

Proposal for Evaluation Management of Concrete Block Pavement (Interlock Pavement) with new Pavement Condition Index

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Abstract

There are several procedures for evaluating flexible (asphalt) and rigid (concrete) pavements. The most world wide known procedures are: Pavement Condition Index (PCI), Pavement Condition Rating (PCR), the Aashto Present Serviceability Index (PSI) and the German Guidelines for Pavement Maintenance Planning (*RPE – Stra 01*). Until now there has been no single procedure for evaluating concrete block pavements (Interlock Pavements). This research shows for the first time how to evaluate these pavements using new pavement condition index, which depends on determining distress types and own deduct value curves. Then, the research provides important conclusions and recommendations for those concerned with concrete block pavements and enable them to take immediate decisions regarding necessity of maintenance measurements.

Keywords

Pavement condition index, Deduct curves, Concrete block pavement distress, Pavement evaluation

1. Introduction

Evaluation of airport and road pavements is nowadays one of the important operations of pavement management systems (PMS). There are several procedures for evaluating flexible (asphalt) and rigid (concrete) pavements. The most world wide known procedure is the Pavement Condition Index (PCI) for road and parking lots which was developed by the US Army Corps of Engineers. It is described in the Annual Book of ASTM Standards (ASTM, 2003). The PCI is defined as a numerical indicator that rates the surface condition of the pavement, where the numerical rating ranges from 0 to 100 with 0 being the worst possible condition and 100 being the best possible condition. The PCI provides a measure of the present condition of the pavement based on the distress observed on the surface of the pavement, which indicates the structural integrity and surface operational condition. It also 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 performance for deterioration, which permits early identification of a major rehabilitation needs. The PCI provides feedback on pavement performance for validation or improvement of current design and maintenance procedures.

As mentioned above, the PCI and other world wide used procedures as: Pavement Condition Rating (PCR) (Pavement Surface Rating Manual, 1992), AASHTO Present Serviceability Index (PSI) (AASHTO Guide, 1993) and the German Guidelines for Pavement Maintenance Planning (Richtlinien fuer die Planung von Erhaltungsmassnahmen an Strassenbefestigungen RPE – Stra 01 2001) are used only to evaluate asphalt and concrete pavement conditions. Until now there has been no single procedure for evaluating concrete block pavements (Interlock Pavements). Based on the PCI procedure, this research

shows an attempt to develop the PCI procedure in order to be used for the evaluation of concrete block pavement condition. The developed procedure will have the abbreviation BPCI. Concerning this, the main steps that must be taken for calculating the PCI (ASTM, 2003) and BPCI as well as their definitions are similar. Accordingly, the BPCI is also considered as a numerical indicator that rates the surface condition of the concrete block pavement, where the numerical rating ranges from 0 to 100 with 0 being the worst possible condition and 100 being the best possible condition. The concrete block pavement must be divided into branches that are divided into sections. Each section is divided into sample units. The type and severity of pavement distress are assessed by visual inspection of the pavement sample units. The quantity of distress has to be measured as described in Sections 3, 4 and 5. The distress data are used to calculate the BPCI for each sample units. The BPCI of the pavement section is determined based on BPCI of the inspected sample units within the section. Furthermore, special deduct curves for concrete block pavement must be created. These curves illustrate the effect of type, density and severity of distress on the pavement (see Section 6, 7, 8 and 9).

2. Methodology

In order to fulfill the purpose of this research, the following methodology has been followed:

1. Describing distress type.
2. Determining distress severity.
3. Describing distress measurement methods.
4. Determining sample unit area.
5. Calculating number of representative sample units.
6. Creating deduct value curves.
7. Creating corrected deduct value curves.

3. Distress Types of Concrete Block Pavement

According to field surveys conducted by the authors on several concrete block pavements in the Gaza Strip, there are 10 distress types which mostly occur in the concrete block pavement during its service life. They are described in the sections 3.1 – 3.10 (see Table 1).

3.1 Sand Free Joints

It is the situation when the sand in joints between the concrete blocks (pavers) gets out. The sand creates friction between the blocks which does not allow the blocks to move. The possible reasons for sand getting out are.

