Tiago David da Costa Prudente Pereira

Degree in Civil Engineering

Rigid Pavements Distresses - Pavement Condition Index Evaluation

Dissertação para obtenção do Grau de Mestre em Engenharia Civil
(Perfil de Estruturas e Geotecnia)

Orientador: Doutora Simona Fontul, Professora Auxiliar convidada

Júri:

Presidente: Dr. Rui Micaelo
Arguente: Eng. Luís Quaresma
Vogal: Dr.ª Simona Fontul

FACULDADE DE CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE NOVA DE LISBOA

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Acknowledgements

The completion of this dissertation would not have been possible without the contribution of several people, but especially my parents.

Firstly I want to thank them for always taught me and gave the best they could and it is to them I owe who I am today. Thank you!

Then I want to thank my advisor Prof. Dr. Simona Fontul throughout her availability, attention, guidance, wisdom and advice, help and willingness. All these factors played an important role in the course of this dissertation.

To all my family and friends for support and motivation, and especially Rúben Pereira for all the help and teaching in JAVA and Rui Coelho for the help in Microsoft Excel, respectively.

Finally, the Department of Civil Engineering, Faculty of Sciences and Technology, and their respective teachers.

(…)

Abstract

Pavements require maintenance in order to provide good service levels during their life period. Because of the significant costs of this operation and the importance of a proper planning, a pavement evaluation methodology, named Pavement Condition Index (PCI), was created by the U.S. Army Corps of Engineers. This methodology allows for the evaluation of the pavement condition along the life period, generally yearly, with minimum costs and, in this way, it is possible to plan the maintenance action and to adopt adequate measures, minimising the rehabilitation costs.

The PCI methodology provides an evaluation based on visual inspection, namely on the distresses observed on the pavement. This condition index of the pavement is classified from 0 to 100, where 0 it is the worst possible condition and 100 the best possible condition.

This methodology of pavement assessment represents a significant tool for management methods such as airport pavement management system (APMS) and life-cycle costs analysis (LCCA). Nevertheless, it has some limitations which can jeopardize the correct evaluation of the pavement behavior.

Therefore the objective of this dissertation is to help reducing its limitations and make it easier and faster to use. Thus, an automated process of PCI calculation was developed, avoiding the abaci consultation, and consequently, minimizing the human error. To facilitate also the visual inspection a Tablet application was developed to replace the common inspection data sheet and thus making the survey easier to be undertaken. Following, an airport pavement condition was study accordingly with the methodology described at Standard Test Method for Airport Pavement Condition Index Surveys D5340, 2011 where its original condition level is compared with the condition level after iterate possible erroneous considered distresses as well as possible rehabilitations. Afterwards, the results obtained were analyzed and the main conclusions presented together with some future developments.

Keywords: Rigid pavements distresses, pavement condition index, structural condition index, alkali-silica reaction.

Resumo

Os pavimentos necessitam de manutenção, a fim de proporcionar bons níveis de serviço durante o seu ciclo de vida. Devido aos custos elevados da operação e da importância de um bom planeamento da manutenção, foi criada pelos U.S. Army Corps of Engineers uma metodologia de avaliação de pavimentos, denominada Índice de Condição do Pavimento (PCI). Esta metodologia permite a avaliação da condição do pavimento ao longo do período de vida, em geral anualmente com custos mínimos e, desta forma, é possível planear a ação de manutenção e de adotar as medidas adequadas, minimizando os custos de reabilitação.

A metodologia (PCI) prevê a avaliação da atual condição do pavimento com base na inspeção visual, nomeadamente, das anomalias observadas no pavimento. Este índice de condição do pavimento é classificado de 0 a 100, onde 0 é a pior condição possível e 100 a melhor condição possível.

Esta metodologia de avaliação de pavimento representa uma ferramenta importante para os métodos de gestão, tais como Gestão de Pavimentos Aeroportuários (Airpor Pavement Management System - APMS) e a Analise de Custo do Ciclo de Vida (Life-Cycle Cost Analysis). No entanto, tem algumas limitações que podem comprometer a correta avaliação da condição do pavimento.

Portanto, o objetivo deste trabalho é de contribuir para a redução das suas limitações e torná-lo mais fácil e rápido de usar. Assim, foi desenvolvido um processo automatizado de cálculo do PCI evitando a consulta ábacos, e assim, minimizando o erro humano. Para facilitar também a inspeção visual foi desenvolvida uma aplicação para Tablet com a finalidade de substituir a folha de inspeção comum, em papel, e, consequentemente tornar a inspeção mais fácil de executar. Seguidamente, foi estudada a condição de um pavimento aeroportuário de acordo com a metodologia descrita no Método de Teste Padrão para Índice de Condição de Pavimentos Aeroportuários D5340, 2011, onde seu nível condição original é comparado com o nível de condição após algumas alterações terem sido efetuadas, como a troca de anomalias e possíveis reabilitações. Depois de uma análise aos resultados dos procedimentos foi realizada seguindo-se então conclusões e desenvolvimentos futuros.

Palavras-chave: Anomalias de pavimentos rígidos, índice de condição do pavimento, índice de condição estrutural, reação alcalis-sílica.

Resumo Alargado

Com o progresso da tecnologia, passou a ser relativamente fácil a deslocação de pessoas e de bens, para diversos pontos do mundo, num espaço de tempo reduzido. Um dos principais responsáveis por este avanço, no que respeita à mobilidade, é o transporte aéreo e a sua evolução ao longo dos anos. Para este tipo de transporte é estritamente necessário garantir a máxima segurança e qualidade dos pavimentos aeroportuários, pois de um único acidente poderão resultar centenas de vítimas. Contudo, ainda que menos eficiente, o transporte rodoviário é muitas vezes o mais económico e em diversos casos sendo mesmo o único meio de transporte possível, tem uma quota significativa no mercado de transportes, seja ele de passageiros ou de mercadorias. Sendo assim, para garantir o conforto e o correto funcionamento dos transportes terrestres, o bom estado do pavimento é essencial.

Visto que a qualidade dos pavimentos é um importante fator para a segurança, este trabalho visa o conhecimento das metodologias para a sua avaliação estrutural e funcional de acordo com a norma da ASTM – D5340, 2011 para aeroportos e pela norma ASTM – D6433, 2011 para estradas. Os pavimentos considerados no âmbito deste estudo foram os pavimentos rígidos.

Os pavimentos rígidos simples são constituídos por lajes de betão de cimento Portland apoiadas numa serie de subcamadas e na fundação, respetivamente. Estes possuem juntas transversais e longitudinais nas quais a transmissão de cargas se realiza, ou por interpenetração do agregado ao nível dos seus bordos, ou através de varões de transmissão de carga. A função das juntas nos pavimentos é a de reduzir a fissuração no betão devida tanto à retração como às tensões induzidas pelas variações da temperatura. A camada abaixo da laje em betão é mais flexível e é geralmente constituída por uma camada granular tratada com cimento ou um betão pobre, que por sua vez assenta numa camada compactada de material granular ou solos.

Os pavimentos rígidos em comparação aos restantes tipos (flexíveis e semi-rígidos) têm maior longevidade, no entanto, como todas as outras construções, requerem manutenção de forma a garantir bons níveis de qualidade, conforto e segurança. Contudo, estas manutenções têm custo inerentes e devem ser cuidadosamente avaliadas. Assim, pretende-se por um lado evitar intervenções desnecessárias e por outro impedir que os danos se tornem irreparáveis e economicamente prejudiciais, com repercussões na segurança dos utilizadores.

Desta forma, e para evitar custos ou danos irreversíveis foi criado pelo U.S. Army Corps of Engineers o método de avaliação dos pavimentos intitulado Pavement Condition Index (PCI), ou o índice de condição do pavimento em português.

O PCI é um indicador numérico do estado da superfície do pavimento, tendo valores entre 0 e 100, que correspondem aos estados de ruína e de condição excelente, respetivamente. Esta metodologia visa classificar um pavimento através da inspeção visual e do registo das suas anomalias, traduzindo-se na determinação de um valor resultante do somatório de vários coeficientes. Os coeficientes são avaliados em função do tipo de anomalia, da quantidade e do grau de gravidade da mesma. A observação das anomalias é efetuada manualmente por inspeção visual.

O PCI constitui um instrumento essencial para a gestão de pavimentos aeroportuários e rodoviários, pois, através da constituição de uma base de dados, é possível criar um método de gestão capaz de avaliar e planear, projetos para a manutenção dos mesmos. No entanto, ainda se trata de uma avaliação subjetiva devido a consulta de ábacos e por não avaliar estruturalmente o pavimento. Um outro fator de subjetividade é dado pela dificuldade em distinguir entre algumas anomalias durante a inspeção visual.

As anomalias que são registadas pela inspeção visual são descritas pelas normas ASTM D5340 e D6433 para aeroportos e estradas respetivamente, onde são explicados os diferentes níveis de severidade assim como, como registar os mesmos durante uma inspeção visual para o cálculo do PCI. A inspeção visual é um procedimento feito a andar com o auxílio de uma folha em papel para registo dos dados. Nesta folha é registado o ramo, a secção, a unidade de amostra e a sua área assim como a data e nome do inspetor, mas essencialmente, o tipo de anomalia e o seu grau de severidade de acordo com as normas anteriormente referidas, para cada laje da unidade de amostra. Com a relação entre o número de lajes afetadas pela anomalia e o número de lajes da unidade de amostra é calculado a densidade da anomalia em percentagem.

Tendo em conta a densidade e o grau de severidade da anomalia, retira-se do ábaco da respetiva anomalia o coeficiente "deduct value" (DV), valor deduzido em português. Com este valor, e seguindo os procedimentos da norma, calcula-se então o índice de estado do pavimento PCI.

O processo de cálculo do PCI é bastante demorado e depende da precisão humana na consulta de abacos. Assim, este processo está sujeito ao erro humano e consequentemente, a avaliação do estado do pavimento é subjetiva, assim como a avaliação do valor global do PCI. Quando utilizado num Sistema de Gestão de Pavimentos Aeroportuários, Airport Pavement Management System (APMS), uma avaliação errada do PCI poderá ter consequências na classificação do aeroporto e na adoção de medidas de manutenção.

Com esta dissertação pretende-se contribuir para reduzir a subjetividade que provem em parte da consulta de abacos para o cálculo do PCI e automatizar o cálculo da condição estrutural do pavimento.

Assim, desenvolveu-se a automatização do cálculo do PCI/SCI (Pavament Condition Index/Structure Pavement Index). O processo começou com a recolha de todos os valores dos ábacos, valores esses retirados por uma interpolação polinomial dos abacos fornecidos pela norma da ASTM D5340 e disponíveis no website da Administração Federal de Aviação (FAA) dos Estados Unidos da América. Como estes valores automatizou-se o processo tornando o cálculo do PCI menos subjetivo, mais rápido e fácil, posteriormente a automatização do PCI introduziu-se o cálculo da condição estrutural (Structural Condition Index – SCI) que por sua vez depende dos coeficientes (DV e CDV) também utilizados para o cálculo do PCI.

No decorrer do processo de automatização, desenvolveu-se também uma aplicação para tablet com o intuito de substituir a folha de registo de dados em papel, utilizada durante a inspeção visual. Como qualquer folha de papel, esta pode perder-se, sujar-se, rasgar-se, etc. Sendo assim, o uso da aplicação no Tablet, para além de automatizar o cálculo do PCI, torna uma vez mais, o processo de inspeção visual significativamente mais fácil, reduzindo também o tempo necessário em gabinete para introdução de dados no computador.

Com base na automatização do PCI/SCI, foi mais fácil estudar a influência da anomalia conhecida como Reação Alcalis-Sílica (RAS) na avaliação de pavimentos aeroportuários rígidos. A reação alcalis-sílica é causada por uma reação química entre alcalinos provenientes do próprio cimento Portland (ou de descongelastes químicos em certos casos) e uns minerais de sílica reativos, dando origem à formação de um gel. Este gel absorve água, retirando resistência ao betão assim como fazendo que ele expanda devido ao volume do gel, danificando assim o pavimento. Os seus sintomas mais vulgares entre outros são: fendilhamento do betão, habitualmente num padrão em mapa/rede; desnivelamento da laje, desagregação de pequenos pedaços da superfície do pavimento e extrusão do selante das juntas. Ora, estes sintomas podem ser facilmente confundidos com os sintomas de outras anomalias como as fendas de retração betão ou fendilhamento generalizado (escamas) e não existe ainda uma forma de avaliação sem o uso de carotes para teste em laboratório.

Então, para verificar e analisar o peso da consideração do RAS no cálculo do PCI/SCI, foram feitas iterações entre o RAS e potenciais anomalias que podem ser confundidas devido a semelhança dos sintomas.

Foram também simulados alguns dos processos mais comuns de reabilitação de pavimentos sendo analisando o efeito dos mesmos na avaliação PCI/SCI do pavimento aeroportuário.

Numa primeira análise, foi comparado o índice de condição do estado original do pavimento com as anomalias recolhidas durante a inspeção visual e o índice de condição do pavimento depois de se substituir o RAS pelas potenciais anomalias que podem ser confundidas com a mesma. Nesta primeira análise verificou-se um aumento razoável da classificação da condição do pavimento, passando de um estado pobre, para um estado razoável, apenas com a mudança de todos os casos de RAS por outras anomalias.

Numa segunda abordagem, simularam-se possíveis reabilitações ao pavimento. Estas reabilitações foram simuladas pela eliminação das anomalias reparadas ou substituição dessas de acordo com os critérios de avaliação do PCI. Analisando os resultados, verificou-se uma ligeira subida no índice de estado do pavimento (PCI) e uma subida significativa no estado estrutural (SCI) do mesmo.

Numa terceira análise, juntaram-se as interações com as reabilitações, ou seja, para além das iterações feitas anteriormente, foram simuladas reabilitações. O resultado desta combinação foi um aumento bastante significativo na condição do pavimento, passando de um estado pobre de serviço para um estado satisfatório.

Com estas iterações, verificou-se a influência que a Reação Alcalis-Sílica tem sobre a avaliação de um pavimento. Uma avaliação visual em que não se considera a existência do RAS em caso de dúvida quando essa esta presente, pode comprometer o bom funcionamento e a vida do pavimento a longo prazo. Assim como, por outro lado, se se considera a existência de RAS quando não esta presente, isso tem implicações no projeto de reabilitação do pavimento, acabando por se despender mais recursos do que realmente seria necessário.

Por tudo isto, é importante o teste laboratorial por meio de carotes retirados do pavimento para assegurar a presença e a extensão de RAS no pavimento, assim como também se devem desenvolver testes para avaliar e classificar o comportamento estrutural de um pavimento com RAS. Sendo assim, para futuros desenvolvimentos, seria adequado o desenvolvimento de dispositivos colocados durante a construção na laje de cimento Portland de maneira a se registar a evolução do RAS desde o seu início, ou pelo menos um acompanhamento da evolução das anomalias desde a construção.

Symbology

$\overline{PCI_r}$ – Area weighted PCI of randomly surveyed sample units;

A_{ri} – Area of random sample unit i;

D_C - Construction deduct due to distress associated with construction procedures (e. g., bleeding);

D_E - Environmental deduct due to distresses associated with environmental effects (e. g., raveling, weathering);

D_M - Materials deduct due to distress associated with materials used in construction (e. g. popouts);

D_O - Operations deduct due to distress associated with operations and maintenance of the pavement (e. g., patching/utility cuts);

D_S - Structural deduct due to distress types, severities, and densities associated with load (e.g., shattered slab);

PCI_f – Mean PCI of surveyed sample units;

PCI_i – PCI of surveyed sample unit i;

PCI_{ri} – PCI of random sample unit i;

PCI_s – PCI section;

n_{insp} – Number of sample units to be inspected

n_{min} – Minimal number of units that must be surveyed to obtain a 95% confidence level;

HDV – Highest deduct value

N – Total number of sample units in the section.

a - An adjustment factor depending on the number of distress types with deduct values in excess of 5 points;

dt - Total number of distress types;

e – Acceptable error in estimating the section PCI. Commonly, e = +/- 5 PCI points;

$f(T_i, S_j, D_{ij})$ - deduct value for distress type T_i, at severity level S_j existing at density D_{ij}.

i – spacing interval of the sample units;

m – Maximum allowable number of distresses;

n – Total number of sample units surveyed;

s – Standard deviation of the PCI from one sample unit to another within the section. When performing the initial inspection, the standard deviation is assumed to be 15 for PCC pavements. This assumption should be checked as described below after PCI values are determined. For subsequent inspections the standard deviation from the preceding inspection should be used to determine n;

sl – Total number of severity levels for each distress type;

Abbreviations

AASHTO - American Association of State Highway and Transportation Officials

ADV – Adjusted Deduct Value

APMS – Airport Pavement Management System

ASR - Alkali-Silica Reaction

ASTM - American Society for Testing and Materials

CDV - Corrected Deduct Value

CRCP - Continuously Reinforced Concrete Pavement

DOT - Department of Transportation

DV - Deduct Value

FAA - Federal Aviation Administration

FOD - Foreign Object Debris

HMA – Hot Mix Asphalt

JPCP - Jointed Plain Concrete Pavement

JRCP - Jointed Reinforced Concrete Pavement

LCCA - Life-Cycle Cost Analyses

M&R - Maintenance and Repair

NPV - Net Present Value

PCC - Portland Concrete Cement

PCI - Pavement Condition Index

PVP – Pavement Maintenance Programs

SCI - Structural Condition Index

SHA - State Highway Agency

SU – Sample Unit

UEAC - Uniform Equivalent Annual Cost

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1 Introduction

1.1 General Presentation

In its most general sense, a road is an open, generally public way for passage of people, animals and vehicles. Before the arising of motorized vehicles were the animal drawn vehicles that prevailed. These, did not require the same needs as the vehicles nowadays because as well as the cargo, the traffic was smaller. The development of traffic, created the necessity of refining the pavements by changing their materials as well as their construction methods. A brief view of how pavement design, construction and performance has evolved should help provide perspective on present and, possible, future practice. Thus, the analysis of pavements in general, and rigid solutions in particular became an important theme to be addressed.

