Using Pavement Condition Index PCI Method to Evaluate the Service Condition of Flexible and Rigid Pavements

(A case study in Sulaimani)

Prepared by

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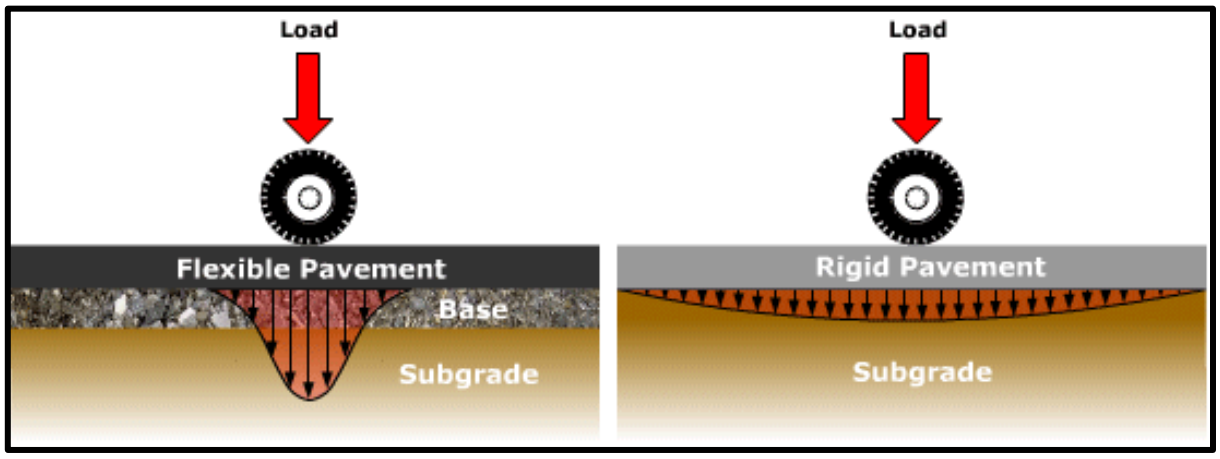

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ABSTRACT

Pavement deterioration is a continuous problem that reduces the service life of the roads if they are note treated before they get worsen. Sometimes quality of the materials and construction are not the only reason, if so, still they can be controlled by periodic inspection and maintenance. Pavement condition index is one of the effective parameter which is necessary to be found out for every road and recommended to be updated every year. The objective of this study is to calculate PCI for two roads in Sulaimani city, including both flexible and rigid pavement. The procedure of ASTM D6433 was followed for visual observation of the defects and total station instrument used for locating the real coordinate of the defects on the roads for further actions to be taken. A 720m long Badinan Road surveyed for rigid pavement and it was found that due to lack periodic maintenances, transverse joints spalled and widened with some other defects which resulted an overall PCI of 41.1 (Fair). For flexible pavement a 1620m long Hawary Shar road surveyed, although transverse and longitudinal cracking were major defects in the road with some other types of defects, but the road performed with a PCI of 95.5 (Excellent). Some maintenance procedure recommended for both pavement type based on the severity level of the defects.

Keywords: Pavement Condition Index, Pavement defects, evaluation of pavement condition, pavement maintenance.

1. Introduction

Highways and airports are the greatest indicators and contributors for the communities' comfort and welfare and they are one of the most important economic activities of the modern world. The progress and the development of the Countries, regions and the cities can be evaluated based on the level and the quality of their highways.

Since the conditions of highways and pavements worsens as the time passes, caused by repetitive traffic loading and environmental factors, there are many researches has been done to estimate the

conditions of pavements in order that proper maintenance and repair strategies and a pavement management system would be prepared.
Before deciding to maintain them it is very important to follow up series of scientific method for estimating the approximate conditions in order that best possible maintenance and repair strategies can be implemented and in this way the life times will be increased.

For this case some researchers used surface distress identification to rate the conditions however some others used functional properties of the pavement to rate them.
(Mohammed A. Al-Neami et al 2017) Used GIS software as a database for identifying the location of each distress point within the surface with complete information during the surveying, and update it continuously, that will help in maintenance decision and stated that continuous monitoring of the pavement conditioning index is necessary to establish the rate of pavement deterioration, which permits early identification of major rehabilitation needs.

