year 2009.
- Figure 9b shows PCA 2017 data which is 9 years after completion of pavement works. The results indicate satisfactory pavement condition.

Site B - NSE Section N2 (KM 90.0 - 93.0) Northbound

- Figure 10a shows PCA 2010 data which is before the rehabilitation works. The results indicate poor condition of pavements with poor IRI, high deflections and high crack index.
- Pavement rehabilitation works were completed in Year 2011.
- Figure 10b shows PCA 2017 data which is 7 years after completion of pavement works. The results indicate satisfactory pavement condition.

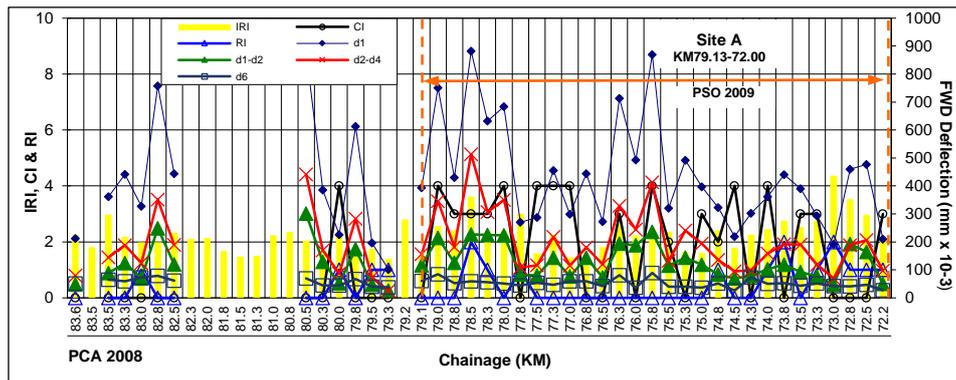


Figure 9a. Site A - Pavement condition of slow lane based on PCA 2008

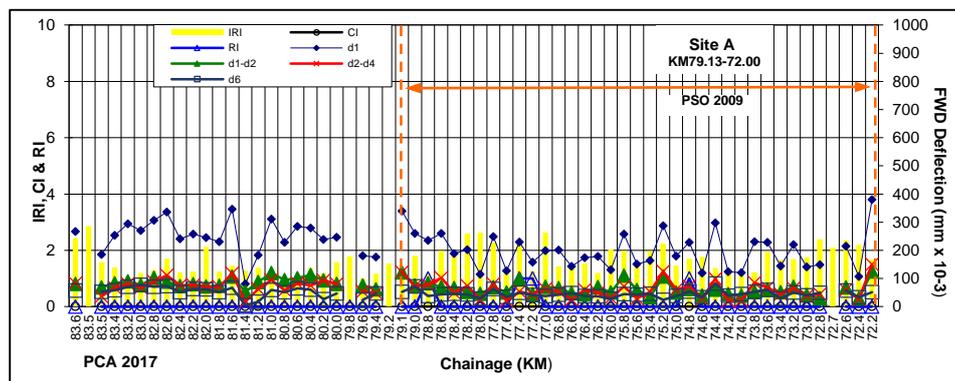


Figure 9b. Site A - Pavement condition of slow lane based on PCA 2017

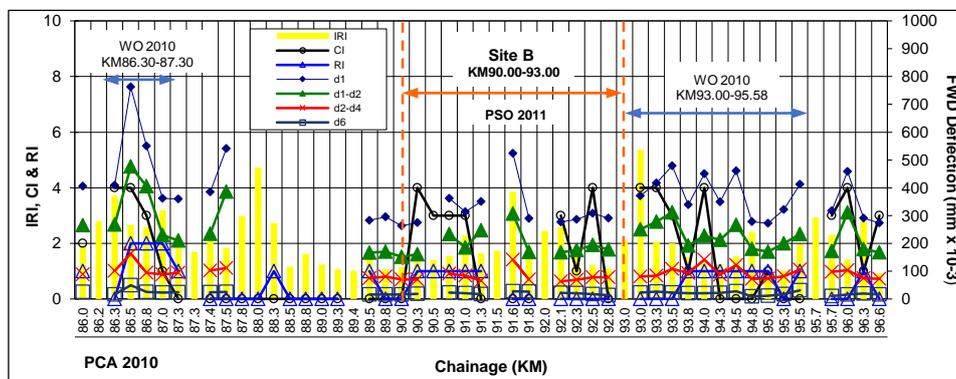


Figure 10a. Site B - Pavement condition of slow lane based on PCA 2010

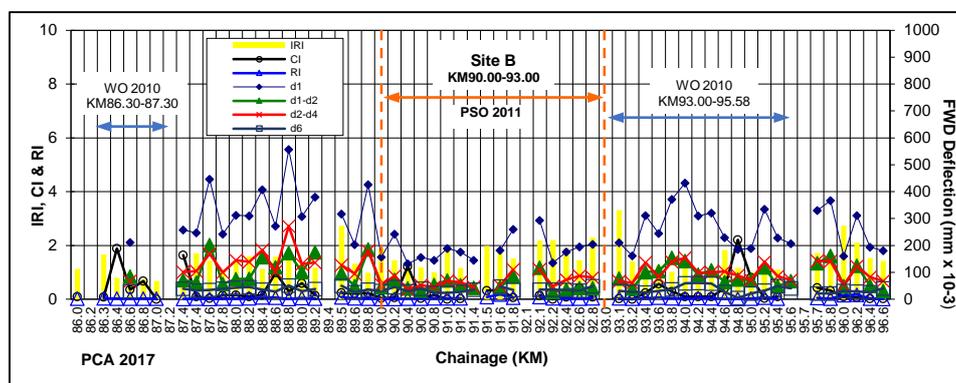


Figure 10b. Site B - Pavement condition of slow lane based on PCA 2017

The above shows improved functional and structural condition of pavements at sites A and B after the rehabilitation works.

6. Conclusions

Pavements deteriorate over time due to traffic loading and environmental effects. Timely intervention is necessary to maintain the existing pavements in satisfactory condition which helps to minimise pavement deterioration and maintenance costs with reduced interruption to the road users.

Pavement condition assessment (PCA) is carried out to determine the functional and structural condition. The network level PCA is carried out periodically and provides an overall assessment of the performance condition of pavements over the expressway network. It also helps to identify pavement sections with poor structural condition along the expressway.

Project level investigation is carried out for selected pavement sections which require maintenance. The data is used to determine the rehabilitation design options using mechanistic approach. The design procedure allows material properties of pavement layers to be incorporated. This approach helps to optimise the design options based on the structural condition of existing pavement.

HDM4 analysis is carried out to determine maintenance strategies which allow monitoring of pavement performance. It also provides maintenance scenarios and financial forecast over a certain period. This scenario analysis helps to determine the most optimal maintenance strategy and financial budget to maintain satisfactory pavement condition along the expressway network.

Pavement maintenance and rehabilitation works along the North-South Expressway (NSE) have been carried out on a yearly basis. Pavement rehabilitation works have been completed in several sections along the NSE. The performance of completed works has been monitored on a yearly basis. The results have shown improved functional and structural condition of pavements.

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