Rigid pavement is the technical term for any road surface made of concrete. This type of pavement is composed of a PCC (Portland cement concrete) surface course which make it substantially "stiffer" due to the high modulus of elasticity of the PCC material.

The most important advantage of using concrete pavement are its durability and ability to hold a shape, by another words, it will remain stable under traffic and will crack when the stress exceeds its tolerances. Rigid pavements, can often serve a life cycle of 20 to 40 years with little or no maintenance or rehabilitation (Pavement Interactive, 2014 d). Thus, it should come as no surprise that rigid pavements are often used in high trafficked areas or airports. But, naturally, there are trade-offs, when a rigid pavement requires major rehabilitation, the options are generally expensive and long lasting.

To avoid the pavement of reaching the state of failure and consequently major rehabilitations, management programs were developed having their basis from regular inspections to the pavements. Those inspections may be by the use of machinery or visual, which is the cheapest and more common method. The visual inspections are done walking over the pavement and its end is to establish the rate of pavement deterioration and thus, determine the maintenance or rehabilitation needs.

The rate of pavement deterioration is done featuring the "Pavement Condition Index", as known as PCI. The PCI was developed by the U.S. Army Corps of Engineers in late 1970's and early 1980's (Air Force Regulation 93-5, 1981) and is a numerical number indicator that rates the surface condition of the pavement based on the distresses observed on the surface.

This method has received widespread acceptance around the world, while enables trained and experienced inspectors to gather consistent and repeatable data pertaining to the pavement system (Broten & E.P., 2001) there are limitations to the procedure that must be addressed, as for example, the subjectivity of the procedure due the human factor. When doing a visual inspection, identifying the correct distress might not be easy due some symptoms resemblances, so the decision will be depended of how experienced the inspection personnel are. Thereafter, the calculation of the pavement rate due the distresses inspected is dependent of abaci consultation, which by it is own is dependent of human precision. All this factors will implicate in the overall evaluation of the pavement and consequently the rehabilitation plans.

Therefore, an automation of the calculation of the PCI rate will reduce the human error and will help improving the accuracy of this method. To aid and simplify the visual inspection procedure as well as the input of data in an informatics data base a Tablet application as a replacement of the common data sheet survey will be created.

1.2 Scope

The work developed in this dissertation addresses rigid pavements mainly airports rigid pavement distresses and intends to contribute to the improvement of the evaluation of the pavement condition index in order to reduce potential evaluation errors due to its subjectivity by automatize the calculation process. The automation of this process consists essentially in the exclusion of the manual consultation of the common abaci for PCI calculation. Also, in order to simplify the overall procedure of inspection, a Tablet application was developed to replace the common data sheet survey used nowadays.

1.3 Methodology

In this dissertation is intended to contribute for the improvement of the use of pavement condition index (PCI) methodology, when assessing rigid pavement distresses.

For a better understanding of the process, the work started by a detailed study of every rigid pavement distress, as well as their causes, presenting possible rehabilitation/maintenance solutions for each one of them. After understanding each distress and their causes, the various levels of severity were studied for each distress, this severity levels are distinguished by the intensity of the damaged caused at the pavement. Thereafter, an explanation of how to measure them is given following the same procedures as (ASTM - D5340, 2011).

After the detailed study of each rigid pavement distress, the main procedures of rehabilitation and maintenance were presented as well as their actions. For better plans of rehabilitation/maintenance the most known pavement management programs are briefly presented. To better understand the PCI and Structural Condition Index (SCI) evaluation and all the actions that are related with them, a detailed explanation of how to calculate PCI/SCI, followed by a practical example of an rigid pavement of an airport evaluation, that was performed accordingly with the Standard Test Method for Airport Pavement Condition Index Surveys.

Additionally, an automated process was developed which further gave origin of a Tablet application. To explain the subjectivity of the PCI and of the possible effect due to the consideration of erroneous distress, several iterations were performed aiming to study the influence of human error in the evaluation of PCI and the effect of maintenance measures.

1.4 Structure of the Dissertation

The dissertation is organized in 7 chapters including the introduction.

In the 2^{nd} chapter the three main types of rigid pavements are presented, as well as their characteristics followed by a complete description of rigid pavements distresses, their causes and possible rehabilitations.

3^{th} chapter presents the levels of severity of each distress presented previously and how to measure them accordingly to the standards from American Society for Testing and Materials (ASTM - D5340, 2011) and (ASTM - D6433, 2011).

In chapter 4^{th} there is a resume of the main maintenance and rehabilitation techniques for rigid pavements, together with a briefly explanation about the Airport Pavement Management System as well as a briefly guideline for a Life Cycle Cost Analysis.

In the 5^{th} chapter there is a complete and detailed explanation of the assessment of the pavement condition index (PCI) and Structural Condition Index (SCI) for airport rigid pavements, from the sampling to the detailed calculation of the pavement conditions index by giving practical examples.

A case study is presented in the 6^{th} chapter. This chapter addresses the procedure that was made to automate the PCI and SCI calculation, the Tablet application and also a study comparing the original pavement state to several iterations made at the original pavement distresses.

Finally the chapter number 7 presents main the conclusion and possible future developments.

2 Rigid Pavements Distresses

2.1 Types of Rigid Pavements

The basic design of rigid pavement is very simple. A surface layer, made up of slabs of Portland cement concrete (PCC), sits on top of a handful of sub-layers. The layer directly under the PCC is more flexible than the concrete, but still quite rigid, it is usually a compacted granular or cement treated subbase, which is supported in turn by a compacted subgrade. This layer provides a stable base for the PCC as well as assists in drainage. Some roads have a second subbase layer under the first that is even more flexible, while others have only the existing soil (Figure 2.1). The decision of whether this second subbase layer is necessary depends on the characteristics of the existing soil (FAA, 2007 b).

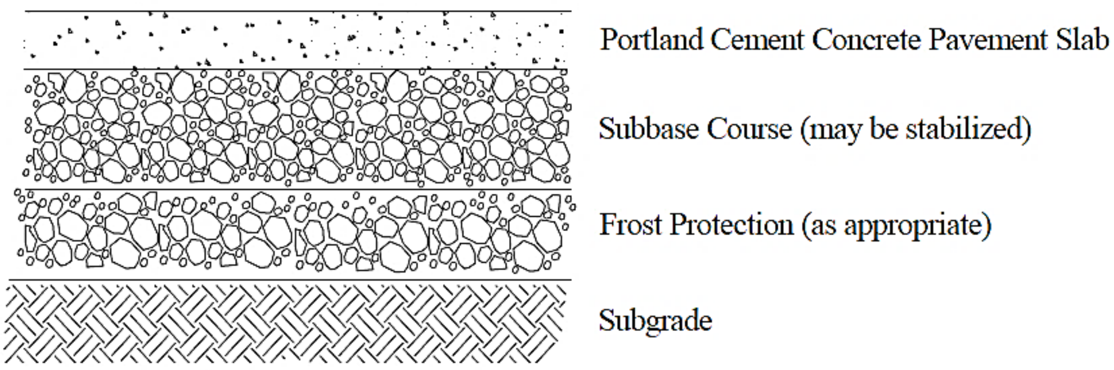

FIGURE 2.1 – TYPICAL RIGID PAVEMENT STRUCTURE (FAA, 2007 B)

The main types of rigid pavements as known as PCC pavements due the Portland Concrete Cement slab above all pavement structure (figure 2.1) are presented herein.

2.1.1 Jointed Plain Concrete Pavement (JPCP)

Is the most common style, made up of slabs with closely spaced contraction joints to control cracking with no steel reinforcement. However, there may be smooth steel bars (dowel bars) at transverse joints and deformed steel bars/connectors (tie bar) at longitudinal joints as well as aggregate interlock (CDEEP, 2014). The spacing between transverse joints is typically between 3.7 to 6.1 m (Pavement Interactive, 2014 a). When cracks develop, they should occur in the cracks between slabs, making the road surface easy to repair.

FIGURE 2.2 – EXAMPLE OF JPCP (BETTER ROADS, 2014)

2.1.2 Jointed Reinforced Concrete Pavement (JRCP)

This type of rigid pavement contains a steel mesh that reinforces the structure of the concrete slab, although do not improve the structural capacity significantly it allows designers to increase the joint spacing and include reinforcing steel to hold together intermediate cracks in each slab. Transverse joint spacing is longer than that for JPCP and typically ranges from about 7.6 to 15.2 m (Pavement Interactive, 2014 a). The reinforcement prevents some cracks, allowing the larger slabs to be effective. Although, when cracks appear, typically occur between slabs.

FIGURE 2.3 – EXAMPLE OF JRCP (PAVEMENT INTERACTIVE, 2014 A)

2.1.3 Continuously Reinforced Concrete Pavement (CRCP)

FIGURE 2.4 – EXAMPLE OF CRCP (ONLINE MANUALS, 2014)

The third type, contains a high quantity of steel reinforcement and does not require joints, as are not designed to crack at them. The cracks usually form on the pavements at intervals of 1.1 m to 2.4 m. The steel reinforcement constitutes about 0.6% to 0.7% of the cross-sectional pavement area and is located near mid-depth in the slab (Pavement Interactive, 2014 a). The reinforcing steel holds cracks together so closely that they do not cause structural problems within the slab. Continuously reinforced pavements generally cost more than jointed reinforced or jointed plain pavements, due to increased quantities of steel. However, they can present superior long-term performance and cost-effectiveness.

2.2 Types of Distresses

Failure in pavements is a phenomenon that has a definite mechanical cause, generally due to traffic. When the pavement is incapable of performing the task that was designed for, it fails. Distresses can also be caused by deficiencies during construction, lack of maintenance and climatic factors.

Cracking is one of the most important distresses of concrete pavements and is a complex issue. It is important to know that for various reasons concrete shrinks, contracts and expands, and bends from loading and the environment, and that these actions can induce cracking. It is equally important to know that this “natural” cracking can be easily controlled by the appropriate use of joints and/or reinforcing steel within the pavement. The way that cracking develops in pavement, is different for the different types of rigid pavements, presented previously. This chapter offers a detailed discussion and description of the types of pavement distresses and relates them to likely causal factors. These distress definitions are both for reinforced and non-reinforced concrete pavements.

Several external signs or indicators make visible the deterioration of a pavement, and often reveal the probable causes of the failure. However, while different distresses possess their own particular characteristics, the various types generally fall into one of the following broad categories (FAA, 2007 a):

- Cracking
- Joints
- Disintegration
- Distortion
- Loss of Skid Resistance
- Other Distresses

The following presentation of PCC (Portland Concrete Cement) pavements distresses was based at: American Society for Testing and Materials D5340 and D6433, 2011; Federal Aviation Administration - Advisory Circular, 2007 and also their website; Pavement Interactive website, 2014; Federal Aviation Administration – Operational of Airport Pavements 2004 and Distress Identification Manual for the Long-Term Pavement Performance Project - Strategic Highway Research Program, 1993.

2.3 Cracking

Cracks in rigid pavements often result from stresses caused by expansion and contraction or warping of the pavement. Overloading, loss of subgrade support, and insufficient and/or improperly cut joints acting singly or in combination are also possible causes. Several different types of cracking can occur:

2.3.1 Longitudinal, Transverse and Diagonal Cracking

Description: It is characterized by cracks that divide the slab into two or three pieces.

Possible Causes: A combination of repeated loads, curling and shrinkage stresses, poor construction techniques, underlying pavement layers that are structurally inadequate for the applied load, or pavement overloads, usually causes this type of distress.

FIGURE 2.5 – EXAMPLES OF LONGITUDINAL AND DIAGONAL CRACKS ON THE LEFT AND ON THE RIGHT TRANSVERSE AND DIAGONAL CRACKS (PAVEMENT INTERACTIVE, 2014 B)

<u>Rehabilitation</u>: Slabs with a single, narrow crack may be repaired by crack sealing (FAA, 2007 a) as presented further at chapter 4. More than one crack generally warrants a full-depth patch (Pavement Interactive, 2014 b).

2.3.2 Durability “D” Cracking

<u>Description</u>: "D" cracking usually appears closely spaced, crescent-shaped cracks running in the vicinity of and parallel to a joint, linear crack or free edges. Since the concrete becomes saturated near joints and cracks, a dark colored deposit can usually be found around this type of cracking and may eventually lead to disintegration of the concrete within 30 to 60 cm of the joint or crack.

<u>Possible Causes:</u> The concrete's inability to withstand environmental factors, such as freeze-thaw cycles because of the expansion of the large aggregate within the PCC slab.

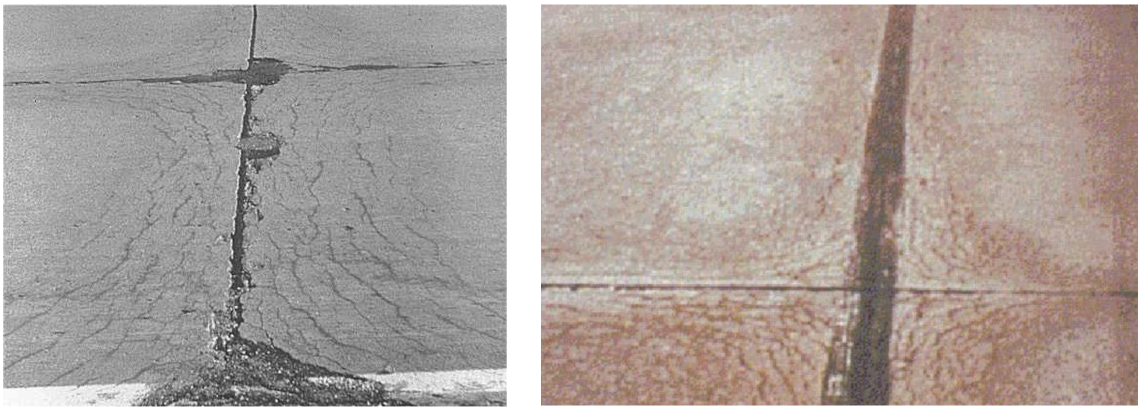

FIGURE 2.6 – EXAMPLES OF DURABILITY CRACK IN A SLAB ((PAVEMENT INTERACTIVE, 2014 B)

Rehabilitation: A full-depth or a partial-depth patch as described at chapter 4 can repair the affected area, although it does not address the root problem and will not, of course, prevent "D" cracking elsewhere (Pavement Interactive, 2014 b). Temporary repairs can be made by removing the immediate surface and provide a thin bonded overlay (FAA, 2007 a).

2.3.3 Corner Breaks

Description: This type of break is characterized by a crack that intersects the joints at a distance less than, or equal to one-half of the slab, describing approximately a 45° angle with the direction of traffic, measured from the corner of the slab.

Possible Causes: Load repetition, combined with loss of support and curling stresses, usually causes cracks at the slab corner. Lack of support may be caused by pumping or loss of load transfer at the joint.

FIGURE 2.7 – EXAMPLES OF CORNER BREAKS AT A HIGH VOLUME TRAFFIC ROAD (PAVEMENT INTERACTIVE, 2014 B)

Rehabilitation: Full-depth patch (FAA, 2007 a).

2.3.4 Shrinkage Cracking

Description: Shrinkage cracks are hairline cracks that are usually only a few cm long and do not extend across the entire slab. They are formed during the setting and curing of the concrete and usually do not extend through the depth of the slab. Typically, shrinkage cracks do not extend deeper than 6.4 mm from the slab surface and may be primarily in the finished surface paste only.

Possible Causes: All PCC will shrink as it sets and cures, therefore shrinkage cracks are expected in rigid pavement and provisions for their control are made. However, uncontrolled shrinkage cracking can indicate (Pavement Interactive, 2014 b):

- Contraction joints sawed too late: In JPCP, if contraction joints are sawed too late the PCC may already have cracked in an undesirable location.
- Poor reinforcing steel design: In CRCP, proper reinforcing steel design should result in shrinkage cracks every 1.2 to 3 m.
- Improper curing technique: If the slab surface is allowed to dry too quickly, it will shrink too quickly and crack.
- High early strength PCC: In an effort to quickly open a newly constructed or rehabilitated section to traffic, high early-strength PCC may be used. This type of PCC can have a high heat of hydration and shrinks more quickly and to a greater extent than typical PCC.

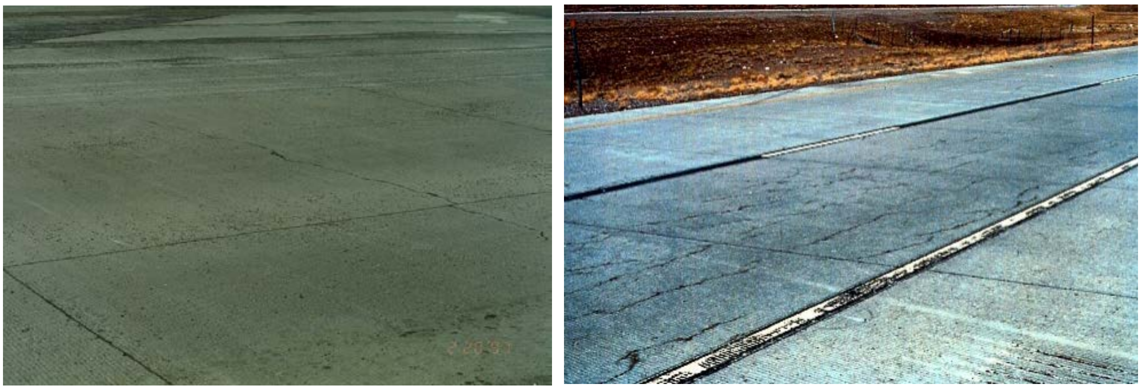

FIGURE 2.8 – EXAMPLE OF SHRINKAGE CRACKING ON NEW SLABS ON THE LEFT AND SEVERE SHRINKAGE CRACKING ON THE RIGHT (PAVEMENT INTERACTIVE, 2014 B)

Rehabilitation: Shrinkage cracks are non-structural and non-propagating. These types of cracks should be considered cosmetic and not subject to conventional repairs (FAA, 2007 a). Epoxy cement and the slab should perform adequately. In severe situations, the entire slab may need replacement (Pavement Interactive, 2014 b).

2.4 Joint Distresses

2.4.1 Joint Seal Damage

Description: Joint seal damage is any condition that enables incompressible materials (soil or rocks) to accumulate in the joints or that allows infiltration of water.