(Fareed M.A. Karim et al. 2016) evaluated the pavement conditions in terms of the surface distresses existing at the time of the field evaluation. The PCI procedure was used in that research since it deals with the subject of pavement distress identification most comprehensively and is based on a sound statistical technique of pavement sampling.

Faris and Mahir, 2012 stated that the maintenance of transportation assets has become a worst challenge for most of the transportation agencies over the world. Trikit-Tooz Road (in the middle of Iraq) was divided into segments to calculate PCI. Based on the results were concluded that managers will be able to compare three types of necessity; financial, physical, and specifications instructions, sometimes Condition Index refers to that assets able to be used for 15 years while specification refers that it can be used for 10 years only and so on.
After thorough searching and investigation within Kurdistan we have not faced any detailed research available that has been done scientifically to estimate the quality level of the pavements and estimate the future or remaining lifespan.

For this reason, we have decided to open this field of research and study by selecting two random samples from Sulaimani city for visual inspection and from there functional evaluation.

We have chosen two types of pavements; an asphalt pavement (flexible pavement) and a reinforced concrete pavement (Rigid pavement).

We have followed ASTM D6433 standard practice for evaluating the surface characteristics of the pavements and from there deriving a set of instructions to indicate the quality level for proposing proper maintenance and repair strategies.

2. Study Area

In this study, two types of pavements have been worked on, rigid and flexible pavement. Since, different types of pavement have varying behavior and characteristics and respond differently to the traffic and weather conditions, it was required to investigate both types.

The road branch selected for rigid pavement defect studies, was a collector road between the 60-meter Malik Mahmood ring road and the Zargata Intersection (traffic). It was a 2 way 2 lane road, about 720 m in length, 9m wide. For PCI determination the road was divided in to 9 segments with the total area of 720 m^2, and the segments further divided into 10 sub segments each with the total area of 72m^2.

The road branch selected for flexible pavement defect studies, was Hawari Shar road which extends from the Kobane bridge at the 60-meter Malik Mahmood ring road to the Hawari Shar Roundabout. It was a 2 way 4 lane road, about 1620 m in length, 12.45m wide. For PCI determination the road was divided into 18 sections, each with the total area of 1122.6m^2 and the sections further divided into 5 subsections, the area of each subsection was 224.52 m^2.

3 Methodology

3.1 PCI (Pavement Conditioning Index) Determination

The Pavement conditioning index is one of the parameters that uses surface distresses for determining the conditions of different types of pavement in order that maintenance and repair strategies can be implemented.

Visual survey or visual inspection of the pavement surface is a good indicator of the current situation of the pavement surface.

It is apparent that from the results of the pavement visual surveying:

- Present condition and future predictions can be assumed.
- Urgent maintenance and repair tasks related to different level of the distresses can be estimated.
- It can also be used to evaluate the performance of the materials and techniques used as the solutions.

PCI is a standard procedure that is used by the highway agencies and administrative decision makers in order to visually assess the current pavement condition. The procedure described in American Society for Testing and Materials (ASTM) D6433-09 (2009), was followed for this study. During a PCI survey, visible signs of deterioration are recorded, the final calculated PCI value is a number from zero to 100, with 100 representing a pavement in excellent condition and zero representing the worst (Fareed M.A. Karim et al. 2016).

The PCI cannot measure structural capacity nor does it provide direct measurement of skid resistance or roughness. It provides an objective and rational basis for determining maintenance and repair needs and priorities. Continuous monitoring of the PCI is used to establish the rate of pavement deterioration, which permits early identification of major rehabilitation needs. The PCI provides feedback on pavement performance for validation or improvement of current pavement design and maintenance procedures (ASTM D6433, 1999).

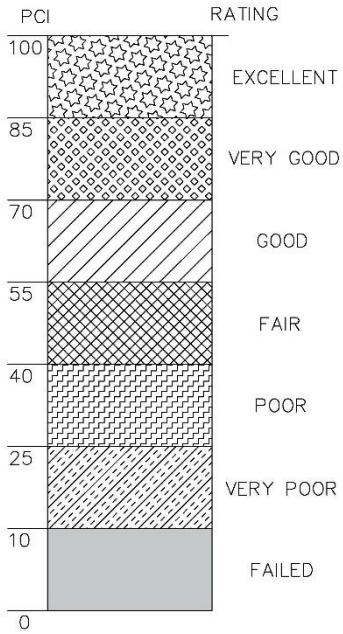

Figure 1: Pavement Condition Index (PCI) and Rating Scale

3.2 Data collection

The data required for determining PCI of each road segment was collected by visual observation with the aid of total station instrument. The data collected by the total station was used for reproducing the road alignment in AutoCAD software and showing the real location of the distresses within the road. The types of the data were distress types, their severity level and measurement of the infected area. Photographs were also taken during the surveying process to help more accurate analysis and decision making.