- Sweeping the pavement by cleaning equipment.
- Washing away of sand by storm water during raining.
- The maximum grain size of sand is too small relative to joint width.

3.2 Different Joint Width Between Blocks

It is the situation when the joint width between pavement blocks in both short and long directions gets larger. During field inspection it is observed that often joint width in the middle of pavement gets larger than that at the edges. Some of the possible reasons of this type are :

- Lack of accuracy during paving process.
- Change of vehicle speed during sudden braking process which may cause different shear (horizontal) forces.

3.3 Faulting

Faulting is the difference in elevation of block edges across joints. Some of common causes of faulting are as follows:

- Inhomogeneous material and thickness of sand bedding.
- Inhomogeneous compaction of lower layers.
- Pumping of material from under the blocks.

3.4 Depression

Depressions are localized pavement surface areas with elevations slightly lower than those of the surrounding pavement. They are caused by:

- Settlement of subgrade.
- Settlement of lower layer because of inhomogeneous compaction

3.5 Removed Blocks

It is the situation when the pavement blocks are removed while the lower layer stay. Some of the possible reasons are :

- Crushing and breaking of the blocks.
- Loss of pavement edge support or protector.

3.6 Infrastructure Digging

It is the situation when the pavement blocks and part of lower layer are removed. This type of distress can be mostly caused by:

- Improper repaving after maintenance measures of infrastructure networks.

3.7 Patching

A patch is an area of pavement that has been replaced with new or original blocks to repair the existing pavement. Patching occurs mostly by repaving the area after conducting maintenance process of infrastructure projects. A patch area usually does not perform as an original pavement section. Some of possible reasons are:

- Improper materials like using a rectangular blocks in a hexaside block pavement.
- Improper repaving process.

Note: If a single patch area is larger than 40% of the total sample area, it cannot be considered as a defect or distress.

3.8 Edge Failure

This is a common defect which happens when a concrete block pavement intersect with another pavement type like asphalt, concrete or another concrete block pavement. In edge areas, depressions, removed blocks, joints between blocks and other distresses can be found. Some of possible reasons are:

- Improper construction.
- Change of vehicle speed during sudden braking process which may cause different shear (horizontal) forces.
- Loss of bound mortar between the two pavements.

3.9 Surface Erosion

It is the situation when the surface of the concrete blocks erodes and block aggregates appear. This will decrease the traffic process quality. This type of distress can be mostly caused by:

- High traffic volume.
- Change of vehicle speeds.
- Improper concrete blocks material.

3.10 Block Failure

Cracking and edge or corner break of concrete blocks are considered as block failures. This can be created by:

- Passing of unallowable heavy vehicles.
- Improper concrete blocks material.
- Insufficient and /or inhomogeneous compaction of lower layers.

4. Distress Severity

The definition of severity for a given defect varies with each distress and is generally a measure of how badly or to what intensity a given defect has deteriorated. There are several possible severities for each distress. In this research, three severity levels (high **H**, medium **M** and low **L**) are chosen according to ASTM (as applied for asphalt and rigid pavement). These are described and illustrated for concrete block pavement in Table 1.

5. Distress Measurement

The procedure of distress measurement can be summarized in the following steps. First, the pavement section to be inspected must be divided in smaller sample units with defined areas (see Section 6). Then each distress in the sample unit has to be surveyed, measured and recorded separately according to its severity. For the following distress types: sand free joints, different joint width between blocks, faulting, depression, removed blocks, infrastructure digging, patching, surface erosion, and block failure has the defect area in the sample unit to be measured. For the distress type edge failure has the defect length to be measured (see Table 1). Finally, the percent density of each distress can be calculated as follows:

$$\text{distress density} = \frac{\text{distress area or length}}{\text{sample unit area}} \times 100\%$$