Possible Causes: Accumulation of materials that prevents the slabs from expanding and may result in buckling, shattering, or spalling. Water infiltration through joint seal damage can cause pumping or deterioration of the sub-base. Typical types of joint seal damage include stripping of joint sealant, extrusion of joint sealant, hardening of the filler (oxidation), loss of bond to the slab edges, and absence of sealant in the joint. Joint seal damage is caused by improper joint width, use of the wrong type of sealant, incorrect application, and/or not properly cleaning the joint before sealing.

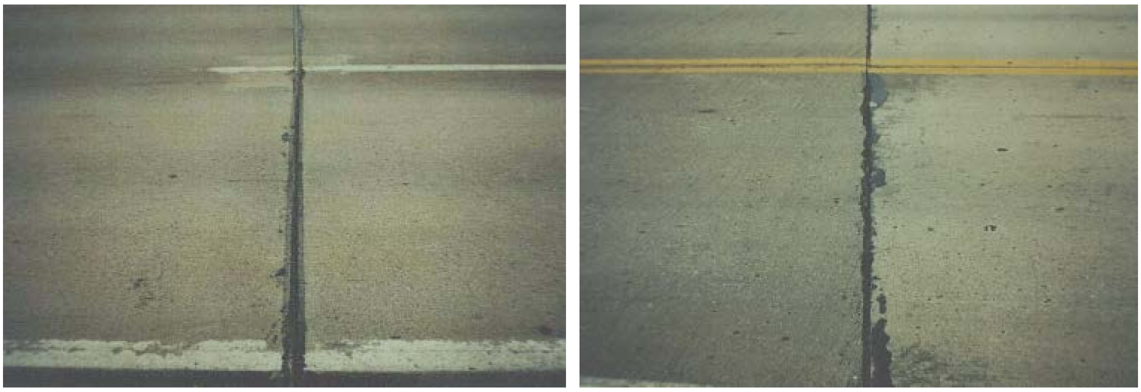

FIGURE 2.9 – EXAMPLE OF LOW SEVERITY JOINT ON THE LEFT AND ON THE RIGHT A MODERATE SEVERITY JOINT (SDDT, 2009)

Rehabilitation: When addressing joint seal damage of an existing preformed sealant, that existing joint sealant may be replaced with new preformed sealant depending on the condition of the joint. If the joint can be re-sawn straight and at a uniform width, even if that joint width is greater than the existing joint width, preformed sealant may be used. In this case, the area of repair must extend from one joint intersection to the next joint intersection. Partial replacement is not acceptable (FAA, 2007 a).

2.4.2 Joint Load Transfer System Deterioration

Description: Transverse crack or corner break developed as a result of joint dowels.

Possible Causes: Load transfer dowel bars can fail for two principal reasons:

- Corrosion. If inadequately protected, dowel bars can corrode over time. The corrosion products occupy volume, which creates tensile stresses around the dowel bars, and a severely corroded dowel bar is weaker and may fail after repeated loading.
- Misalignment. Dowel bars inserted crooked or too close to the slab edge may create localized stresses high enough to break the slab. Misalignment can occur during original construction or during dowel bar retrofits.

FIGURE 2.10 – EXAMPLE OF A DOWEL BAR CORROSION ON THE LEFT AND ON THE RIGHT A PATCH OVER AN AREA OF DOWEL BAR FAILURE (PAVEMENT INTERACTIVE, 2014 B)

Rehabilitation: Removal and replacement of the affected joint load transfer system followed by a full-depth patch for affected area.

2.5 Disintegration

Disintegration is the breaking up of a pavement into small, loose particles and includes the dislodging of aggregate particles. Improper curing and finishing of the concrete, unsuitable aggregates, and improper mixing of the concrete can cause this distress. Disintegration falls into several categories:

2.5.1 Scaling, Map Cracking or Crazing

Description: This distress refers to a network of shallow, fine, or hair-like cracks that extend only through the upper surface of the concrete. Generally scaling is exhibit by delamination or disintegration of the slab surface to the depth of the defect usually 6 to 13 mm. Map cracking or crazing usually results from improper curing and/or finishing of the concrete and may lead to scaling of the surface. This distress is often noticeable with little or no surface deterioration. Severe cases of scaling, map cracking, or crazing can produce considerable foreign objects debris (FOD), which can damage propellers and jet engines.

Possible Causes: Construction defects, material defects and environmental factors.

- Construction defects include: over-finishing, addition of water to the pavement surface during finishing, lack of curing, attempted surface repairs of fresh concrete with mortar. Generally this occurs over a portion of a slab.
- Material defects include: inadequate air entrainment for the climate. Generally this occurs over several slabs that were affected by the concrete batches.
- Environmental factors: freezing of concrete before adequate strength gained or thermal cycles from certain aircraft, generally over a large area for freezing, and isolated areas for thermal effects. Typically, the FOD from scaling is removed by sweeping, but the concrete will continue to scale until the affected depth is removed or expended.

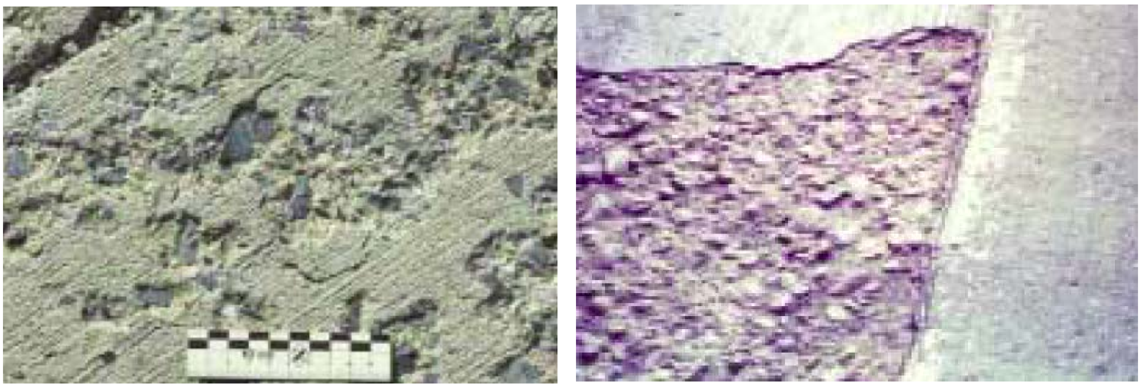

FIGURE 2.11 – EXAMPLE OF SCALING (MILLER & BELLINGER, 2003)

Rehabilitation: If the distress is severe and produces FOD, the repair method is to remove the immediate surface and provide a thin bonded overlay (FAA, 2007 a).

2.5.2 Alkali-Silica Reaction

Description: Alkali-Silica reaction is the expansive reaction that takes place in Portland concrete cement (PCC) between alkali (contained in the cement paste) and elements within an aggregate (certain reactive silica minerals) that forms a gel usually white, brown or gray, staining may be present at the crack surface also. This reaction, which occurs to some extent in most PCC, can result in map or pattern cracking, surface popouts, increase in concrete volume and spalling if it is severe enough.

Possible Causes (Pavement Interactive, 2014 b):

- Initial alkaline depolymerization and dissolution of reactive silica. Cement (a high-alkali substance) can increase the solubility of non-crystalline silica and the rate at which it dissolves. Additionally, the cement will raise the pH of the surrounding medium which will affect the crystalline silica.

- Formation of a hydrous alkali silicate gel. The initial dissolution of reactive silica then opens up the aggregate pore structure and allows more silica to dissolve into solution. The end result is alkali-silica gel that is formed in place. This gel formation is not expansive itself but it does destroy the integrity of the aggregate particle.
- Attraction of water by the gel. The gel attracts considerable amounts of water and expands. If the expansion is great enough, the resulting stress will crack the now-weakened aggregate and surrounding cement paste.
- Formation of a gel colloid. After the gel ingests enough water, the water takes over and the substance becomes an alkali-silica gel disbursed in a water fluid. This fluid then escapes to surrounding cracks and voids and may partake in secondary reactions.

FIGURE 2.12 – EXAMPLES OF MAP CRACKING RESULTING FROM ALKALI-AGGREGATE REACTION (THOMAS, FOURNIER, FOLLIARD, & RESENDEZ, 2011)

<u>Rehabilitation (how to control it)</u> (Pavement Interactive, 2014 b):

- Avoiding susceptible aggregates. Local experience may show that certain types of rock contain reactive silica. Typically rock types that may be susceptible are: siliceous limestone, chert, shale, volcanic glass, synthetic glass, sandstone, opaline rocks and quartzite. River rock is also typically susceptible.
- Pozzolanic admixture. By reacting with the calcium hydroxide in the cement paste, a pozzolan can lower the pH of the pore solution. Additionally, the silica contained in a pozzolan may react with the alkali in the cement. This reaction is not harmful because it essentially skips the expansive water attraction step.
- Low-alkali cement. Less alkali available for reaction will limit gel formation.
- Low water-cement ratio. The lower the water-cement ratio, the less permeable the concrete. Low permeability will help limit the supply of water to the alkali-silica gel.

In sum, alkali-silica reactions are expansive in nature and occur in most PCC. If the reaction is severe enough it can fracture aggregates and surrounding paste resulting in cracking, popouts and spalling. There are several ways of avoiding this reaction, the simplest of which is just avoiding susceptible aggregate. Otherwise, once alkali-silica is detected full-depth patch is necessary.

2.5.3 Spalling

Description: Cracking, breaking or chipping of joint/crack edges. Usually occurs within about 0.6 m of joint/crack edge on airports and about 0.5 m on roads and generally angles downward to intersect the joint.

Possible Causes (Pavement Interactive, 2014 b):

- Excessive stresses at the joint/crack caused by infiltration of incompressible materials and subsequent expansion (can also cause blowups).
- Disintegration of the PCC from freeze-thaw action or “D” cracking.
- Weak PCC at a joint caused by inadequate consolidation during construction. This can sometimes occur at a construction joint if, low quality PCC is used to fill in the last bit of slab volume or dowels are improperly inserted.
- Misalignment or corroded dowel.
- Heavy traffic loading.

FIGURE 2.13 – EXAMPLES OF SPALLING ALONG A LINEAR CRACK ON THE LEFT (PAVEMENT INTERACTIVE, 2014 B) AND A JOINT AND CORNER SPALLING ON THE RIGHT (FLORIDA DEPARTMENT OF TRANSPORTATION, 2012)

Rehabilitation: Spalling less than 75 mm wide from the crack face can generally be repaired with a partial-depth patch or filled with joint seal repair. Spalling greater than about 75 mm from the crack face may indicated possible spalling at the joint bottom and should be repaired with a full-depth patch (FAA, 2007 a).

2.5.4 Blowups

Description: Blowups normally occur only in thin pavement sections, although blowups can also appear at drainage structures (manholes, inlets, etc.). They generally occur during hot weather because of the additional thermal expansion of the concrete. Blowups usually occur at a transverse crack or joint that is not wide enough to permit expansion of the concrete slabs. Insufficient width may result from infiltration of incompressible materials into the joint space or by gradual closure of the joint caused by expansion of the concrete due to ASR. When expansive pressure cannot be relieved, a localized upward movement of the slab edges (buckling) or shattering will occur in the vicinity of the joint.

Possible Causes: During cold periods (winter) PCC slabs contract leaving wider joint openings. If these openings become filled with incompressible material (such as rocks or soil), subsequent PCC slab expansion during hot periods (spring, summer) may cause high compressive stresses. If these stresses are great enough, the slabs may buckle and shatter to relieve the stresses. Blowup can be accelerated by:

- Joint spalling (reduces slab contact area and provides incompressible material to fill the joint/crack);
- Durability "D" cracking (weakens the slab near the joint/crack area);
- Freeze-thaw damage (weakens the slab near the joint/crack area).

FIGURE 2.14 – EXAMPLES OF BLOWUP DISTRESS (PAVEMENT INTERACTIVE, 2014 B)

Rehabilitation: Full-depth patch.

2.5.5 Shattered Slab/Divided Slabs

Description: A shattered slab is defined as a slab where intersecting cracks break up the slab into four or more pieces.

Possible Causes: This is primarily caused by overloading due to traffic and/or inadequate foundation support.

FIGURE 2.15 – EXAMPLES OF A SHATTERED SLAB DISTRESS (STOCK-IT, 2014)

Rehabilitation: A shattered slab requires replacing the full slab. Follow the same procedures used for blowup repairs (full-depth patch) except remove unstable subgrade materials and replace with select material. Correct poor drainage conditions by installing drains for removal of excess water (FAA, 2007 a).

2.5.6 Punchout

Description: This distress is a condition that often occurs in CRCP between two closely spaced cracks or between a crack and a joint with usually 1.5 m wide. The Punchout can take many different shapes and forms, but it is usually defined by a crack and a joint.

Possible Causes: This distress is caused by heavy repeated loads, inadequate slab thickness, loss of foundation support, or a localized concrete construction deficiency, for example, honeycombing.

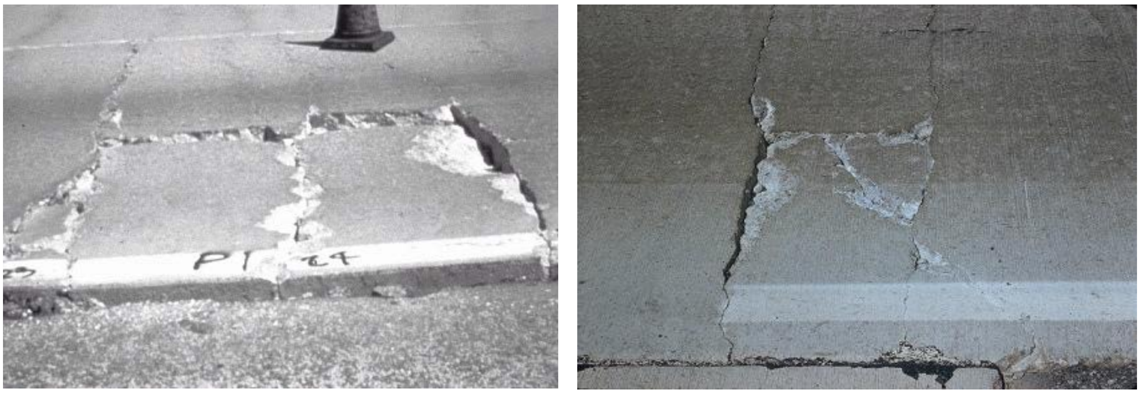

FIGURE 2.16 – EXAMPLES OF PUNCHOUT DISTRESS (PAVEMENT INTERACTIVE, 2014 B)

Rehabilitation: Full depth-patch.

2.5.7 Popouts

Description: A popout is defined as a small piece of pavement that breaks loose from the concrete surface. Popouts usually range from approximately 25 to 100 mm in diameter and 13 to 50 mm depth. A popout may also be a singular piece of large aggregate that breaks loose from the concrete surface or may be clay balls in the concrete mix.

Possible Causes: This is caused by freeze-thaw action in combination with poor aggregates. Poor durability can be a result of a number of items such as:

- Poor aggregate freeze-thaw resistance
- Expansive aggregates
- Alkali-Aggregate Reactions

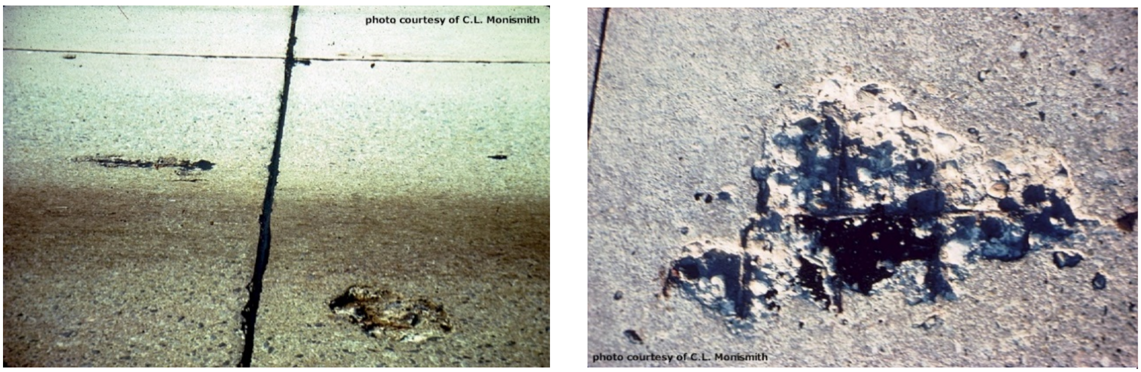

FIGURE 2.17 – EXAMPLES OF POPOUTS DISTRESS (PAVEMENT INTERACTIVE, 2014 B)

Rehabilitation: Isolated low severity popouts may not warrant repair. Larger popouts or a group of popouts can generally be repaired with a partial depth patch or filled with the same materials as used for repairing cracks or joints in PCC pavements.

2.5.8 Patching

Description: A patch is defined as an area where the original pavement has been removed and replaced by a filler material. Patching is usually divided into two types:

- Small: A small patch is defined as an area less than 0.5 m^2.
- Large and Utility Cuts. A large patch is defined as an area greater than 0.5 m^2. A utility cut is defined as a patch that has replaced the original pavement due to placement of underground utilities.

Possible Causes: Loss of support, heavy load repetitions, moisture, and thermal gradients can all cause distress.

FIGURE 2.18 – EXAMPLES OF SLAB PATCHING (FAA, 2014)

Rehabilitation: Patching small, large or utility cuts typically require removal and replacement of the patch. For extensive large patches, removal and replacement of the slab is recommended.

2.6 Distortion

Distortion refers to a change in the pavement surface's original position, and it results from foundation settlement, expansive soils, frost-susceptible soils, or loss of fines through improperly designed subdrains or drainage systems. Two types of distortion generally occur:

2.6.1 Pumping

Description: The deflection of the slab when loaded may cause pumping, which is characterized by the ejection of water and underlying material through the joints or cracks in a pavement. As the water is ejected, it carries particles of gravel, sand, clay, or silt with it, resulting in a progressive loss of pavement support that can lead to cracking. Evidence of pumping includes surface staining and base or subgrade material on the pavement close to joints or cracks. Pumping near joints indicates poor joint-load transfer, a poor joint seal, and/or the presence of ground water.