3.3 Analyzing the study area

The data analysis process was achieved through the following steps:

1. Coordinate data was used for drawing the road alignment and locating the distresses on it.
2. Data collected by visual observation was used for identifying the defects and their severity levels (including their measurement).
3. Deduct values were determined from ASTM D6433 graphs for each segment separately and sections as a group of segments.
4. Corrected deduct values were determined for each section using the standard procedure. If none or only one individual deduct value was greater than 2 then corrected deduct value CDV was determined. If more than one individual deduct value was greater than two, then CDV was found from the total deduct value by using (q) parameter, which was equal to the number of deduct values greater than 2.
5. PCI was determined from this equation PCI = 100-Max CDV.

4.1 PCI Calculation

4.1.1 Badinan Road (Rigid Pavement)

Is a collector road between the 60-meter Malik Mahmood ring road and the Zargata Intersection. The branch is 720m in length and 9m wide 2 way 2 lane road. It is defined under one branch which divided into 9 sections each composed of 10 imaginary slabs with 8 meter in length.

The procedure explained in ASTM D6433 followed for calculation of PCI of the branch. The road visually inspected to find out any kind of defect happened within the

road and Total Station device used for defining exact location (X,Y,Z) of each defect, in order to make a map for the road including the location of the defects for further actions required to be taken in the future by the corresponding authorities (Fig.4-1)

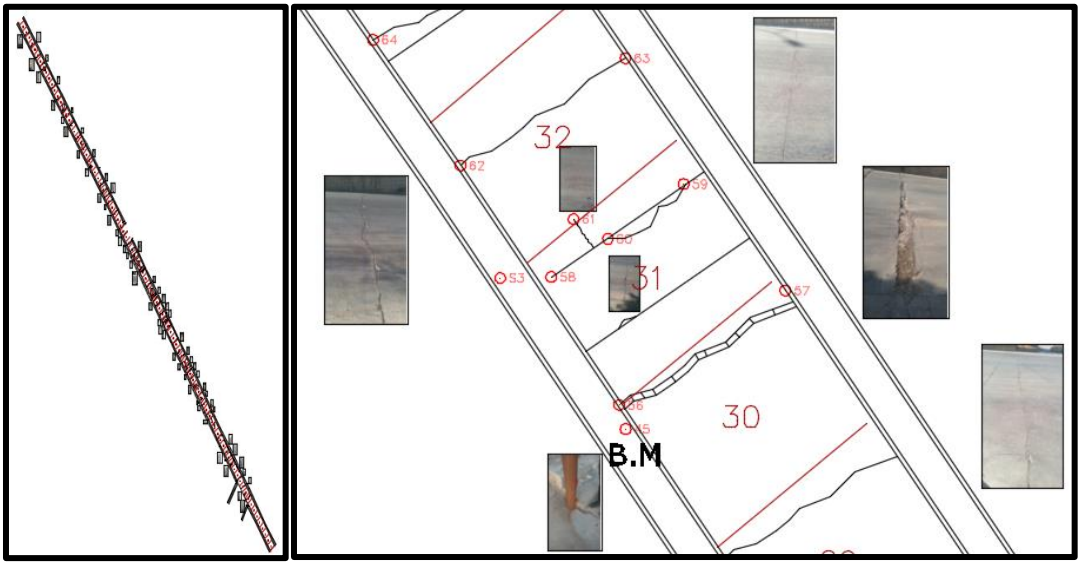

Figure 2: Badinan Road Defect Layout plan

The road layout and location of the defects for the further maintenance and necessary actions were drawn from the coordinate data collected by total station during surveying.