6. Sample Unit Area

The BPCI procedure for calculating the sample unit area depends on statistical bases. Conducted field inspections of concrete block pavement sections with sample units with length between 6 m and 10 m have shown that the inventory of distresses in these sample units is easier and faster than in sample units with smaller or larger lengths. Accordingly, it has been decided in this research to consider the length 6 – 10 m (average = 8 m) as acceptable length. The width of the sample unit is determined by calculating the average of concrete block pavement widths of all roads in the Khan Younis City in cooperation with the municipality (Project and Urban Planning Department 2007). Depending on the following equations the sample width and standard deviation are calculated as follows:

$$W_{avg} = \frac{\sum W}{n} = 9.75 \text{ m}$$

Table 1: Type, Severity Level and Measurement of Distresses in Concrete Block Pavement

NO.	Distress Type	Severity Level			Measurement
		Low	Medium	High	
1	Sand free joints	No severity levels			Area (m ²)
2	Different joint width between blocks	3.5 – 8 mm	8 – 15 mm	15 – 30 mm	Area (m ²)
3	Faulting	<10 mm	10 – 25 mm	25 – 50 mm	Area (m ²)
4	Depression	Equivalent Diameter (m)			Area (m ²)
	Depth (mm)	< 0.5	0.5 – 1.5	> 1.5	
	< 30	Low	Low	Medium	
	30 - 70	Low	Medium	Medium	
	> 70	Medium	High	High	
5	Removed blocks	Joint width 30 - 80 mm	Joint width >80 mm or faulting > a half of block height	Removed the whole block	Area (m ²)
6	Infrastructure digging	Depth = 0	Depth < 0.7 of a block height	Depth > 0.7 of a block height	Area (m ²)
7	Patching	Improper repaving	Any low or medium severity distress exists in the patch	Any high severity distress exists in the patch	Area (m ²)
8	Edge failure	Improper repaving	Any low or medium severity distress exists in the edge area	Any high severity distress exists in the edge area	Length (m)
9	Surface erosion	< 5 mm	5 - 10 mm	> 10 mm	Area (m ²)
10	Block failure	Cracks	Break	Full damaged	Area (m ²)

$$W_{avg} = \frac{\sum W}{n}$$

$$\sigma^2 = \frac{\sum (W - W_{avg})^2}{n} = 12.02 \text{ m}^2$$

$$\sigma = \sqrt{\sigma^2} = 3.47 \approx 3.5 \text{ m}$$

Where: W = Road width, n = Sample size, σ = standard deviation.

As a result of the previous statistical process, the sample width is equal 9.75 ± 3.5 m. Multiplying the average width (9.75 ± 3.5 m) by the average length (8 m) the sample unit area is equal $(80 \pm 30 \text{ m}^2)$.

7. Number of Representative Sample Units

According to ASTM the number of sample units to be inspected may vary from:

- all number of the sample units in the section or
- a number of sample units that provide a 95 % confidence level.

All sample units of the section may be inspected to determine the BPCI of the section. This is usually precluded for routine management purposes by available manpower, funds and time. Total sampling, however, is desirable for project analysis to help estimate maintenance and repair quantities.

The minimum number of sample units (n) that must be surveyed within a given section to obtain a statistically adequate estimate (95 % confidence) of the BPCI of the section is calculated using the following equation and rounding n to the next highest whole number.

$$n = \frac{N \times \delta^2}{\frac{e^2}{4} \times (N - 1) + \delta^2}$$

Where:

- n = number of sample units that must be surveyed (rounding to the next highest whole number).
- N = total number of the sample units in the section.
- e = acceptable error in estimating the section BPCI, commonly 5%.
- δ = standard deviation of the BPCI from the sample unit to another within the section. Use initial value of 15 and then check the assumption as follows:

$$\delta^2 = \sqrt{\frac{(BPCI_i - BPCI_s)^2}{n - 1}}$$

Where:

- $BPCI_i$ = BPCI of surveyed units.
- $BPCI_s$ = BPCI of section (mean BPCI of surveyed sample units).
- n = total number of sample units surveyed.