Possible Causes: Water accumulation underneath the slab. This can be caused by such things as: a high water table, poor drainage, and panel cracks or poor joint seals that allow water to infiltrate the underlying material.

FIGURE 2.19 – ON THE LEFT IT'S AN EXAMPLE OF PUMPING IN ACTION AND ON THE RIGHT IS AN EXAMPLE OF PUMPING DISTRESS (PAVEMENT INTERACTIVE, 2014 B)

Rehabilitation: First, the pumping area should be repaired with a full-depth patch to remove any deteriorated slab areas. Second, consideration should be given to using dowel bars to increase load transfer across any significant transverse joints created by the repair. Third, consideration should be given to stabilizing any slabs adjacent to the pumping area as significant amounts of their underlying base, subbase or subgrade may have been removed by the pumping. Finally, the source of water or cause of poor drainage should be addressed (Pavement Interactive, 2014 b).

2.6.2 Settlement or Faulting

Description: Settlement or faulting is a difference in elevation at a joint or crack, usually the approach slab is higher than the leave slab due to pumping, the most common faulting mechanism. This distress is typically associated with undoweled JPCP.

Possible Causes: Loss of load transfer device (key, dowel, etc.), or swelling soils, soft foundation, pumping or eroding of material from under the slab and curling of the slab edges due to temperature and moisture changes.

FIGURE 2.20 – EXAMPLE OF FAULTING DISTRESS AT THE LEFT AND A CLOSE-UP ON THE RIGHT ((PAVEMENT INTERACTIVE, 2014 B)

Rehabilitation: In the case of airports runways any faulting heights has to be repaired, in roads, less than 3 mm, do not need to be repaired. Faulting in an undoweled JPCP (jointed plain concrete pavement) greater than 6 mm in case of airports runways is a candidate for a dowel bar retrofit, and between 10 and 20 mm in the case of roads. Faulting in excess of 13 mm in airports or 20 mm in roads generally requires total reconstruction.

2.7 Loss of Skid Resistance

Skid resistance refers to the ability of a pavement to provide a surface with the desired friction characteristics under all weather conditions. It is a function of the surface texture. Loss of skid resistance is caused by the wearing down of the textured surface through normal wear and tear or the buildup of contaminants.

2.7.1 Polished Aggregates

Description: Some aggregates become polished quickly under traffic. Naturally polished aggregates create skid hazards if used in the pavement without crushing.

Possible Causes: Repeated traffic applications. Generally, as a pavement ages the protruding rough, angular particles become polished. This can occur quicker if the aggregate is susceptible to abrasion or subject to excessive studded tire wear.

FIGURE 2.21 – EXAMPLES OF POLISHED AGGREGATE DISTRESS (PAVEMENT INTERACTIVE, 2014 B)

Rehabilitation: Crushing the naturally polished aggregates creates rough angular faces that provide good skid resistance (FAA, 2007 a). Since polished aggregate distress normally occurs over an extensive area, consider milling, grooving, or diamond grinding the entire pavement surface.

2.7.2 Contaminants

Description: Rubber deposits building up over a period of time will reduce the surface friction characteristics of a pavement. Oil spills and other contaminants will also reduce the surface friction characteristics.

Rehabilitation: Remove rubber deposits with high-pressure water or biodegradable chemicals.

2.8 Other Distresses

Construction consequences refers to the depressions caused by inadequate construction or settlements due the same.

2.8.1 Lane/Shoulder Dropoff

Description: Is the difference between the edge of a slab and outside shoulder.

Possible Causes: This dropoff most often occurs when the materials in the traveled lane and shoulder are different. This distress is usually caused by shoulder erosion or shoulder settlement due to inadequate compaction during construction. Lane-shoulder dropoffs of 5cm or even lower can cause vehicular loss of control and lead to accidents.

FIGURE 2.22 – EXAMPLES OF LANE/SHOULDER DROPOFF (FHA, 2014 B)

Rehabilitation (how to avoid it): Shaping the edge of the pavement to 30 degrees minimizes the problem of vertical drop-off. This angle provides a safer roadway edge that allows drivers to re-enter the paved road safely. The Safety Edge also improves pavement density, which makes the edge durable (FHA, 2014 b).

2.8.2 Railroad Crossing

<u>Description</u>: Railroad crossing distress is characterized by depressions or bumps around the tracks.

FIGURE 2.23 – EXAMPLE OF A RAILROAD CROSSING (FAA, 2014)

<u>Rehabilitation</u>: Does not have a defined rehabilitation procedure.

2.9 Comparison between JPCP Roads and Airport Distresses

As shown earlier, the rigid pavements distresses between roads and airports even though the same name, the impact of the same distress in roads or airports may be different. This difference is due essentially to the vehicles each one is intended to serve. In a road a bad pavement condition can be very uncomfortable or even put the passengers in danger in some severity cases, although, in the case of airports where planes full of people take off and land all the time the bad function of the pavement can cause an accident and might set many lives in risk, so, by this, it's clear that the approach to airport rigid pavements distresses must be more rigorous.

This rigor between Airports and Roads rigid pavements are mainly defined by the width of the cracks as noticed at Longitudinal/Transverse and Diagonal Cracking, potential of foreign objects debris and differences of faulting.

TABLE 2.1 – COMPARISON BETWEEN ROADS AND AIRPORTS RIGID PAVEMENTS

Distress Type	Severity Levels	Airports (highway)	Roads
Longitudinal, Transverse and Diagonal Cracks	Low	≤ 3 mm	≤ 13 mm
	Moderate	≥ 3 mm and ≤ 25 mm	≥ 13 mm and ≤ 50 mm
	High	≥25 mm	≥50 mm
Faulting	Low	≤ 6 mm	≥ 3 mm and ≤ 10 mm
	Moderate	≥ 6 mm and ≤ 13 mm	≥ 10 mm and ≤ 20 mm
	High	≥13 mm	≥20 mm

The table above summarizes the rules of measure used to determine the severity level for each type of rigid pavement (Airports or Roads). For example, a crack with 10 mm, in roads is considered a low severity crack, on the other hand, in airports is already a moderate severity crack. Also the potential creation of foreign object debris in the cracks, in airport, also contribute to raise the severity level of the distresses.

3 Types of Pavements Maintenance and Rehabilitation

The combined effects of traffic loading and the environment will cause defects, over time, on every pavement, no matter how well-designed/constructed. Therefore, maintenance and rehabilitation actions are planned and performed in order to slow down or reset this deterioration process.

3.1 Maintenance

Maintenance actions, such as joint and crack sealing, fog seals and patching are the techniques used to prolong pavement life by slowing the rate of deterioration by identifying and addressing specific pavement deficiencies that contribute to overall deterioration. Thus, the performance of a pavement is directly tied to the timing, type and quality of the maintenance it receives. This section, taken largely from (Roberts, 1996) and American Concrete Pavement Association (ACPA) maintenance guidelines for concrete pavements, describes the more common preventative and corrective maintenance options for rigid pavement.

3.1.1 Joint and Crack Sealing

Sealant products are used to fill joints and cracks in order to prevent the entrance of water or other non-compressible substances and also to reduce dowel bar corrosion by reducing the entrance of chemicals. Although, most rigid pavement joints are sealed at the time of new construction, the useful sealant life is limited as stated by the ACPA on their web site:

"A typical hot-pour sealant provides an average of 3 to 5 years of life after proper installation. Some low-modulus or PVC (poly-vinyl chloride) coal-tars can perform well past 8 years. Silicone sealants have performed well for periods exceeding 8 to 10 years on roadways. This type of performance hinges on joint preparation and installation. Of extreme importance is that the joint be clean and dry. Compression seals provide service for periods often exceeding 15 years and sometimes 20 years."

Therefore, there are some properties to be considered for long-term performance (ACPA, 1995 a)

- **Elasticity**. The ability of a sealant to return to its original size when stretched or compressed.
- **Modulus**. The change in internal stresses in a sealant while being stretched and compressed over a range of temperatures (stiffness of material). A low modulus is desirable and is particularly important in cold weather climates.
- **Adhesion**. The ability of a sealant to adhere to concrete. Initial adhesion and long-term adhesion are equally important. (Not applicable to compression seals).
- **Cohesion**. Ability of a sealant to resist tearing from tensile stresses. (Not applicable to compression seals).
- **Compatibility**. Relative reaction of the sealant to materials which it contacts (such as backer roads and other sealants).
- **Weatherability**. Ability of a sealant to resist deterioration when exposed to the elements (primarily ultra violet sun rays and ozone).
- **Jet Fuel Resistance**. Ability of a sealant to resist degradation in contact with jet fuel. Some material swelling may occur in contact with jet fuel. Upon evaporation the sealant material must return to the original shape and maintain adherence to the reservoir walls.

Materials: Hot-pour seals, compression seals, silicone seals.

FIGURE 3.1 – ON THE LEFT IS A JOINT SEALING AND IT'S CLOSE-UP ON THE RIGHT (OSU, 2014)

3.1.2 Slab Stabilization

Slab stabilization seeks to fill voids beneath the slab, corner or joints (ACPA, 1995 a) caused by pumping, consolidation, subgrade failure or other means. If left untreated, these voids, which are often not much deeper than 3 mm (ACPA, 1994), may cause other problems such as faulting, corner breaks or cracking. Voids are typically filled by pumping grout through holes drilled through the slab.

The success of stabilization depends on (ACPA, 1994):

- Determining the optimal time to stabilize;
- Accurately detecting voids;
- Selecting acceptable stabilization materials;
- Correctly estimating material quantities;
- Using appropriate construction practices.

Materials: Pozzolan-cement grout.

FIGURE 3.2 – DIFFERENCE OF ELEVATION DUE TO PUMPING, CONSOLIDATION OR OTHER MEANS ON THE LEFT (PRIME RESINS, 2014) AND AN EXAMPLE OF SLAB STABILIZATION ON THE RIGHT (EAGLE LIFTING, 2014)

3.1.3 Diamond Grinding

Diamond grinding refers to a process where gang-mounted diamond saw blades are used to shave off a thin, 1.5 to 19 mm top layer of an existing PCC surface in order to restore smoothness and friction characteristics. Most often, it is used to restore roadway friction or remove roughness caused by faulting, studded tire wear, and slab warping and curling. Another very important effect of diamond grinding is the significant increase in surface macro-texture and consequent noise reduction and safety improvement. Safety is improved by a temporary increase in skid friction resistance and a reduction in the potential for hydroplaning (FHA, 2014 a).

Materials: Gang-mounted diamond saw blade

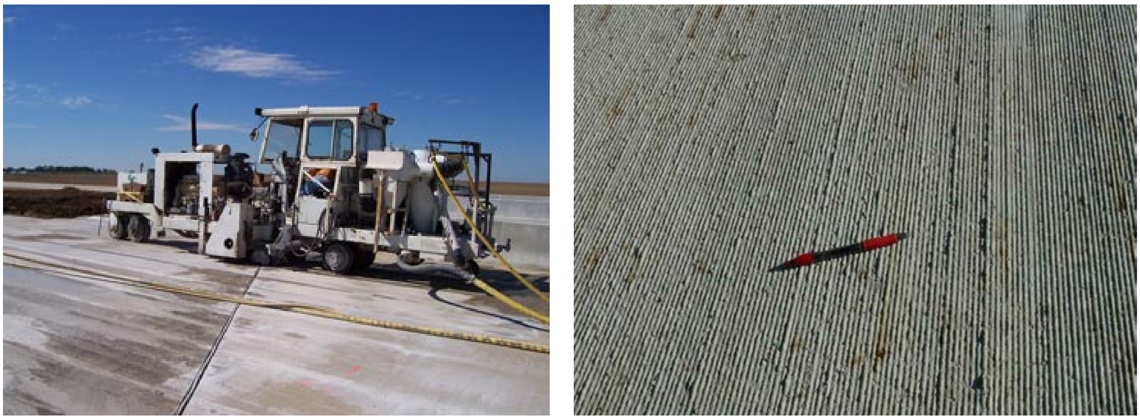

FIGURE 3.3 – DIAMOND GRINDING ON THE LEFT (FHA, 2014 B) AND CLOSE-UP ON THE RIGHT (EPG, 2014)

3.1.4 Patches

Rigid pavement patches are used to treat localized slab problems such as spalling, scaling, map cracking, joint deterioration, corner breaks or punchouts. If the problem is limited in depth, then a partial depth patch may be appropriate, otherwise a full depth patch is recommended. A high quality patch can be considered a permanent repair, although all patches are treated as a form of pavement distress.

3.1.4.1 Partial Depth Patch

Partial depth patches are used to restore localized areas of slab damage that are confined to the upper one-third of slab depth. Generally, this includes light to moderate spalling and localized areas of severe scaling (ACPA, 1998). Partial depth patches are usually small, often only 50 to 75 mm deep and covering an area less than 1 m^2 (ACPA, 1998). The generally partial depth patching process proceeds as follows (ACPA, 1998):

- **Locate the area to be patched**. Extend the patch beyond the damaged area by 75 to 100 mm.
- **Remove the damaged material**. Removal is usually accomplished by sawing and chipping. Small areas can be removed by sawing around the patch edges and then chipping out the interior. The patch should be deep enough to remove all the damaged material.
- **Clean the area to be patched**. Sandblasting or water blasting removes loose particles and creates a rough texture to which the bonding agent can adhere.
- **Apply a bonding agent**. A cementitious grout is used to help the patch material bond to the original slab material.

- **Place, finish and cure the PCC**. The PCC should be placed so that the patch is of the same elevation as the surrounding slab. Finishing the patch from the center to the edges helps push the PCC patch material firmly against the existing slab and increases the potential for a high strength bond.

FIGURE 3.4 – CORING FROM SPALL REPAIRED AREA ON THE LEFT AND ON THE RIGHT A SMALL PATCH EXAMPLE (PAVEMENT INTERACTIVE, 2014 C)

3.1.4.2 Full Depth Patch

Full depth patches are used to restore localized areas of slab damage that extend beyond the upper one-third of slab depth or originate from the slab bottom. Corner breaks and punchouts should almost always be patched to full depth. When deciding between a partial and full depth patch for spalling and slab cracking, realize that joint spalls extending more than about 75 to 150 mm from the joint are indicative of possible slab bottom spalling. Corner breaks and slab cracking are indicative of structural inadequacies that cannot be addressed with partial depth patching. These problems should be addressed using a full depth patch. A PCC full depth patching process proceeds as follows (ACPA, 1995 b):

- **Locate the area to be patched**. If the area to be patched is too close to an existing joint or crack, the patch area should be extended as follows:
    - Patch boundary within 2 m of an existing undoweled transverse joint. Extend the patch to the transverse joint.
    - Patch boundary on an existing doweled transverse joint. If the other side of the joint does not require repair, extend the patch beyond the transverse joint by about 0.3 m to remove the existing dowels.
    - The patch boundary falls on an existing crack (CRCP). Extend the patch beyond the crack by about 0.15 m.

- **Remove the damaged material**. Usually, full depth saw cuts are used to isolate the repair area from the rest of the pavement. Then, the isolated section is lifted out as a whole or broken up and removed.
- **Prepare the patch area**. The base material and subgrade is compacted, smoothed and dried. Dowel bars holes are drilled into the adjacent slab transverse sections and dowel bars are inserted to provide load transfer across the patch boundary. Slab replacements longer than about 4.5 m require longitudinal tie bars as well.
- **Apply a bonding agent**. A cementitious grout is used to help the patch material bond to the original slab material.
- **Place, finish and cure the PCC**. The PCC should be placed so that the patch is of the same elevation as the surrounding slab. Vibratory screeds are often used to strike off and finish full depth patches.

FIGURE 3.5 – ON THE LEFT IS A BASE PREPARATION TO FULL DEPTH PATCH AND ON THE RIGHT IS A WORKER DRILLING HOLES FOR A TIE BAR PLACEMENT (OSU, 2014)

3.2 Rehabilitation

Rehabilitation is the act of repairing portions of an existing pavement that significantly affects its structure and stops the deterioration process. For instance, removing and replacing the wearing course in a pavement provides new wearing course material on which the deterioration process begins anew.

A wholesale replacement of the entire pavement structure is considered reconstruction rather than rehabilitation since it follows new pavement construction methods. Rigid pavement rehabilitation options depend upon local conditions and pavement distress types but typically include (OSU, 2014):

- Dowel bar retrofit
- Structural Hot Mix Asphalt (HMA) overlays
- PCC overlays

3.2.1 Dowel Bar Retrofit

Dowel bar retrofitting is a method used to restore or provide better load transfer across transverse joints or cracks using dowel bars. Usually, dowel bar retrofits are required by excessive faulting due to a loss of aggregate interlock over time. The basic procedure is as follows (Pavement Interactive, 2014 c):

1. Cut slots across the joint. Typically, three or four slots are cut across the joint in each wheel path. These slots are cut parallel to the direction of traffic flow and must also be parallel to one another so that the retrofitted dowel bars do not restrict slab expansion and contraction.
2. Insert dowel bars into the slots. Each dowel bar is placed on a small support to keep it at the correct elevation. A Styrofoam joint reformer and plastic end caps are used to allow the slab to expand without bearing on the grout.
3. Fill the slot with grout. A small maximum aggregate size (e.g., 10 mm) is used to ensure the grout fills in completely around the dowel.
4. Diamond grind the entire pavement area. This removes any elevation differences due to faulting or grout placement.

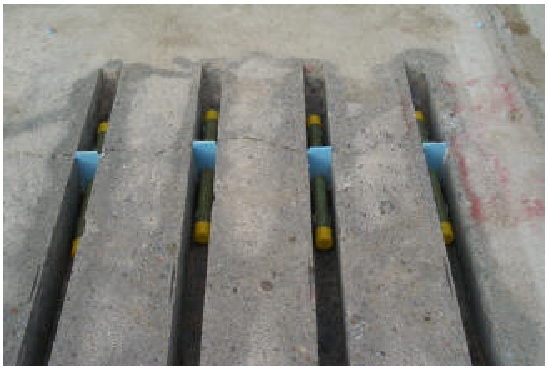

FIGURE 3.6 – ON THE LEFT IS THE DOWEL BARS SLOTS AND ON THE RIGHT THE DOWEL BARS IN IT (PAVEMENT INTERACTIVE, 2014 C)

FIGURE 3.7 – FILLING THE SLOTS WITH GROUT ON THE LEFT AND THE FINAL WORK AT THE RIGHT (PAVEMENT INTERACTIVE, 2014 C)

3.2.2 Structural Hot Mix Asphalt overlays

Hot Mix Asphalt (HMA) structural overlays are used to increase rigid pavement structural capacity. Therefore, they are considered rehabilitation, although they typically have some maintenance type benefits as well (OSU, 2014).