Table 1: PCI Calculation Sample for Badinan Road

NO	DISTRESS TYPES	SEV.LEVEL	NO.SLAB	DENSITY %	DV	PCI
1	24	H	1	10	24	62
	39	H	1	10	15	
	39	M	2	20	9	
	29	H	1	10	17	
2	39	H	1	10	15	25
	39	M	2	20	9	
	29	L	6	60	22	
	29	M	1	10	6	
	29	H	1	10	17	
	23	H	2	20	51	
	28	H	3	30	37	
	24	H	1	10	23	

DV								TOTAL	q	CDV
24	17	15	9					65	4	38
24	17	15	2					58	3	37
24	17	2	2					45	2	36
24	2	2	2					30	1	29
M=	7.98							PCI= 100 - MCDV = 100-38 = 62		
51	37	23	22	17	7.50			157.5	6	70
51	37	23	22	17	2			152	5	74
51	37	23	22	2	2			137	4	75
51	37	23	2	2	2			117	3	72
51	37	2	2	2	2			96	2	67
51	2	2	2	2	2			61	1	60
								0		
								0		
M=	5.50							PCI= 100 - MCDV = 100-75 = 25		

Table 2: Defects densities within the Badinan road

DEFECTS	SEVERITY LEVEL	DENSITY	SEVERITY LEVEL	DENSITY	SEVERITY LEVEL	DENSITY
	H	%	M	%	L	%
DURABILITY CRACKING	4.5	0.6	0	0.0	0	0.0
SPALLING OF TRANSVERSE JOINTS	85.79	11.9	70.49	9.8	9	1.3
PATCH/PATCH DETERIORATION	20.86	2.9	0.11	0.0	18.78	2.6
MAP CRACKING AND SCALING	4.11	0.6	0	0.0	0	0.0
TRANSVERSE CRACKING	101.75	14.1	36	5.0	46.46	6.5
SCALING	11.76	1.6	6.09	0.8	0	0.0
CORNER BREAK	0	0.0	1	0.1	5	0.7
LONGITUDINAL CRACKING	1.2	0.2	2.82	0.4	0	0.0
UTILITY CUT PATCHING	0	0	0.5	0.1	0	0.0

From the above table, it is obviously seen that transverse cracking and spalling of transverse joints are two major defects with the highest density in the rigid pavement under inspection. During the survey and riding through the road several times, it was noticed that lack of maintenance has caused damage to the joint seal and with time the joint has started to spall and widen, which affect riding quality and reduces the traffic in turn.

Table 3: PCI for the Badinan Road

BADINAN ROAD (RIGID PAVEMENT)			
Section number	**Sample unit area (m2)**	**PCI**	**Rating**
1	**720**	**62**	**GOOD**
2	**720**	**25**	**VERY POOR**
3	**720**	**30**	**POOR**
4	**720**	**23**	**VERY POOR**
5	**720**	**38**	**POOR**
6	**720**	**48**	**FAIR**
7	**720**	**46**	**FAIR**
8	**720**	**38**	**POOR**
9	**720**	**60**	**GOOD**
Average		**41.1**	**FAIR**

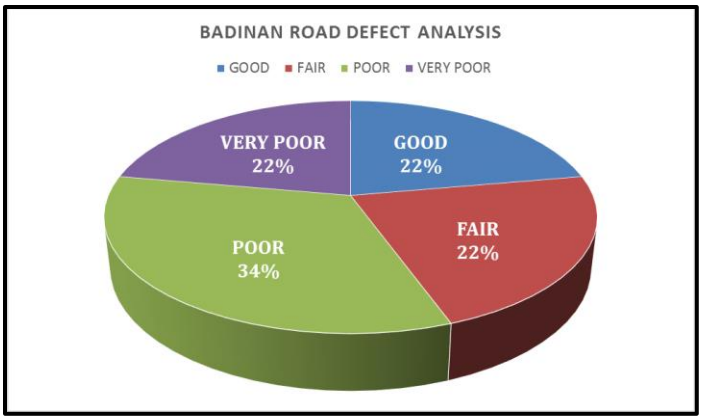

Figure 3: Badinan Road Defect Analysis

From the analysis results for PCI, it was found that 22% of the road was in a very poor condition, 34% was in a poor condition, 22% was in a fair condition, 22% was in a good condition and the average road condition was found to be in a fair condition. Since the exact location of the defects are known, a proper action can be taken and the treatment which required can be applied as explained previously.

4.1.2 Hawari Shar Road (Flexible Pavement)

Is a flexible pavement that extended from the Kobane interchange at the 60-meter Malik Mahmood ring road to the Hawari Shar Roundabout. The branch of road is a 2 way 4 lane road, which is 1620 m in length and 12.45m in width. For PCI determination the road branch was divided into 18 sections, each with the area of 1122.6m^2 and the sections was further divided into 5 sample units each of 224.52 m^2 as recommended by ASTM D6433 (Fig.4-3).