8. Deduct Value Curves

As mentioned above, the pavement condition index of concrete block pavement BPCI is defined as a numerical indicator that rates the surface condition of the concrete block pavement, where the numerical rating ranges from 0 to 100 with 0 being the worst possible condition and 100 being the best possible condition. This means: a pavement usually begins its service life in excellent condition (BPCI = 100). As traffic is applied to the pavement and with climate interaction with the pavement the BPCI will continue to drop to particular level. The BPCI at this level is equal (100 – deduct value). Deduct values can be found from deduct value curves which have to be created for each distress density and if possible for three severity levels (L, M, H). It is worth mentioning that the deduct value curves illustrate the effect of type, density and severity of distress on the pavement. In this research, the following methodology has been followed to create deduct value curves for concrete block pavement:

1. determine the severity of each distress existing in the concrete block pavement separately.

2. calculate the density of each distress using a sample unit area with the allowable range ($80 \pm 30 \text{ m}^2$).
3. estimate by visual inspection the deduct value (DV) caused only by the inspected distress (ignore all other distresses in the sample). Table 2 gives an example for visual estimation of the distress surface erosion.
4. plot the relationship between the density (X-axis) and deduct value (Y-axis). Figures (A1- A10) in the Appendix illustrate the deduct value curves of all described distresses.

Table 2: An Example for Visual Estimation of Density and Deduct Values (DV) for Several Severities of the Distress "Surface Erosion"

Low severity	Density	7	44	31	17	70	5	100
	DV	0.3	3.0	2.0	0.8	7.0	0.2	10.0
Medium severity	Density	37	23	27	44	3	9	100
	DV	6.0	3.5	4.0	7.0	0.5	1.5	20.0
High severity	Density	17	31	13	5	27	40	100
	DV	4.5	9.0	3.0	1.0	7.5	12.0	30.0

9. Corrected Deduct Value Curves (CDV)

In order to find the effect of many distresses existing as a group in the concrete block pavement on the current BPCI, the summation of their deduct values (total deduct value, TDV) has to be corrected. For this reason, corrected deduct value curves have to be created. In this research, the following methodology has been followed to create corrected deduct value curves for concrete block pavement:

1. estimate by visual inspection the BPCI for each sample unit.
2. calculate the corrected deduct value ($CDV = 100 - BPCI$).
3. calculate the density for each distress type existing in the sample unit.
4. using the deduct value curves, determine the deduct value DV for each distress type existing in the sample unit.
5. compute the total deduct value ($TDV = \sum DV$) for the inspected sample unit in consideration of number of surveyed distresses q (see Table 3).
6. create a diagram showing a relationship between TDV (X-axis) and CDV (Y-axis) for each q (see Figure 1).

Table 3: Total Deduct Values (TDV) and Corrected Deduct Values (CDV) for Different Number of Distresses (q)

Distress number $q = 2$	TDV	28	40	15	60
	CDV	25	35	13.5	50
Distress number $q = 3$	TDV	30	25	45	70
	CDV	23	19	33	49
Distress number $q = 4$	TDV	35	48	70	81
	CDV	22	30	43	49

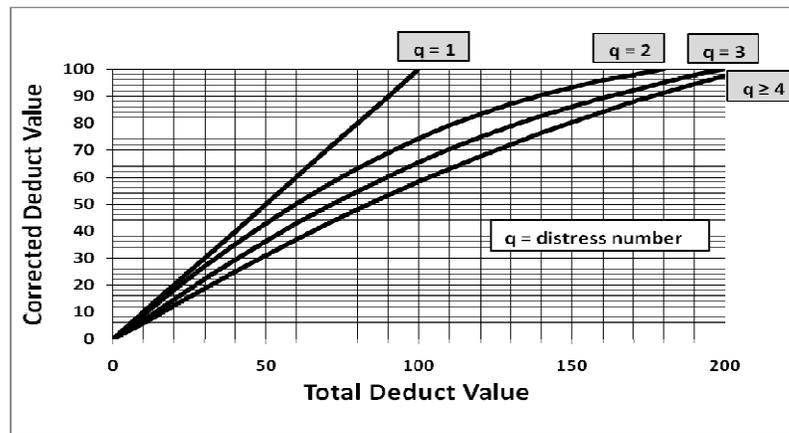


Figure 1: Corrected Deduct Value Curves

10. Pavement Condition Rating

It is essential for general evaluation and maintenance goals to express the condition index from (BPCI = 0) to (BPCI = 100) which a pavement faces in its service life in stages or rating. In this research, the pavement condition rating according to ASTM has been adopted for the concrete block pavement. It is a description of pavement condition as a function of the BPCI value that varies from failed to excellent as shown in Figure 2.