3.2.3 Structural PCC Overlays

PCC overlays are structural solutions and can be divided into two types (Mack, Hawbaker, & Cole, 1998)

- Unbonded. Bonding between the existing rigid pavement and the PCC overlay is intentionally prevented by using a slurry seal, bituminous surface treatments (BST), or HMA bond breaking interlayer. Unbonded PCC overlays are typically 125 to 305 mm thick (AASHTO, 1993).

  This intentional separation allows the original pavement and overlay to act independently of each other and helps prevent distresses in the existing pavement from reflecting through into the overlay (OSU, 2014). Unbonded overlays are generally used as an alternative to rubblization when the existing rigid pavement is badly deteriorated.

  Their primary advantages are that they:
  1. Can be applied over a badly deteriorated pavement without much surface preparation and;
  2. They do not require the existing pavement to be removed.

  Their primary disadvantages are:
  1. Because they are relatively thick and placed directly over the existing pavement, they add substantially to roadway elevation, which could pose overhead clearance problems, and;
  2. They are relatively expensive.

- Bonded. PCC overlay consists of a relatively thin PCC layer (typically less than 100 mm thick) over an existing rigid pavement. The overlay is intentionally bonded to the existing pavement with a PCC slurry or grout in order to create a composite pavement section (McGhee, 1994). Bonded overlays are generally used to add structural capacity to existing rigid pavements that have little deterioration (e.g., no faulting or spalling and cracked slabs should be replaced before overlay).

Their primary advantages are that they:

1. Are thinner than unbonded overlays and;
2. Their structural design accounts for the strength of the underlying pavement.

Their primary disadvantages are:

1. They should not be applied over badly distressed pavements because the distress may affect bond quality, and;
2. They are dependent upon good bond development if for some reason this does not occur, the pavement could be structurally inadequate.

3.3 Pavement Maintenance Programs

In most of pavements and specially the airports pavements have been adopted strategies of pavements maintenance and rehabilitation based on the immediate necessity of intervention (actual state of the pavement) and on the experience, instead of strategies on a long term, based on documentation about the state and behavior of the pavement along its life.

The choice between strategies of maintenance and rehabilitation based on experience results, often, in a repeated application of the same choice with a few alternatives, not allowing the adoption of a strategy that consider an analysis of performance and costs over a life cycle of the pavements (LCCA – Life-Cycle Cost Analysis).

When using an approach that consider the actual state of the pavement, alternatives are selected of maintenance and rehabilitation based on the analysis of many indicators of its condition. This methodology, by intervene in function of the current state of the pavement, may not be the best, regarding the costs of the interventions during its life cycle.

Since these approaches worked reasonably well in the past, they became part of the standard operating procedure in some agencies. Today, however, with limited money to spend on maintenance and rehabilitation and new technologies providing more options for repair, this options became obsolete. By this, it is necessary to find out what the best actions to take and what are the immediate and future implications thereof. Given this, pavements managements programs were developed.

3.3.1 Airport Pavement Management System

One of these pavement management programs is designated by Airport Management Pavement System (APMS) and not only evaluates the present condition of a pavement, but also predicts its future condition that can be among others, through the use of a pavement condition indicator (PCI).

Briefly, a pavement management system allows (Silva, 2009):

- Proportionate an objective and coherent evaluation of the condition of a network of pavements.
- Proportionate a systematic and documentable technical base capable of determinate the necessities of maintenance and rehabilitation.
- Identify the budgetary needs to maintenance and rehabilitation to diverse level of pavements function.
- Provide documentation about the present state and future of the pavements of a network.
- Determine the cost of pavements life cycle for several maintenance and rehabilitation alternatives.
- Identify the impact of minor repairs, to the overall performance of the pavements network.

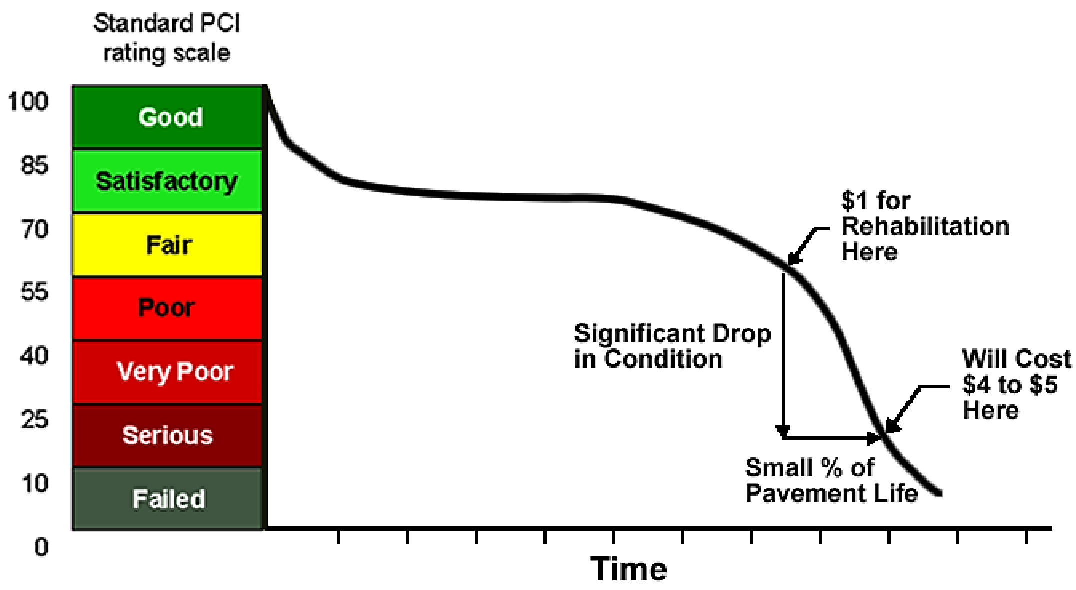

FIGURE 3.8 – TYPICAL PAVEMENT CONDITION LIFE CYCLE (PAVER, 2014)

With this methodology it is possible through the adopted rate of pavement deterioration, find different alternatives for a life cycle costs analysis, being possible to determinate the best time for rehabilitation procedures.

The figure 3.8, illustrate the trend of deterioration of a pavement and the costs related to its rehabilitation along its life. Pavements, generally, present a good performance for most of their life, but, when they reach the critical state they begin to deteriorate. Several studies have shown that maintaining a pavement in good condition versus periodically rehabilitating a pavement in poor condition is four to five times less expensive (FAA, 2006)

3.3.2 Life-Cycle Cost Analysis

This brief section provides guidance on conducting Life-Cycle Cost Analyses (LCCA) for pavement rehabilitation projects to assess the long-term cost effectiveness of alternative rehabilitation strategies.

3.3.2.1 Purpose of LCCA

The primary purpose of an LCCA is to quantify the long-term implication of initial pavement design decisions on the future cost of maintenance and rehabilitation activities necessary to maintain some pre-established minimum acceptable level of service for some specified time.

LCCA does not, however, address equity issues. It incorporates initial and discounted future agency, user, and other relevant costs over the life of candidate alternatives, LCCA attempts to identify the best value for investment expenditures (i.e., the lowest long-term cost that satisfies the performance objective). The logical analytical evaluation framework that life-cycle cost analyses foster is as important as the LCCA results themselves. It is essential that all impacts be accurate for LCCA results to be meaningful (Walls & Smith, 1998)

3.3.2.2 Life-Cycle Cost Analysis Procedures for Rehabilitation Projects

LCCA should be conducted as early in the project development cycle as practicable. The level of detail included in the LCCA should be consistent with the level of investment. Typical LCCA models that are based on primary rehabilitation strategies can be used to reduce unnecessarily repetitive analyses and only consider differential costs among rehabilitation alternatives. Costs common to all alternatives will cancel out and should not be included in the analysis. Inclusion of all potential LCCA factors in every analysis is counterproductive; however, all LCCA factors and assumptions should be addressed, even if only limited to an explanation of the rationale for not including eliminated factors in detail. Sunk costs, which are irrelevant to the analysis, should not be included (BDEM, 2010).

3.3.2.3 LCCA Guidelines

Consider the following guidelines when conducting life-cycle costs analyses to assess rehabilitation project alternatives (BDEM, 2010):

1. LCCA Analysis Period. The LCCA analysis period, or the time horizon over which rehabilitation alternatives are evaluated, should be sufficient to reflect long-term cost differences associated with reasonable strategies. An analysis period of 30 to 40 years is reasonable for rehabilitation projects.
2. Economic Efficiency Indicator. Net present value (NPV) is the economic efficiency indicator of choice which is based on the simple fact that present dollars are presumed to be worth more than in the future, (APA, 2011). The uniform equivalent annual cost (UEAC) indicator is also
3. Dollar Type. Future cost and benefit streams should be estimated in constant dollars and discounted to the present using a real discount rate. Although nominal dollars can be used with nominal discount rates, use of real/constant dollars and real discount rates eliminates the need to estimate and include an inflation premium. In any given LCCA, real/constant or nominal dollars must not be mixed (i.e., all costs must be in real dollars or all costs must be in nominal dollars). Furthermore, the discount rate selected must be consistent with the dollar type used (i.e., use real cost and real discount rate or nominal cost and nominal discount rate).
4. Discount Rate. The Department uses a discount rate of 3% for new pavements and this rate is acceptable for rehabilitation.
5. Overhead Costs. Although most analyses include traditional Department construction costs, some do not fully account for the Departments engineering and construction management overhead. This can be a serious oversight on short-lived rehabilitation projects as the Department's design processes potentially lengthen in an era of downsizing.
6. Annual Maintenance Costs. Routine, reactive-type annual maintenance costs have only a marginal effect on NPV. They are hard to obtain, generally very small in comparison to initial construction and rehabilitation costs, and differentials between competing rehabilitation strategies are usually very small, particularly when discounted over a 30 to 40 year analysis period.
7. User Costs. User costs are the travel time delay, vehicle operating, and crash costs incurred by highway users. The LCCA should primarily focus on work zone user cost differences between alternatives, especially on travel delay when demand exceeds work zone capacity for an alternative. User costs are heavily influenced by the current and future traffic demands, facility capacity, circuitous detours, and the timing, duration, and frequency of work zone-induced capacity restrictions. Directional hourly traffic demand forecasts for the analysis year in question are essential for determining work zone user costs. The vehicle classes analyzed should include passenger vehicles, single-unit trucks, and combination trucks.
8. Salvage Value. Salvage value should be based on the remaining life of an alternative at the end of the analysis period.

4 Assessment of Pavement Condition Index and Structural Condition Index

The assessment of Pavement Condition Index (PCI) procedure presented herein is fully based on Standard Test Method for Airport Pavement Condition Index Surveys (ASTM - D5340, 2011).

4.1 Summary of Test Method

This test method covers the determination of airport pavement condition through visual surveys of asphalt-surfaced (AC) pavements, including porous friction courses, and plain (JPCP) or reinforced (JRCP) jointed Portland cement concrete (PCC) pavements, using the Pavement Condition Index (PCI) method of quantifying pavement condition. The PCI for airport pavements was developed by the US Army Corps of Engineers through the funding provided by the U.S. Air Force. It was further verified and adopted by Federal Aviation Administration (FAA) and the U.S. Naval Facilities Engineering Command.

4.2 Significance and Use

The PCI is a numerical indicator that rates the surface condition of the pavement from 0 to 100, where 0 it's the worst possible condition and 100 the best possible condition. The PCI provides a measure of the present condition of the pavement based on the type and severity of distresses observed on the surface of the pavement which also indicates the structural integrity and surface operational condition (localized roughness and safety). The PCI is a subjective method in terms of quantifying the structural and functional condition of the pavement, as it neither measures the bearing capacity, nor quantities the level of surface characteristics but provides feedback on pavement performance for validation or improvement of current pavement design and maintenance procedures.

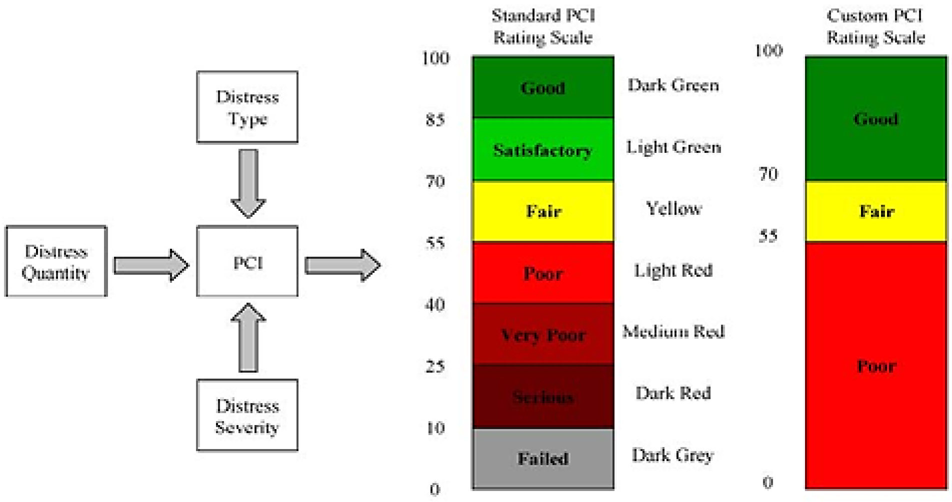

FIGURE 4.1 – PAVEMENT CONDITION INDEX RATING SCALE (PAVER, 2014)

4.3 Visual Inspection

The PCI evaluation is registered manually by a visual inspection survey walking over each slab of the sample unit, recording and sketching all distresses existing in the slab along their severity level on the data sheet (figure 4.2).

4.4 Apparatus

Data Sheets, or other field recording instruments that record at a minimum the following information: date, location, branch, section, sample unit size, slab number and size, distress types, severity levels, quantities, and names of surveyors. Example of a data sheet for PCC pavements is shown at figure 4.2.

AIRFIELD CONCRETE PAVEMENTS
CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT

BRANCH____________ SECTION____________ SAMPLE UNIT____________
SURVEYED BY__________ DATE____________ SAMPLE AREA____________

Distress Types

1. Blow up
2. Corner Break
3. Long/Trans/ Diagonal Crack
4. Durability Crack
5. Joint Seal Damage
6. Patching, 5 sf
7. Patching/Utility Cut
8. Popouts
9. Pumping
10. Scaling/Map Crack/ Crazing
11. Settlement/Fault
12. Shattered Slab
13. Shrinkage Crack
14. Spalling-Joints
15. Spalling-Corner
16. Alkali-Silica Reaction

DIST TYPE	SEV	NO. SLABS	DENSITY %	DEDUCT VALUE

SKETCH:

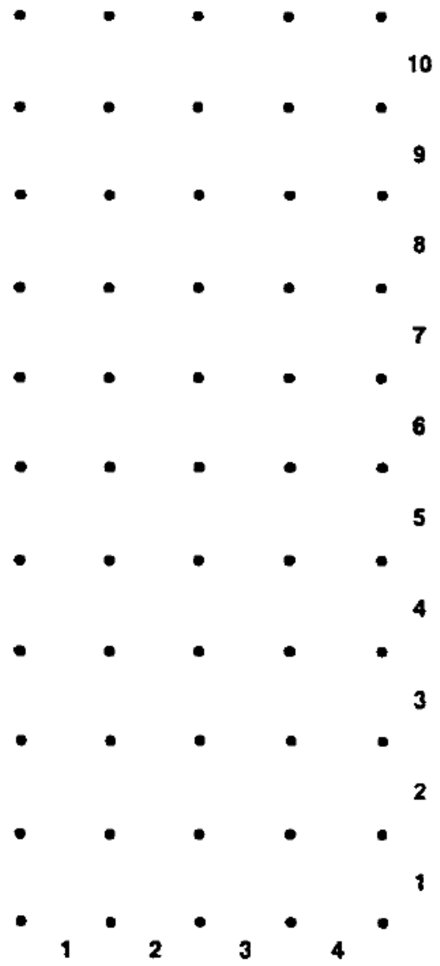

FIGURE 4.2 – RIGID PAVEMENT CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT (ASTM - D5340, 2011)

4.5 Sampling and Sample Units

The first thing to do is to identify the areas of the pavement with different uses into branches, such as runways, taxiways and aprons layout plan, than divide each single area into sections based on the pavement design, construction history, traffic and condition. After the sections are properly separated, divide the pavement sections into sample units.

A sample unit is a subdivision of a pavement section that has a standard range of 20 contiguous slabs (+/- 8 slabs if the total number of slabs in the section is not evenly divide by 20). If the pavement slabs in PCC have joints spacing greater than 8 m, subdivide each slab into imaginary slabs. The imaginary slabs should all be less than or equal to 8 m in length, and the imaginary joints dividing the slabs are assumed to be in perfect condition. This is needed because the Deduct Values (DV) were developed for jointed concrete slabs less than 8 m.

Second, individual sample units to be inspected should be marked or identified by GPS in a manner to allow inspectors and quality control personnel to easily locate them on the pavement surface. Paint marks along the edges and sketches with locations connected to physical pavement features are accepted. Nails or other foreign object debris (FOD) sources are not recommended. It is necessary to be able to accurately relocate the sample units to allow verification of current distress data, to examine changes in condition with time of a particular sample unit, and to enable future inspections of the same sample unit if desired.