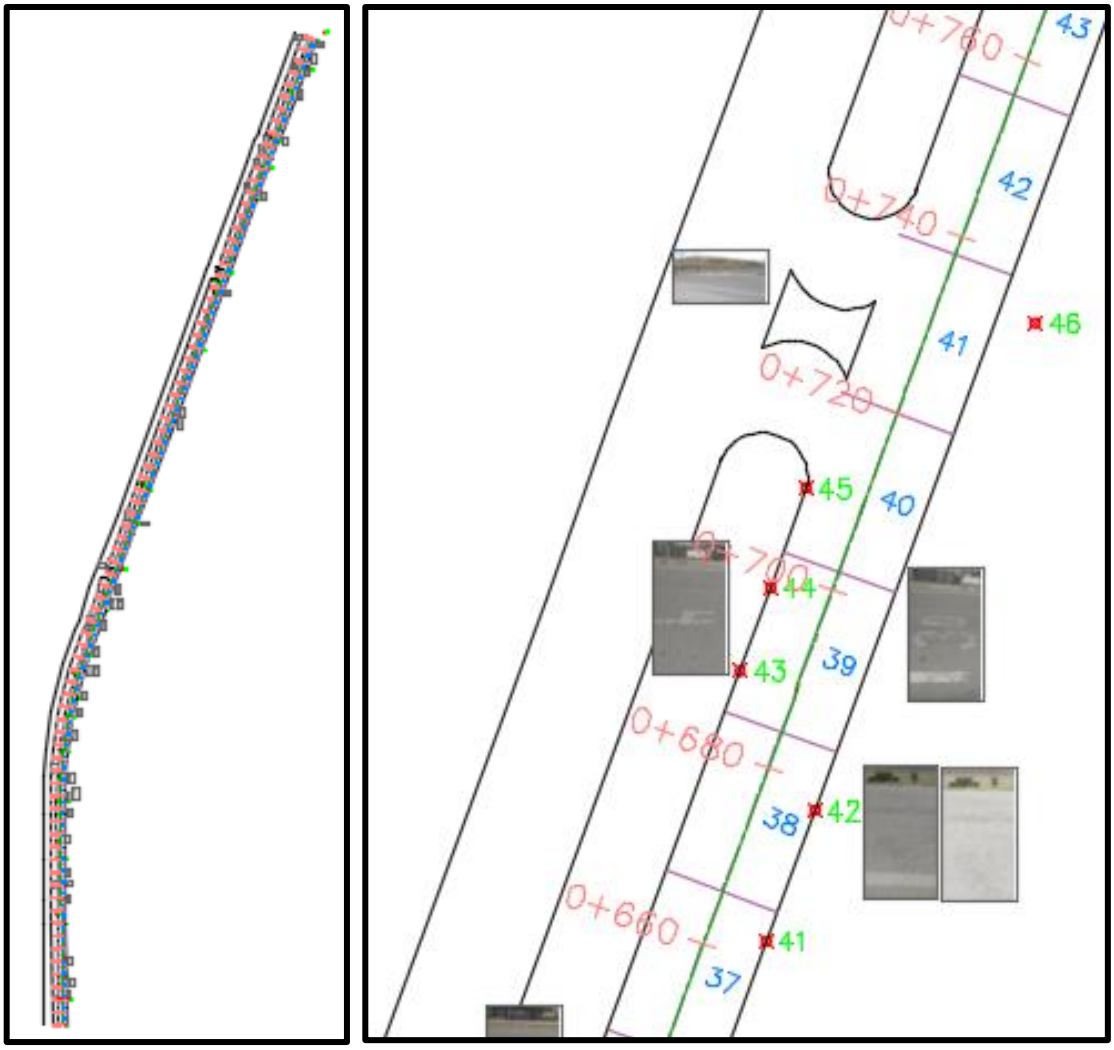

Figure 4: Hawary Shar Road Defect Layout Plan

The complete road branch was taken for calculation of PCI as tabulated below (Table 4) and summary of the analyses shown in Table 6.