BPCI	100	85	70	55	40	25	10	0
Rating	Excellent	V. Good	Good	Fair	Poor	V. Poor	Failed	

Figure 2: Concrete Block Pavement Condition Index BPCI and Rating Chart

11. Example for Concrete Block Pavement Evaluation

Each chosen sample unit should be individually inspected. The actual inspection is performed by walking over each sample unit being surveyed and recording distress existing in the sample on the concrete block pavement survey data sheet. Table 4 shows an example for evaluating a sample unit of concrete block pavement.

Table 4: An Example for Evaluating a Sample Unit of Concrete Block Pavement

Distress type	Density	Severity	DV	TDV	q	CDV figure 1	BPCI
Faulting	40	H	20	100	3	65	100 – 65 = 35
Depression	20	M	20				
Patching	30	H	60				
Rating	Pavement is poor						

12. Conclusions and Recommendations

The pavement condition index of concrete block pavement (BPCI), like flexible and rigid pavements, is a numerical rating which indicates the type, the severity and the density of the inspected distress. It provides a common index for comparing the condition and performance of pavements at all their life stages. It can also provide an advice for appropriate maintenance procedures and costs. For this reason, a concrete block pavement condition manual should be established or developed. The development of this manual can be only realized in cooperation among several institutions which have to enlarge the research field to include the following:

1. studying several road networks of concrete block pavement in other regions in consideration of environment and traffic conditions.
2. inspecting and recording all distresses which are, for sure, more than the (10) distresses observed in this research.
3. developing and improving the deduct value and corrected deduct value curves.