Third, select the sample units to be inspected. The number of sample units to be inspected may vary from all of the sample units in the section, a number of sample units that provides a 95% confidence level, or a lesser number. All the sample units in the section may be inspected to determine the PCI of the section, although, this is usually precluded for routine management purposes by available manpower, funds and time. Therefore, there is a minimal number of units (n_{min}), that must be surveyed to obtain a statistically adequate estimate (95% confidence level) of PCI of the section.

$$n_{min} = \frac{Ns^2}{\left(\left(\frac{e^2}{4}\right)(N-1) + s^2\right)} \tag{4.1}$$

Note: rounding n_{min} to the next highest whole number.

Where:

e – Acceptable error in estimating the section PCI. Commonly, e = +/- 5 PCI points;

s – Standard deviation of the PCI from one sample unit to another within the section. When performing the initial inspection, the standard deviation is assumed to be 15 for PCC pavements. This assumption should be checked as described below after PCI values are determined. For subsequent inspections the standard deviation from the preceding inspection should be used to determine n;

N – Total number of sample units in the section.

If obtaining the 95 % confidence level is critical, the adequacy of the number of sample units surveyed must be confirmed. The number of sample units was estimated based on an assumed standard deviation. Calculate the actual standard deviation(s) as follows:

$$s = \sqrt{\sum_{i=1}^{n} \frac{\left(PCI_i - PCI_f\right)^2}{(n-1)}} \qquad (4.2)$$

Where:

PCI_i – PCI of surveyed sample unit i;

PCI_f – Mean PCI of surveyed sample units;

n – Total number of sample units surveyed.

Calculate the revised minimum number of sample units (n_{min}) to be surveyed using the calculated standard deviation (s). If the revised number of sample units to be surveyed is greater than the number of sample units already surveyed, select and survey additional random sample units. These sample units should be evenly spaced across the section. Repeat the process of checking the revised number of sample units and surveying additional random sample units until the total number of sample units (n) surveyed equals or exceeds the minimum required sample units (n_{min}), using the actual total sample standard deviation.

A lesser sampling rate than the above mentioned 95% confidence level can be used based on the condition survey objective. As an example, one agency uses the following table for selecting the number of sample units to be inspected for other than project analysis:

TABLE 4.1 – ALTERNATIVE CRITTER TO DETERMINATE THE NUMBER OF SAMPLES

Given (n)	**Survey**
1 to 5 sample units	1 sample unit
6 to 10 sample units	2 sample units
11 to 15 sample units	3 sample units
16 to 40 sample units	4 sample units
Over 40 sample units	10%

Finally, once the number of sample units to be inspected has been determined, compute the spacing interval of the units using systematic random sampling. Samples are equally spaced throughout the section with the first sample selected at random. The spacing interval (i) of the units to be sampled is calculated by the following formula rounded to the next lowest whole number:

$$i = \frac{N}{n_{insp}} \tag{4.3}$$

Where:

N – Total number of sample units in the section;

n_{insp} – Number of sample units to be inspected

The first sample unit to be inspected is selected at random from sample units 1 through i. The sample units within a section that are successive increments of the interval i after the first randomly selected unit are also inspected.

4.6 Calculation of PCI for PCC Pavement

For each unique combination of distress type and severity level, it has to be recorded the number of slabs in which they occur. For example, in the figure 4.3 there are two slabs containing low-severity longitudinal cracking.

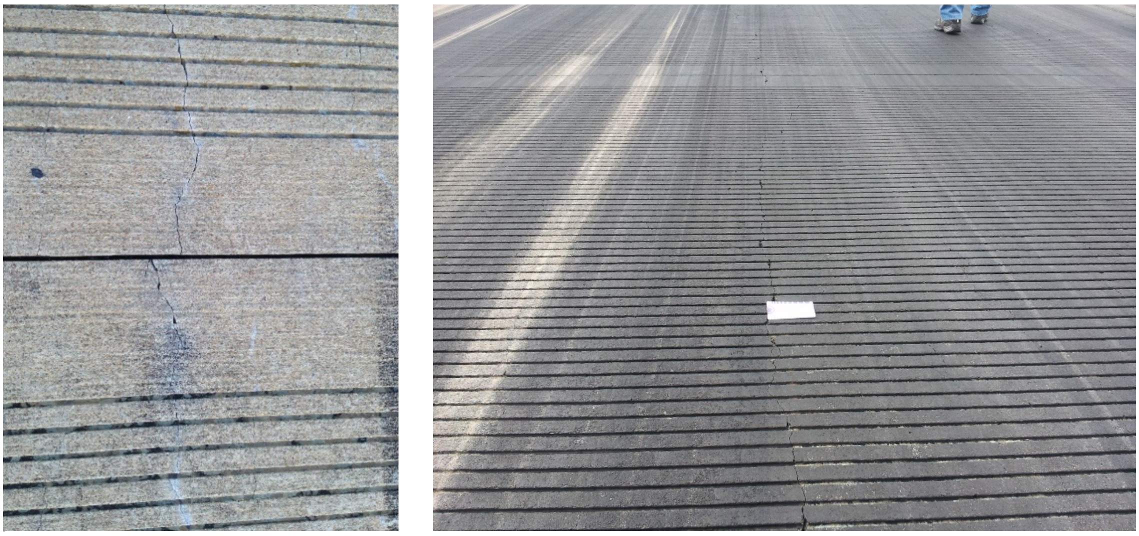

FIGURE 4.3 – LOW SEVERITY L/T/D AT TWO RUNAWAY SLABS (LNEC, 2013).

So, in the data sheet it will look like this:

TABLE 4.2 – EXAMPLE OF HOW TO FILL A PCC SURVEY DATA SHEET.

Distress Type	Severity Levels	Number of Slabs	Density %	Deduct Value
3	L	2		

4.6.1 Calculation of Density

To calculate the percentage of density, divide the number of slabs recorded from a specific distress by the total number of slabs in the sample unit (usually 20) and multiply by 100. For example:

$$Density\ \% = \frac{2}{20} \times 100 = 10 \qquad (4.4)$$

TABLE 4.3 – EXAMPLE OF HOW TO FILL A PCC SURVEY DATA SHEET AFTER THE CALCULATION OF THE DENSITY %.

Distress Type	Severity Levels	Number of Slabs	Density %	Deduct Value
3	L	2	10	

4.6.2 Calculation of Deduct Value

To determine the Deduct Value (DV) it must use the DV abaci at *Appendix I*. There are DV graphic curves for most of the distresses. In this case, we'll use the DV abacus graphic number 3 which is for Longitudinal, Transverse and Diagonal cracking.

As presented at *Appendix I* graphic, there is a curve for each severity level, in this case, the blue curve that corresponds to the low severity level, has to be used.

From the density and the severity level curve it is possible to determine the DV (see figure 4.4) by drawing a vertical line starting at 10 and a horizontal line starting at the intersection between the vertical line and the curve to the axis of the DVs.

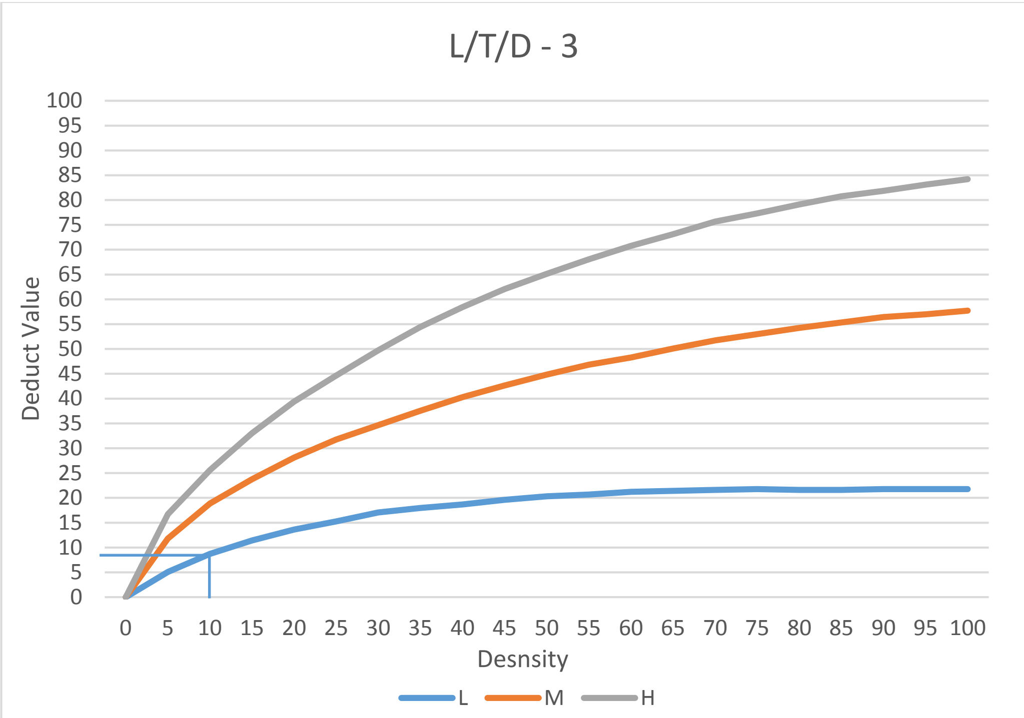

FIGURE 4.4 – LONGITUDINAL, TRANSVERSE AND DIAGONAL CRACKING ABACUS FOR DV CALCULATION

TABLE 4.4 – EXAMPLE OF HOW TO FILL A PCC SURVEY DATA SHEET AFTER DV.

Distress Type	Severity Levels	Number of Slabs	Density %	Deduct Value
3	L	2	10	8.71

4.6.3 Calculation of Corrected Deduct Value

The Pavement Condition Index (PCI) is given by:

$$PCI = 100 - HCDV \tag{4.5}$$

Where:

100 – Maximum PCI.

HCDV – Highest corrected deduct value (CDV).

Another example is presented herein.

TABLE 4.5 – EXAMPLE OF A PCC SURVEY DATA SHEET FILLED.

Distress Type	Severity Levels	Number of Slabs	Density %	Deduct Value
5	L	20	100	2
3	L	2	10	8.71
6	L	1	5	1.74
16	L	11	55	18.71
10	M	4	20	17.38
13	N/D	6	30	4.84

To determinate the PCI, first the CDV is determinate, but if none or only one individual DV is greater than five, the total DV is used in place of the maximum CDV in determining PCI. For example, if only the first three lines of Table 4.5 are considered as having distresses recorded, only one DV is bigger than five (8.71), so the PCI is:

$$PCI = 100 - (2 + 8.71 + 1.74) = 87.55 \tag{4.6}$$

Otherwise, if more than one DV is bigger than five, in order to determine the maximum CDV another procedure is followed.

First, the maximum allowable number of distresses, “m”, are calculated.

$$m = 1 + \left(\frac{9}{95}\right) * (100 * HDV) \leq 10 \tag{4.7}$$

Where:

HDV – Highest deduct value.

For example, considering Table 4.5:

$$m = 1 + \left(\frac{9}{95}\right) * (100 - 18.71) = 8.7012 \quad (4.8)$$

This means that only eight distresses have to be considered for this PCI calculation.

Secondly, the “m” highest DVs have to be entered on line 1 of the following table, including the fraction obtained by multiplying the last DV by the fractional portion of “m”. If less DVs are available, enter all of the DVs.

Sum the DVs and enter it under “Total”. Count the number of DVs greater than five and enter it under “q”.

For example:

TABLE 4.6 – EXAMPLE OF HOW TO DETERMINE THE CDV.

#	Deduct Values							Total	q	CDV
1	18.71	17.38	8.71	4.84	2	1.74	1.74*0.7012=1.22	54.6	3	
2										
3										

Third, to determine CDV the appropriate correction curve included in *Appendix II* has to be used, and as done before to determine the DV, with the “Total” and the “q” determine CDV.

Copy DVs on current line to next line, changing the smallest DV greater than five to five. Repeat the same procedure to determine CDV until “q”=1 (see table 4.7).

TABLE 4.7 – EXAMPLE OF THE PROCEDURE WHEN YOU HAVE MORE THAN ONE DV GREATER THAN FIVE.

#	Deduct Values							Total	q	CDV
1	18.71	17.38	8.71	4.84	2	1.74	1.74*0.7012=1.22	54.6	3	40.67
2	18.71	17.38	5	4.84	2	1.74	1.22	50.9	2	43.03
3	18.71	5	5	4.84	2	1.74	1.22	38.5	1	38.5

Finally the PCI is given by:

$$\boldsymbol{PCI} = 100 - (43.03) = \mathbf{56.97} \tag{4.9}$$

4.7 Determination of PCI of the Section

The PCI section (PCI_s) is calculated as the area weighted PCI of the randomly surveyed sample units ($\overline{PCI_r}$) using:

$$PCI_s = \overline{PCI_r} = \frac{\sum_{i=1}^{n}(PCI_{ri} \cdot A_{ri})}{\sum_{i=1}^{n} A_{ri}} \tag{4.10}$$

Where:

$\overline{PCI_r}$ – Area weighted PCI of randomly surveyed sample units;

PCI_{ri} – PCI of random sample unit i;

A_{ri} – Area of random sample unit i;

n – Total number of sample unit surveyed.

For better understanding of the procedure a case study is presented in Chapter 5.

4.8 Assessment of Structural Condition Index

4.8.1 Structural Condition Index Definition

The Structural Condition Index (SCI) is derived from the pavement condition index (PCI) and it is the summation of structural components from PCI. The use of SCI differentiates the two types of distresses: one is structural-related due to loads, and the other is non-structural-related.

As already referred the PCI is a numerical rating indicating the operational condition of an airport pavement based on a visual survey. The scale ranges from 100 to 0, with 100 representing a pavement in excellent condition and 0 representing complete failure (ASTM - D5340, 2011).

For airport rigid pavements, the PCI recognizes 16 different types of distresses as referred previously in chapter 2. Deduct Values are assigned depending on the type of distress, its severity and the amount or density of the distress in the pavement, therefore, it can be described by the equation (Rollings, 1988):

$$PCI = 100 - a \sum_{i=1}^{dt} \sum_{j=1}^{sl} f\left(T_i, S_j, D_{ij}\right) \quad (4.11)$$

Where:

a - An adjustment factor depending on the number of distress types with deduct values in excess of 5 points;

dt - Total number of distress types;

sl – Total number of severity levels for each distress type;

$f(T_i, S_j, D_{ij})$ - deduct value for distress type T_i, at severity level S_j existing at density D_{ij}.

The PCI may conceptually also be considered as follows:

$$PCI = 100 - D_S - D_E - D_M - D_C - D_O \quad (4.12)$$

Where:

D_S - Structural deduct due to distress types, severities, and densities associated with load (e.g., shattered slab);

D_E - Environmental deduct due to distresses associated with environmental effects (e. g., raveling, weathering);

D_M - Materials deduct due to distress associated with materials used in construction (e. g. popouts);

D_C - Construction deduct due to distress associated with construction procedures (e. g., bleeding);

D_O - Operations deduct due to distress associated with operations and maintenance of the pavement (e. g., patching/utility cuts);

Similar to the PCI definition, the SCI can be defined as (Rollings, 1988):

$$SCI = 100 - a \sum_{i=1}^{m} \sum_{j=1}^{n} f(T_i, S_j, D_{ij}) \tag{4.13}$$

With the variables as defined previously, but T is now limited to only those distress types associated with structural deterioration caused by loads. It also follows that

$$SCI = 100 - all\ other\ deduct\ values \tag{4.14}$$

The same author also shows the PCI distress types that have been selected to be used with rigid pavements to determine the SCI value (see table 4.8).

TABLE 4.8 – RIGID PAVEMENT DISTRESS TYPES USED WITH THE SCI

Number	Distress Type	Associated Severity Levels
2	Corner Break	3
3	Longitudinal, Transverse and Diagonal Cracking	3
12	Shattered Slab	3
13	Shrinkage Cracks*	1
14	Spalling Joints	3
15	Spalling Corner	3

* Used only to describe a load induced crack that extends only part way across a slab. In the SCI it does not include conventional shrinkage cracks due to curing problems.

Distress number 13, shrinkage cracking, is included in the SCI because this distress type would include a tight, load-related crack that does not extend across the entire width or length of the slab as well as the conventional shrinkage cracking because of improper curing procedures. With further traffic this crack, if caused by loads, will propagate across the slab into a Type 3 Longitudinal, Transverse and Diagonal crack of low severity with a higher deduct value. For the SCI value, this distress will be counted only when it is caused by load and not if it is a result of improper concrete curing practice (Rollings, 1988).

4.8.2 Calculation Example

Having the following table has an example, we can see that in this particular sample unit we have six distresses, although, just the 3 (longitudinal, transverse and diagonal cracking) and the 14 (Joint Spalling) can be selected to determine the SCI.

TABLE 4.9 – EXAMPLE DATA FOR SCI CALCULATION (DISTRESS 3 AND 14)

Distress Type	Severity Levels	Number of Slabs	Density %	Deduct Value
3	***L***	***6***	***30***	***17.06***
4	L	4	20	10.67
6	L	4	20	3.65
14	***L***	***1***	***5***	***2.56***
14	***M***	***1***	***5***	***4.94***
16	L	19	95	21.85

4.8.2.1 Adjusted Deduct Value

When having more than one deduct value to calculate the SCI, the procedure is to find and adjusted value. This adjusted value as for PCI is calculated with the aid of the corrected deduct value (CDV) abaci. Therefore, all DV numbers to calculate the SCI must be summed as follows.

$$17.06 + 2.56 + 4.94 = 24.56 \tag{4.15}$$

With the total, and having more than one structural distress an Adjusted Deduct Value (ADV) is needed. This ADV is taken from the CDV abaci representing the curves the number of structural distresses (q1 – 1 structural distress, q2 – 2 structural distresses and so on) and the value is **17.88**.

After having the ADV the procedure is:

$$\boldsymbol{SCI} = 100 - 17.88 = \mathbf{82.12} \tag{4.16}$$

By the Federal Aviation Administration (FAA, 2004) a SCI of 80 in a rigid pavement is defined as structural failure and is consistent with 50% of the slabs in the traffic area exhibiting structural cracks.

5 Case Study

5.1 General

Currently, the visual inspection survey is done manually, using the data sheet showed in figure 4.2, as any sheet it can be damaged by water, soiled, ripped, lost, and so on. Also the data sheet has to be copied to a digital device, computer, etc.