Table 4: PCI Calculation Sample for Hawary Shar Road

HAWARI SHAR ROAD (FLEXIBLE PAVEMENT)														
Segm. No.	Type of Defect	Severity Level	Measure	Unit	Branch	Section	Av.Sigment Length (m)	Av.Road Width (m)	Siment Area (m2)	Section Area (m2)	Deduct Value	CDV	PCI	Av. PCI
1	-						18	12.47	224.52		-	-	100	
2	-						18	12.47	224.52		-	-	100	
3	TRANSVERSE CRACKIN	M	12.47	ML		1	18	12.47	224.52	1122.6	13	13	87	97.67
	BLOCK CRACKIN	L	1.35	M2							0	0	100	
4	BLOCK CRACKIN	L	2.5	M2			18	12.47	224.52		1	1	99	
5	-						18	12.47	224.52		-	-	100	
6	BLEEDING	H	3	M2			18	12.47	224.52		7	7	93	
7	-						18	12.47	224.52		-	-	100	
8	-					2	18	12.47	224.52	1122.6	-	-	100	98.6
9	-						18	12.47	224.52		-	-	100	
10	-						18	12.47	224.52		-	-	100	

Table 5: Density of the defects within the Hawary Shar Road

DEFECTS	DENSITY/SEVERITY LEVEL		
	H	M	L
1. ALLIGATOR CRACKING	0.00	3.56	0.45
2. BLEEDING	1.34	0.00	0.00
3. BLOCK CRACKING	18.22	21.20	1.71
10. LONGITUDINAL/TRANSVERSE CRACKING	0.00	34.49	1.38
11. PATCHING & UTILITY CUT	0.00	0.98	0.00
13. POTHOLES	0.00	0.03	0.00
19. WEATHERING & RAVELING	6.06	15.17	1.78

From the above table it is seen that the defect with the highest density within the Hawary Shar road are block cracking, Longitudinal/transverse cracking, and weathering & raveling. Although the road performs well with an excellent Condition Index, but still needs some maintenance to preserve the existing condition and maintain it for a longer time.

Table 5: PCI for the Badinan Road

Section	Area	Av.PCI	Rating
1	1122.6	97.7	**EXCELLENT**
2	1122.6	98.6	**EXCELLENT**
3	1122.6	100	**EXCELLENT**
4	1122.6	92.8	**EXCELLENT**
5	1122.6	90.8	**EXCELLENT**
6	1122.6	99.4	**EXCELLENT**
7	1122.6	98.8	**EXCELLENT**
8	1122.6	95	**EXCELLENT**
9	1122.6	97.4	**EXCELLENT**
10	1122.6	100	**EXCELLENT**
11	1122.6	95.3	**EXCELLENT**
12	1122.6	96.8	**EXCELLENT**
13	1122.6	100	**EXCELLENT**
14	1122.6	92.8	**EXCELLENT**
15	1122.6	100	**EXCELLENT**
16	1122.6	92	**EXCELLENT**
17	1122.6	95.6	**EXCELLENT**
18	1122.6	88.6	**EXCELLENT**

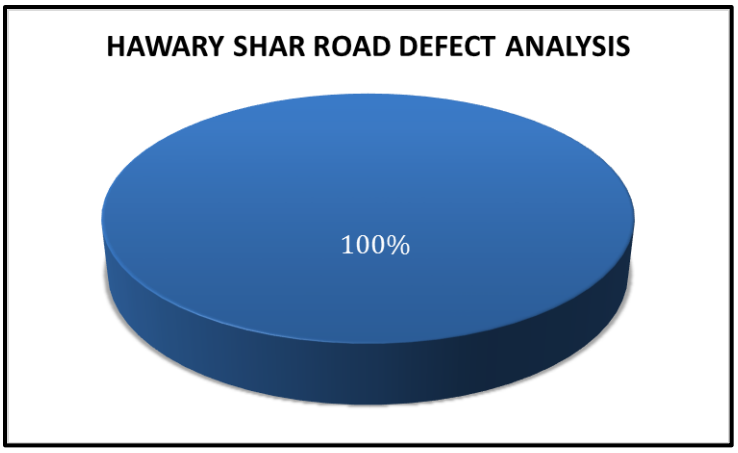

Figure 5: Hawary Shar Road Defect Analysis

From the analysis results for PCI, it was found that 100% of the road was in an excellent condition. This mean the road is in a condition that no major treatment required, but still there are cracks and potholes that they require maintenance like sealing and small patching to prevent them from getting worse and maintaining the condition index of the road for a longer period of time.