13. Acknowledgements

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14. References

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Appendix

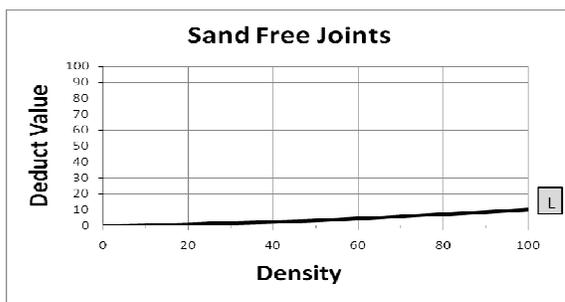


Figure A1: Sand Free Joints

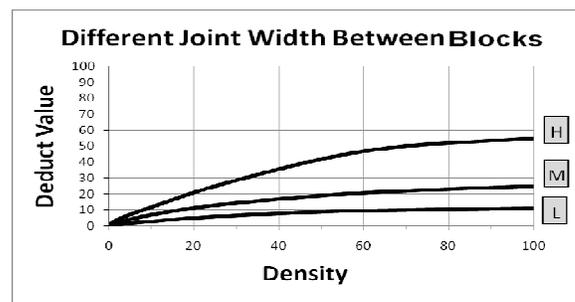


Figure A2: Different Joints Width Between Blocks

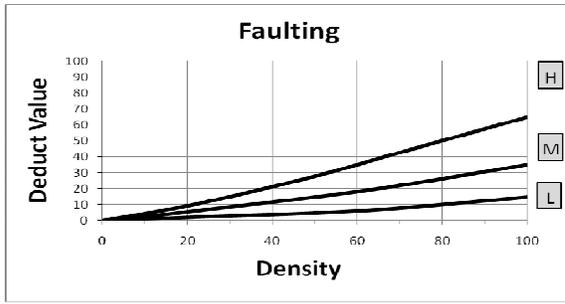


Figure A3: Faulting

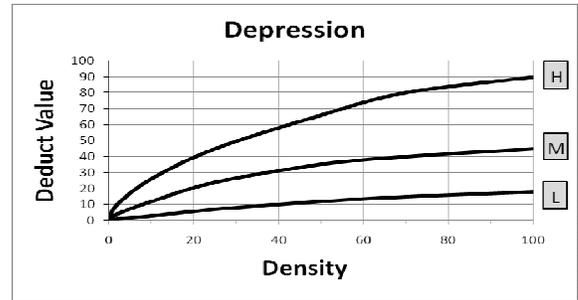


Figure A4: Depression

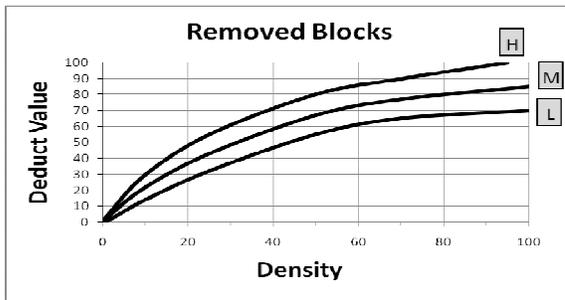


Figure A5: Removed Blocks

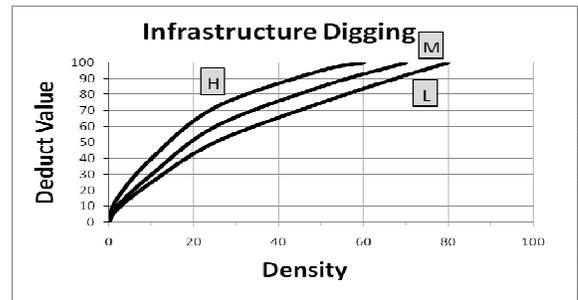


Figure A6: Infrastructure Digging

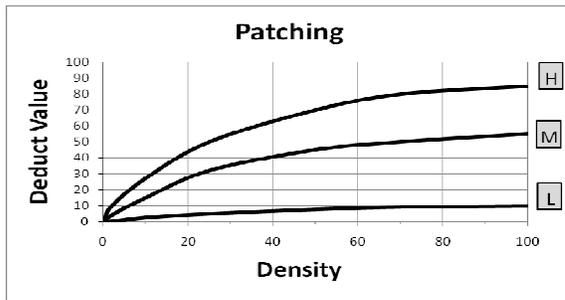


Figure A7: Patching

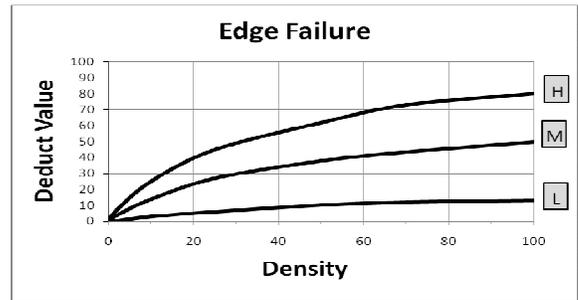


Figure A8: Edge Failure

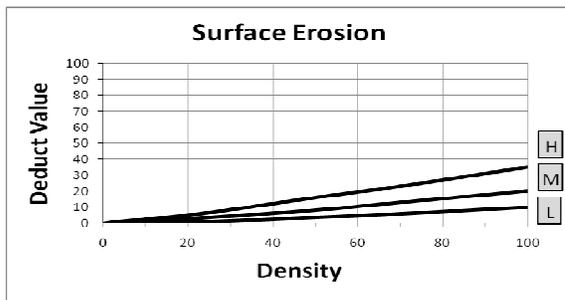


Figure A9: Surface Erosion

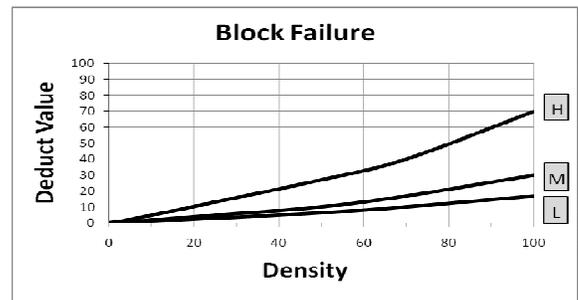


Figure A10: Block Failure