In a normal inspection, the technician has to fill the sheets with all the potential distresses and then go to the office and insert manually all the information on a general software, in order to process and evaluate the state of the pavement. This is time consuming and errors can occur during inserting the data into computer, requiring generally two people, and the need to double check the information. Therefore, this process requires improvements in order to make this job faster and easier.

The calculation of the PCI, as explained previously depends on abaci consultation and therefore, the risk of errors induced by the lack of human precision exists, due to errors in reading the values. This lack of precision may compromise the correct evaluation of a pavement and consequently, the solutions to be adopted for rehabilitation process, as well as their costs.

For all these reasons, the replacement of the data survey sheet with a tablet application will make this survey more confident, comfortable, fast and easier.

In this study two automation levels of the PCI/SCI evaluation process were developed. A first one aiming at improving the inspection by developing a data sheet application for a tablet, and a second one, that enables the processing of the values automatically, without the need of consulting manually the abaci. These two processes are described further on this chapter.

5.2 Data Collection for the Case Study

The data collection for this study was performed in a real airport pavement by Laboratório Nacional de Engenharia Civil (LNEC) - (Fontul, 2013) following the methodology described in (ASTM - D5340, 2011).

First, the airport pavement was divided according to their operational function into branches, as runway, taxiway and apron areas. Each branch was divided into sections according to their construction, maintenance, usage history and condition. Finally each section was divided into sample units. Then to assess the severity and type of distress a visual inspection over each sample unit was performed. For this case study only the runway is considered.

5.2.1 Runway Characteristics

The runway studied is a jointed plain concrete pavement (JPCP) and is oriented North/South, and has a total length of approximately 3360 m, and 45 m width.

The concrete slabs have approximately 5 m length and 4.5 m width, making a total of 10 slabs in a cross section.

The pavement structure of the runway is composed of the following layers, above the subgrade:

a. Runway ends (0 – 500 m and 2860 – 3360 m)
   - Graded crushed aggregate sub-base layer, 20 cm thick;
   - Cement treated aggregate base layer (CTB), 25 cm thick;
   - “Rock chips” layer for leveling, 2 cm thick;
   - Portland cement concrete (PCC) slabs, 40 cm thick.

b. Runway middle part, central slabs (500 – 2860 m). This structure was adopted in six central slabs in this section.
   - Graded crushed aggregate sub-base layer, 20 cm thick;
   - Cement treated aggregate base layer (CTB), 25 cm thick;
   - "Rock chips" layer for leveling, 2 cm thick;
   - Portland cement concrete (PCC) slabs, 36 cm thick.

c. Runway middle part, lateral slabs (500 - 2860 m). This structure represents the two lateral slabs.
   - Graded crushed aggregate sub-base layer, 20 cm thick;
   - Cement treated aggregate base layer (CTB), 25 cm thick;
   - "Rock chips" layer for leveling, 2 cm thick;
   - Portland cement concrete (PCC) slabs, 31.5 cm thick.

The division of the runway pavements into sections for PCI/SCI evaluation purpose was based on geometric characteristics and on traffic use. The sections obtained based on these criteria are presented in the following table.

TABLE 5.1 – SECTION IDENTIFICATION AND CHARACTERISTICS

Description	Design Pavement Layer Thickness (mm)			PCI Zones Identification	
	PCC	CTB	Sub-base	Section ID	Samples inspected
Runway	400	250	200	R1	R11, R12, R13, R14, R15
	360	250	200	R2	R21 to R214
	315	250	200	R3	R31 to R35
	400	250	200	R4	R41 to R45

Consequently, based on structure, the runway was divided into four sections:

- R1 - Runway North end (0 - 500 m) covers an area of 22500 m^2 ;
- R2 - Runway middle part, central slabs (500 - 2860 m from North end) covers an area of area of 63720 m^2;
- R3 - Runway middle part, lateral slabs (500 - 2860 m from North end) covers an area of 21240 $m^{2;}$
- R4 - Runway South end (2860 – 3360 m from North end), that has the same structure and area as runway North end but a different traffic usage.

For each section a total of 10% of the total sample units were selected for inspection, which resulted:

- Section R1 has five sample units from R11 to R15;
- Section R2 has fourteen sample units from R21 to R214;
- Section R3 has five samples units from R31 to R35;
- Sections R4 has five sample unis from R41 to R45.

The sample units were chosen randomly in each section, although evenly spaced between each other. Each sample is divided in twenty contiguous slabs and marked along the edges with the respective sample name, for example R11. Moreover, the location of each sample unit was identified by GPS at the center of sample unit.

Once identified each sample unit to be inspected, the procedure to PCI and SCI evaluation was done accordingly with is presented in chapter 4.

5.2.2 Runway PCI/SCI Results

TABLE 5.2 – RUNWAY RESULTS OF PCI/SCI

Branch	Section	Sample	Sample Unit PCI Value	Sample Unit SCI value	Section PCI Value	Section SCI Value
Runway	R1	R11	78	98	77	97
		R12	79	98		
		R13	81	95		
		R14	69	97		
		R15	78	95		
	R2	R21	70	100	56	86
		R22	68	90		
		R23	56	90		
		R24	30	44		
		R25	54	79		
		R26	34	77		
		R27	60	82		
		R28	72	92		
		R29	67	89		
		R210	55	77		
		R211	47	91		
		R212	12	48		
		R213	51	80		
		R214	43	83		
	R3	R31	62	82	69	89
		R32	58	77		
		R33	78	100		
		R34	68	86		
		R35	78	98		
	R4	R41	56	84	60	87
		R42	35	80		
		R43	40	84		
		R44	65	92		
		R45	60	93		

5.3 The Process of Automation of PCI Calculation

5.3.1 Automation of Deduct Value calculation

The whole idea has initiates using "MS Excel" by starting to automate the PCI calculation from the airport runway visual inspection data sheets survey. After performing the process manually (chapter 4) was noticed that the use of abacus manually is not only time consuming but also subjective.

For example, the Corner Break distress at density 15:

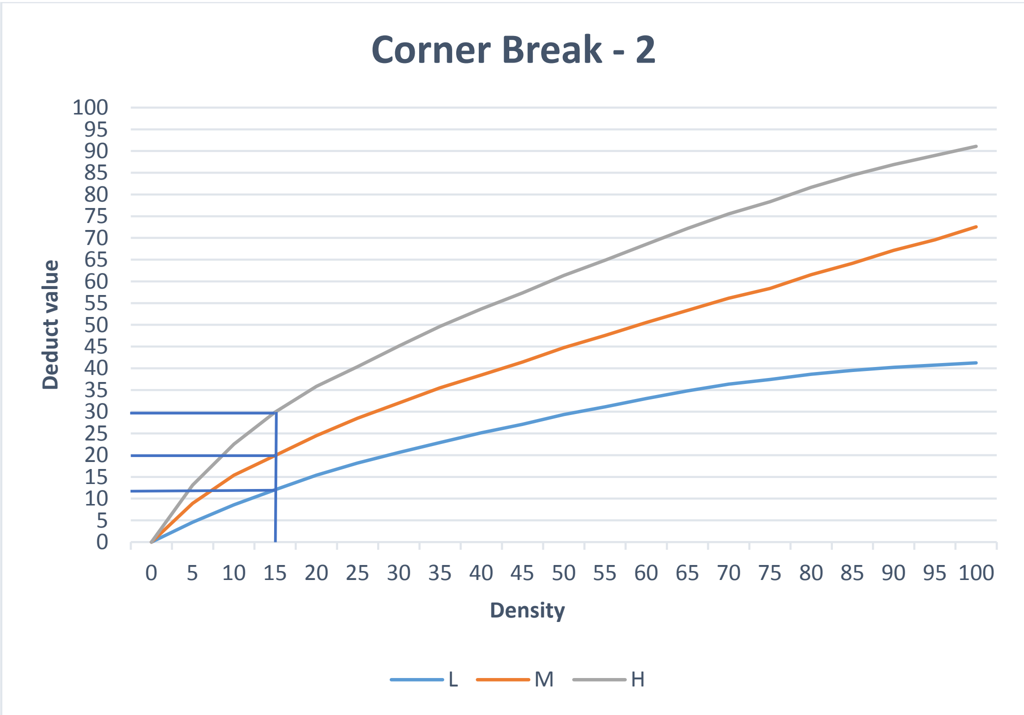

FIGURE 5.1 – CORNER BREAK ABACUS

If a line is drown, crossing the severity level curves at 15, the Deduct Values (DV) will be apparently at low severity 11, at moderate severity 20 and at high severity 30. Well, in this case it might not be much further from the real values, but the reading performed by different persons can be, and the propagation of the error at the end of the evaluation of the section might be significant.

By this, the first step was to avoid the manually consultation of the abacus and with that, to reduce the subjectivity and human error of the PCI evaluation. The process started by taking all the values from the sixteen abaci. From those, twelve has three severity level curves, three just one for twenty possible distress densities, and one does not have an abaci just a value for each severity level. All these values were taken by a spline interpolation from the abacus given from (ASTM - D5340, 2011) norm and are available at the FAA website.

Once having all the DVs the procedure was to organize each distress DV in a table, for example:

TABLE 5.3 – ALL DEDUCT VALUES FOR CORNER BREAK ABACUS (2)

Density\ Severity	L	M	H
0	0	0	0
5	4.55	8.92	13.11
10	8.57	15.38	22.55
15	12.06	19.93	29.9
20	15.38	24.48	35.84
25	18.18	28.5	40.38
30	20.63	31.99	45.1
35	22.9	35.49	49.65
40	25.17	38.46	53.67
45	27.1	41.43	57.34
50	29.37	44.76	61.36
55	31.12	47.55	64.86
60	33.04	50.52	68.53
65	34.79	53.32	72.2
70	36.36	56.12	75.52
75	37.41	58.39	78.32
80	38.64	61.54	81.64
85	39.51	64.16	84.44
90	40.21	67.13	86.89
95	40.73	69.58	88.99
100	41.26	72.55	91.08

Thus, the procedure was to assign each severity level to a column, for example, every time the severity level is low "L" the program will search for values on the second column, moderate "M" at the third and so on. After assign each severity level to each column the following step was to assign each density to a line. So, for example, if we have low severity distress with 15 of density, the program will look for the DV at the fifth line and second column, which is 12.06 (previously, when checking for the DV manually the value was 11, so it is 1.06 points of PCI difference in just one sample unit). Once finished this step, the following one was to automate the calculation of the density. Thus, the inspector just have to decide which distress, which severity level and how many slabs are affected and the deduct values will automatically be calculated.

5.3.2 Automation of Corrected Deduct Value calculation

The procedure of corrected deduct value (CDV) calculation was similar to DV's. It started from taking all the CDV numbers from Corrected Deduct Value abacus from the six curves from 10 to 10, starting at 0 and ending at 180 as show below at Table 5.4 with the "q" representing the quantity of number greater than 5.

TABLE 5.4 – CORRECTED DEDUCT VALUES TABLE

CDV\q	q1	q2	q3	q4	q6	q8
0	0	0	0	0	0	0
10	10	7	7	6	6	5
20	20	16	14.5	13	13	12
30	30	24.5	22	20.5	20	19
40	40	33	30	27.5	26	25
50	50	42	37	35	33	31
60	60	51	45	42	40	37
70	70	60	53	49	46.5	42.9
80	80	68.5	60.5	55.8	53	48.5
90	90	77	68	62.5	59	54,5
100	100	85.5	75.9	68	64.5	60
110	100	91	82.8	74	70	64.5
120	100	96.5	88.8	79	74.8	70
130	100	100	93.9	84	79.8	74
140	100	100	97.8	88	84	77.9
150	100	100	100	92	87.9	82
160	100	100	100	95.5	91.5	85
170	100	100	100	98	94	88
180	100	100	100	100	96.2	91

To calculate the CDV first it is necessary to calculate the "m" with highest DV as shown at the chapter 4. For example:

TABLE 5.5 – PCI DATA SHEET FROM THE AIRPORT VISUAL SURVEY SAMPLE UNIT R22 AS AN EXAMPLE

Distress type	Severity Level	Number of Slabs	Density %	Deduct Values
13	N/D	12	60	9.68
6	L	2	10	2.43
16	L	20	100	22.03
15	L	1	5	2.33

To calculate the m, the program will look for the highest number in the column of the DV, resulting in this case the value of m:

m ≤ 10
8.3866

Which mean that the table is limited to the 8 higher DV numbers to calculate the CDV, plus the lower DV multiplied by the fraction of the m (2.33×0.3866). In this case four DV numbers are used, as follows:

TABLE 5.6 – CALCULATION OF CDV VALUE

#	Deduct Values									Total	q	CDV
1	22.03	9.68	2.43	2.33					0.900778	37.37	2	
2	22.03	5	2.43	2.33					0.900778	32.69	1	

The values in the table are organized from the highest to the lowest DV, in every line, changing the lowest number greater than 5 to 5 after the second line, giving thus the number of "q" which as explained before (chapter 4) is the number of DVs greater than 5. Done this, the calculation of the CDV can be programmed.

The difference in this case, compared with the previous automation of abaci, is that the sum of the DVs is not an integer number (such as 10, 20), and there are just six curves when eight are needed (see figure 6.2).

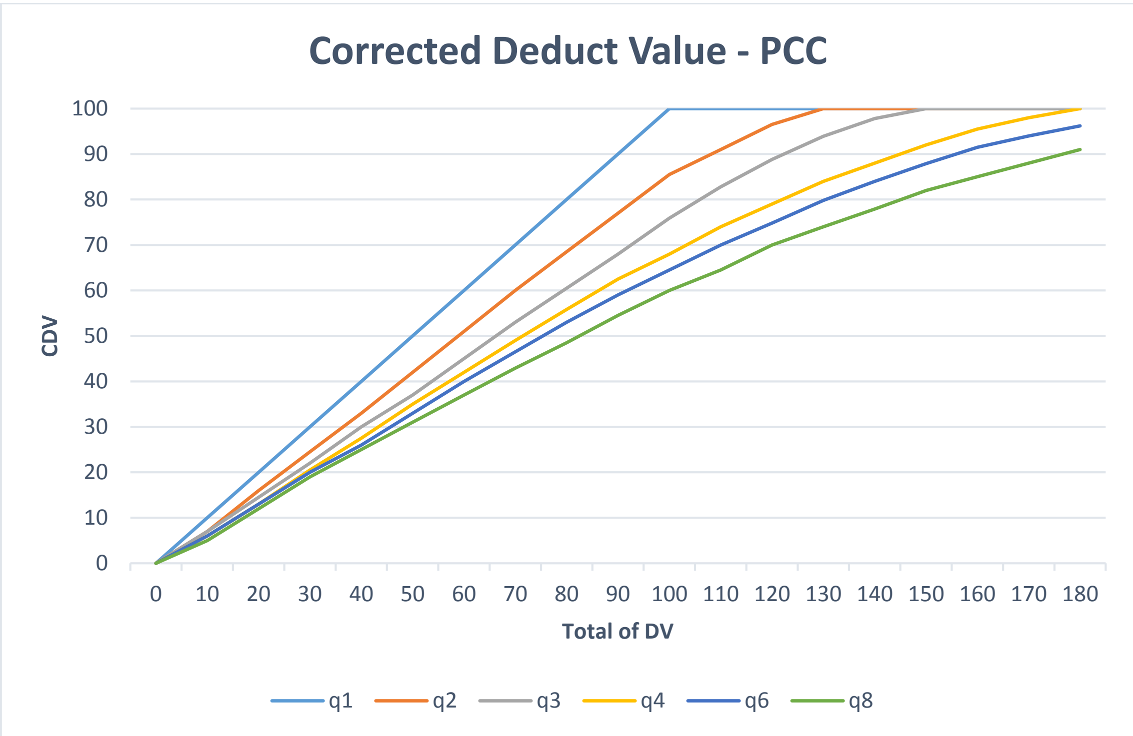

FIGURE 5.2 – CORRECTED DEDUCT VALUE CURVES - PCC

As shown in figure 5.2 abacus, there are six curves. The curve q1, when only one DV number is greater than 5, the curve q2 when two DV numbers are greater than 5 and successively up to q8.

Although, it is possible to have five and seven numbers greater than 5, which make necessary to have the curves q5 and q7. To have those curves, the procedure was to make an average between the known points in the line above and below, for example, to q5 curve, the average was made between q4 and q6 points.

Once the “missing” curves were “found”, the following procedure was to automate the calculation of CDV.

TABLE 5.7 – CDV NUMBERS TO ALL CURVES

CDV\q	q1	q2	q3	q4	q5	q6	q7	q8
0	0	0	0	0	0	0	0	0
10	10	7	7	6	6	6	5,5	5
20	20	16	14.5	13	13	13	12.5	12
30	30	24.5	22	20.5	20.25	20	19.5	19
40	40	33	30	27.5	26.75	26	25.5	25
50	50	42	37	35	34	33	32	31
60	60	51	45	42	41	40	38.5	37
70	70	60	53	49	47.75	46.5	44.7	42.9
80	80	68.5	60.5	55.8	54.4	53	50.75	48.5
90	90	77	68	62.5	60.75	59	56.75	54.5
100	100	85.5	75.9	68	66.25	64.5	62.25	60
110	100	91	82.8	74	72	70	67.25	64.5
120	100	96.5	88.8	79	76.9	74.8	72.4	70
130	100	100	93.9	84	81.9	79.8	76.9	74
140	100	100	97.8	88	86	84	80.95	77.9
150	100	100	100	92	89.95	87.9	84.95	82
160	100	100	100	95.5	93.5	91.5	88.25	85
170	100	100	100	98	96	94	91	88
180	100	100	100	100	98.1	96.2	93.6	91

The calculation of the CDV was made between two points of the same curve by the line equation for each q curve. For example:

$$y = bx + a$$

Where:

y – It is the dependent conjunct of the data.

b – It is the slop

x – It is the independent conjunct of the data.

a – It is the regression line

Coming as example for q2:

TABLE 5.8 – REGRESSION LINE POINTS AND SLOPE FROM CDV GRAPHIC CURVE Q2

q2	
a	**b**
0	0.7
-2	0.9
-1	0.85
-1	0.85
-3	0.9
-3	0.9
-3	0.9
0.5	0.85
0.5	0.85
0.5	0.85
30.5	0.55
30.5	0.55
54.5	0.35
100	0
100	0
100	0
100	0
100	0

The first line of "a" and "b", was calculated by the regression line and slope, respectively between the first two points of the table 5.7 marked by black. The second line of "a" and "b" between the second and third points from the CDV table (table 6.7) marked by red and so on.