5. Suggesting Maintenance Procedure

One of the most important part of pavement evaluation study, is suggesting maintenances for each distress type at different severity levels. Selecting proper maintenance depends on understanding the factors led to the distress in the pavement (David, 2006).

5.1 Rigid pavement

The road selected for the study of PCI for rigid pavement was a 720 m in length Urban Collector Street. The following defects and distresses found within the road:

a- **Durability cracking**: Is progressive deterioration of concrete, which occurs as a result of freeze-thaw damage in large aggregates.

Causes : The major factors which influence the development of "D" cracking, are the availability of moisture (including the quality of base drainage), the occurrence of freeze-thaw cycles, the coarse aggregate composition (sedimentary rocks suck as limestone and dolomite are generally the most susceptible), the pore size distribution of the coarse aggregate, and the maximum aggregate size.

Suggested treatment: Cutting the defected area to a proper depth and removing loose pieces from the pavement to provide sufficient bonding between existing concrete and new concrete with special properties.

b- **Spalling of transverse joints**: Joint spalling and joint deterioration are terms which refer to cracking, chipping, or fraying of concrete slab edges at transvers or longitudinal joints.

Causes: Joint spalling has several possible causes, including excessively early wet sawing of transverse joints, infiltration of incompressible (especially where delamination has occurred due to inadequate curing), high reinforcing steel, alkali-aggregate reaction, "D" cracking, misaligned or corroded load transfer devices, weak concrete in the vicinity of the joint (e.g., honeycombing, caused by poor consolidation), or damage caused by cold milling, grinding, or joint cleaning.

Suggested treatment: Patching the defected area and refilling with a special concrete, providing bonding agent between old and new concrete.

a- **Patch/patch deterioration**: is an area where the original pavement has been removed and replaced by filler material. A utility cut is a patch that has replaced the original pavement to allow the installation or maintenance of underground utilities.

Causes: Improper bonding between old and new concrete or low strength filler material used for the patching purpose or combination of both of them. Pathing sometimes deteriorated due to their level being higher or lower than original road level, which in turn a higher impact wheel load is exerted on them.

Suggested treatment: Mill off and re-lay the patch.

b- **Map cracking and scaling**: Is a network of shallow, fine, or hairline cracks that extend only through the upper surface of the concrete. The cracks tend to intersect at angles of 120°.

Causes: is caused by concrete over-finishing and may lead to surface scaling, which is the breakdown of the slab surface to a depth of approximately 6 to 13 mm (1⁄4 to 1⁄2 in.). Scaling also may be caused by: deicing salts, improper construction, freeze-thaw cycles and poor aggregate.

Suggested treatment: Depending on severity level and quality of riding the surface need to be scraped and refilled with special concrete providing bonding agent.

c- **Cracking (Longitudinal & Transverse)**: Is the predominant structural distress in jointed plain concrete highway pavements. Repeated heavy wheel loads cause fatigue damage in the concrete slab, which eventually results in slab cracking. Since wheel loads at the outer slab edge generally produce the greatest stresses, midway between the transverse joints, transverse cracking most commonly results at mid-slab.

Causes: The number and magnitude of applied loads, the thickness and stiffness of the concrete slab, the stiffness and uniformity provided by the base and foundation, the degree of friction between the slab and base, the degree of load transfer at transverse and longitudinal joints and cracks, the quality of drainage, and climatic influences (daily and seasonal temperature and moisture cycles which influence slab curling, joint and crack opening, and foundation support).

Suggested treatment: Depending on severity level, the crack required to be sealed or cut-patched.

d- **Corner break**: Is a crack that intersects the joints at a distance less than or equal to one-half the slab length on both sides, measured from the corner of the slab.

Causes: Load repetition combined with loss of support and curling stresses usually cause corner breaks.

Suggested treatment: Depending on severity level, the crack required to be cut-patched with strengthening the foundation.

5.2 Flexible pavement

The road selected for the study of PCI for flexible pavement was a 1620 m in length Urban Collector Street. The following defects and distresses found within the road:

a- **Alligator cracking**: Is a series of interconnecting cracks, caused by fatigue failure of the asphalt concrete surface under repeated traffic loading.

Causes: Factors which influence the development of alligator cracking, are the number and magnitude of applied loads, the structural design of the pavement (layer materials and thicknesses), the quality and uniformity of foundation support, the consistency of the asphalt cement, the asphalt content, the air voids and aggregate characteristics of the asphalt concrete mix, and the climate of the site (i.e., the seasonal range and distribution of temperatures).

Suggested treatment: Depending on severity level, Strengthening the pavement or reconstruction, Strengthening the base or reconstruction, Base recycling or reconstruction, Improve the drainage and reconstruct, Replace or treat wearing course.

b- **Bleeding**: Bleeding is a film of bituminous material on the pavement surface that creates a shiny, glasslike, reflecting surface that usually becomes quite sticky.

Causes: Excessive amounts of asphaltic cement or tars in the mix, excess application of a bituminous sealant, or low air void content, or a combination thereof. It occurs when asphalt fills the voids of the mix during hot weather and then expands onto the pavement surface.

Suggested treatment: Applying hot sand to clot up the excess binder to the stone size.

c- **Block cracking**: Block cracks are interconnected cracks that divide the pavement into approximately rectangular pieces.

Causes: Shrinkage of the asphalt concrete and daily temperature cycling, which results in daily stress/strain cycling. It is not load-associated.

Suggested treatment: Depending on the cause of cracking, Seal cracks or replace bituminous surfacing or Cut and patch.

d- **Longitudinal/transverse cracking**: Longitudinal cracks are parallel to the pavement's centerline or laydown direction. Transverse cracks extend across the pavement at approximately right angles to the pavement centerline or direction of laydown. These types of cracks are not usually load-associated.

Causes: A poorly constructed paving lane joint. Shrinkage of the AC surface due to low temperatures or hardening of the asphalt, or daily temperature cycling, or both.

Suggested treatment: Treatment these cracks depend on the severity and intensity. In the case of low severity do not do something in the medium severity resort to fill the cracks. In the case of high severity use overlays surface, or implementing to thin overlay.

e- **Patching & utility cut**: Is an area of pavement that has been replaced with new material to repair the existing pavement. A patch is considered a defect no matter how well it is performing (a patched area or adjacent area usually does not perform as well as an original pavement section). Generally, some roughness is associated with this distress.

Causes: Repair of the defected area of the existing pavement.

Suggested treatment: There is no specific treatment for this defect, since; it is a repair type itself, but it is possible to remove the patch and reconstruct it.

a- **Potholes**: Are small—usually less than 750 mm (30 in.) in diameter—bowl-shaped depressions in the pavement surface. They generally have sharp edges and vertical sides near the top of the hole. When holes are created by high-severity alligator cracking, they should be identified as potholes, not as weathering.

Causes: Alligator cracking begin to be sever as water penetrate through them to the underlying layers and pieces of asphalt are thrown away by vehicle wheel movement over the cracks.

Suggested treatment: Based on severity level, it can be patched only or cut patched.

b- **Weathering & raveling**: Weathering and raveling are the wearing away of the pavement surface due to a loss of asphalt or tar binder and dislodged aggregate particles. These distresses indicate that, either the asphalt binder has hardened appreciably or that a poor-quality mixture is present. In addition, raveling may be caused by certain types of traffic, for example, tracked vehicles. Softening of the surface and dislodging of the aggregates due to oil spillage also are included under raveling.

Causes: Raveling and weathering occur as a result of loss of bond between aggregates and the asphalt binder. This may occur due to hardening of the asphalt cement, dust on the aggregate which interferes with asphalt adhesion, localized areas of segregation in the asphalt concrete mix where fine aggregate particles are lacking, or low in-place density of the mix due to inadequate compaction. High air void contents are associated with more rapid aging and increased likelihood of raveling.

Suggested treatment: Thin bituminous overlay.

6. Conclusions & Recommendations

From the evaluation of PCI for both flexible and rigid pavement of the study areas, the following conclusion can be drawn:

1- PCI gives a good image about the road condition, and this study has to be done annually for the road networks and the data has to be collected in a database format with the aid of

GIS and advanced road scanner for continuous monitoring and maintenance decisions which permits early identification of major rehabilitation needs.

2- From PCI calculation it was found that Hawary Shar road (flexible pavement) doesn't need serious maintenance and repairs while Badinan Road (rigid Pavement) requires maintenances especially transvers joints which they had significant effect on the condition indices of the road sections.

3- It is recommended to achieve PCI survey with the aid of road scanner or a larger number of trained surveyor to better detection of the defects and their severity levels since the traffic movement cannot be blocked at the sections under inspection which is the major source of errors.

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