Resulting for the example given at table 5.5:

TABLE 5.9 – RESULTS FROM UNIT SAMPLE R22

	q1	q2
Value to Search	32.69	37.37
Value given	**32.69**	**30.76**
Auxiliary a:	0	-1
Auxiliary b:	1	0.85

Finally the PCI calculation comes as:

$$\boldsymbol{PCI} = 100 - highest\ value\ give = 100 - 32.69 = \mathbf{67.31}$$

5.3.3 Structural Condition Index Automation

The automation of the Structural Condition Index (SCI) was practically done with the automation of the PCI, if a sample unit (SU) have one of the six distresses mentioned for structural failure as showed before and presented by (Rollings, 1988) the procedure is to subtract that deduct value to 100, which represent a pavement in a totally safe structural behavior. If a sample unit have more than one structural distress, an adjusted deduct value (ADV) is need. That ADV will be taken as explained at chapter 5 from the CDV abaci. For example:

TABLE 5.10 – SCI AUTOMATION FROM UNIT SAMPLE R22 AS AN EXAMPLE

SCI Distresses				
13	N/D	12	60	9,68
15	L	1	5	2.33
			Total	12.01
			Adj. DV	8.81
			SU. SCI	**91.19**

TABLE 5.11 – ADJUSTED DEDUCT VALUE CALCULATION

	q2
Value to Search	12.01
Value given	**8.81**
Auxiliary a:	-2
Auxiliary b:	0.9

5.4 The Tablet Application – AirPav Inspector

The Tablet application was developed in parallel with the automation of the PCI/SCI calculation. However, in this case, the programming is made in Java[tm] using free software provided by the website (Android, 2014) Eclipse.

The AirPav Inspector's end is to replace the data sheet survey (figure 4.2) and make all the visual inspection procedure from evaluation and registration of the distresses to the calculation of PCI much easier. All visual survey will be register at the same data base with the respective information, date, location, branch, section, sample unit, slab number, distress types, severity levels, quantities and name of the surveyors to each unit sample, instead of various data sheet for each unit sample.

The program has a standard of twenty buttons simulating the usual number of twenty contiguous slabs in a unit sample as also has a data base with all rigid pavements distresses details, from description to how the measurements should be done to evaluate the severity levels. Each sample unit will be grouped accordingly with their branch and section.

FIGURE 5.3 – AIRPAV INSPECTOR

Each button gives the surveyor the option to choose the potential distress affecting the slab (figure 5.4).

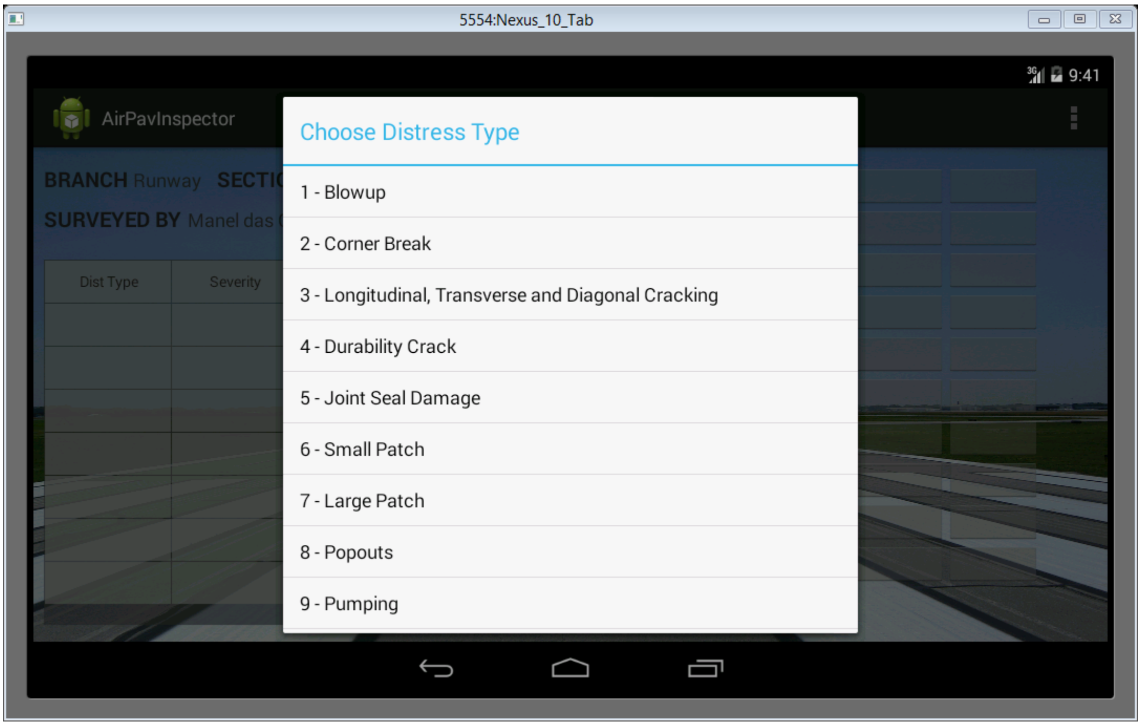

FIGURE 5.4 – AIRPAV INSPECTOR DISTRESS OPTION

The distresses will appear as a number accordingly with the (ASTM - D5340, 2011) from 1 to 16 as shown in the figure above. After choosing the potential distress, another pop-up will appear with the option of choosing the level of severity (figure 5.5). In the case of a slab with more than one severity of the same distress, the AirPav Inspector will automatically choose the higher severity of the same distress type, accordingly with the critter given by (ASTM - D5340, 2011).

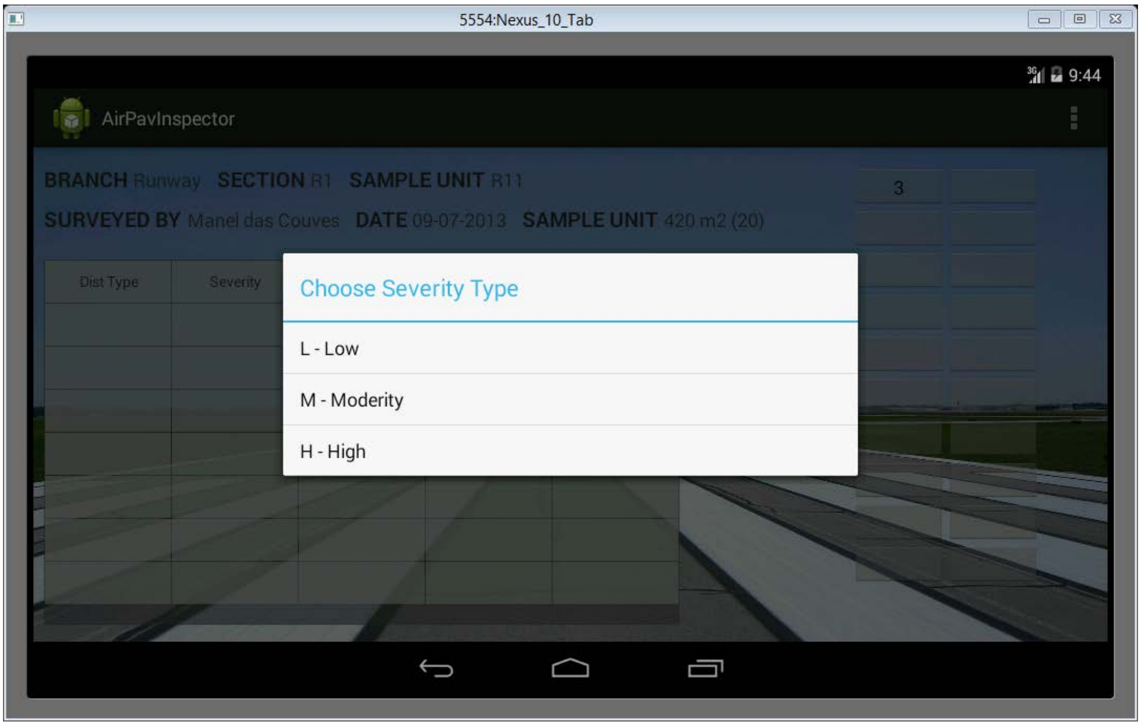

FIGURE 5.5 – AIRPAV INSPECTOR SEVERITY OPTION

After this steps, the distresses will be grouped in a table similarly to the real data sheet survey (see figure 4.2 and figure 5.3) by distress type, severity level, number of slabs, density and deduct value. The table will be automatically updated during the input data for each slab (figure 6.6).

FIGURE 5.6 – AIRPAV INSPECTOR CALCULATION OF THE DEDUCT VALUE

The surveyors now with the AirPav Inspector just have to choose accordingly to their knowledge and the data base given by the AirPav Inspector and gathered in this thesis, the types of distresses and their severity level and the Deduct Value will be automatically calculate.

For now, the tablet application is in its beta version and currently it has to be used in symbioses with the automation of the PCI/SCI made in MS Excel to calculate the overall PCI. Nevertheless, all the procedure is already significantly faster and easier to be performed.

5.5 Analysis of the Impact of Subjectivity of Visual Inspection

Maintenance and rehabilitation solutions would be easy to be planed if pavements exhibited clear signs that they had reached this point, but unfortunately, they do not. A pavement deteriorating from environmental damage may have a number of cracks that need filling but still remain structurally sound. On the other hand, this same pavement may be in the early stages of load damage deterioration, which can only be detected with proper testing.

Therefore, differentiating between some of airport rigid pavements distresses may be subjective. In this subjectivity there is one of the sixteen airport distresses that needs special attention due to its severity and evolution in time and also due to the resemblance of its symptoms to other distresses, the Alkali-Silica Reaction (ASR) (Thomas, Fournier, Folliard, & Resendez, 2012). This distress as explained before (chapter 2), has among other symptoms a map pattern cracking, fine lines of cracks, extrusion of the joint sealant material and surface pop-outs. Those visual symptoms can be easily mistaken to another distress types such as Scaling/Map Cracking (figure 5.7) or Shrinkage Cracking for example.

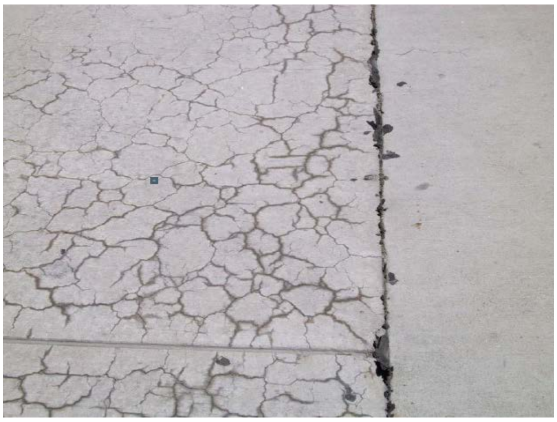

FIGURE 5.7 – ON THE LEFT THERE IS AN EXAMPLE OF SCALING/MAP CRACKING AND ON THE RIGHT AN EXAMPLE OF ASR WITH JOINT SEALANT FAILURE (THOMAS, FOURNIER, FOLLIARD, & RESENDEZ, 2012)

It should be taken into account that ASR is much more damaging to the pavement than the other distresses. Consequently, when doing a visual inspection sometimes it is hard to judge which distress is affecting the pavement without destructive tests for proper laboratory testing.

Therefore, for this study the methodology consists in considering that the ASR evaluation was erroneous in the original visual inspection, so, this distress was replaced in the iteration analysis by other distresses that present similar effects as ASR, such as Shrinkage Cracking (13), Scaling/Map Cracking (10) and Longitudinal, Transverse and Diagonal Cracking (3).

For the analysis of the subjectivity and of the influence of ASR in the final PCI classification, were chosen the two worst sections of the inspected airport presented previously, the section R2 and R4 (see table 5.2). Each sample unit was inspected and sketched on an individual data sheet survey as it is shown in the figure 5.8 as an example.

AIRFIELD CONCRETE PAVEMENTS
CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT

BRANCH: Runway | SECTION: R2 | SAMPLE UNIT: R214

SURVEYED BY: | DATE: 13/07/2013 | SAMPLE AREA: 20

Distress Types

1- Blow up
2- Corner Break
3- Long/Tran/Diagonal Crack
4- Durability Crack
5- Joint Seal Damage
6- Patching <0,5m²
7- Patching/Utility Cut >0,5m²
8- Popouts
9- Pumping
10- Scaling/Map Crack/Crazing
11- Settlement/Fault
12- Shattered Slab
13- Shrinkage Crack
14- Spalling-Joints
15- Spalling-Corner
16- Alkali-Silica Reaction

DIST TYPE	SEV	Nº SLABS	DENSITY %	DEDUCT VALUE
5	L	20	100	2
3	L	8	40	18.69
4	L	3	15	8.5
8	N/D	3	15	9.89
10	L	13	65	4.66
13	N/D	3	15	2.87
16	L	16	80	21.5
16	M	1	5	14.16

SKETCH

16L 10L 13	16L 3L 8			
16L 4L 8	16L 3L 8 10L			
16L 4L 3L	16L 3L 10L			
16L 10L	16L 3L			
16L 13 10L	16L 10L			
3L 10L 16L	3L 13 10L			
10L	16L 10L			
10L 16L	10L 16L			
4L 3L	16L 10L			
16M	16L			

FIGURE 5.8 – DATA SHEET SURVEY ON SAMPLE UNIT R214 OF THE SECTION R2

In this particular example (sample unit R214), it is possible to notice that there are seventeen slabs affected by ASR, most part of these slabs besides of ASR are affected by other distresses, such as Scaling/Map Cracking, Shrinkage Cracking and Longitudinal, Transverse and Diagonal Cracking. These distresses have, as shown before, similar symptoms, and without proper testing it is difficult to be sure of which ones are affecting the slab. Therefore, an iterated process was made, replacing ASR by other possible mistaken distresses. To demonstrate the procedure, an example is presented herein in the table 5.12.

TABLE 5.12 – ITERATION TABLE FROM ALKALI-SILICA REACTION TO SCALING/MAP CRACKING AT SAMPLE UNIT R214

Distress type	Severity level	Number of Slabs	Density %	Deduct Value
5	L	20	100	2
3	L	8	40	18.69
4	L	3	15	8.5
8	N/D	3	15	9.89
10	L	18	90	6.09
13	N/D	3	15	2.87
10	M	1	5	4.3

In the table 5.12, ASR (16) was replaced by Scaling/Map Cracking (10). The slabs having both distresses 16 and 10 were registered as having only 10, once only two slabs were registered with 10 Cracking without 16, two slabs were added to the sixteen already registered, as it is possible to see at table 5.12.

This procedure was repeated on all the sample units for all the iterations to calculate the overall PCI and SCI of the sections according with (ASTM - D5340, 2011).

The following column graphics (figure 6.9 and 6.10) show the differences of PCI and SCI respectively at section R2, in each sample unit, after change the ASR (16) to Scaling/Map Cracking (10) and Shrinkage Cracking (13).

As it is possible to see in the figure 6.9 after the modification of ASR to other distresses the PCI in each sample unit improved significantly when comparing to the original, however, in some sample units the alteration to Scaling/Map Cracking raised the PCI more than the Shrinkage Cracking and vice versa. Although, the same does not happen in figure 6.10 where the modification of ASR to Scaling/Map Cracking did not change anything at the SCI level when comparing to the original. The reason is due the fact that both ASR and Scaling/Map Cracking are not considered a structural distress (Rollings, 1988).

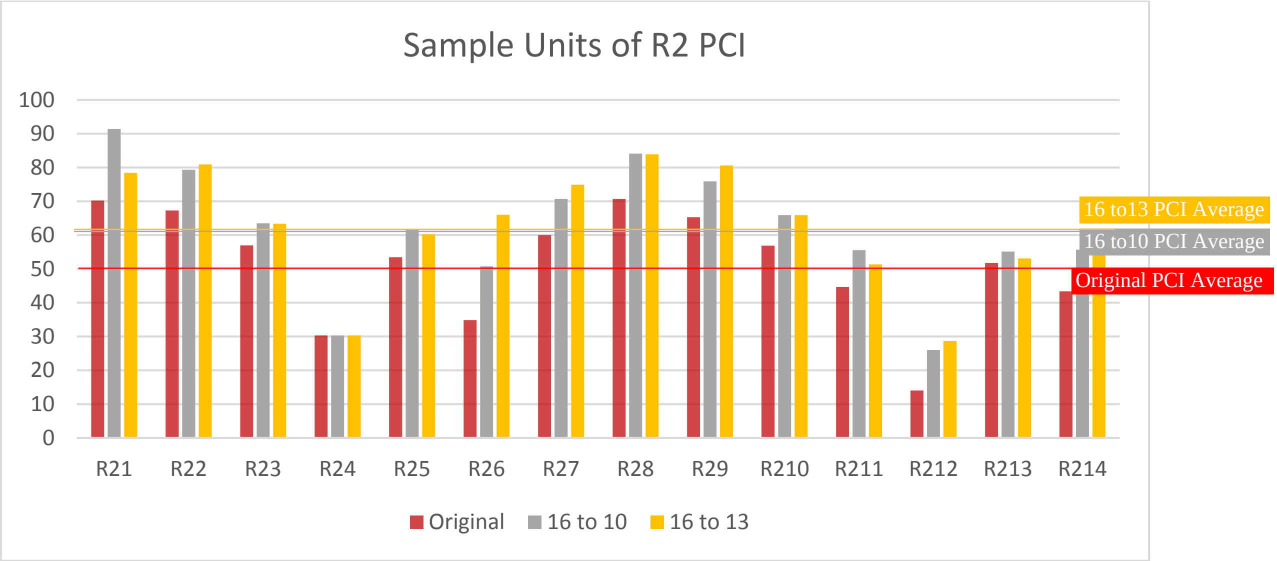

FIGURE 5.9 – PCI SAMPLE UNITS OF SECTION R2

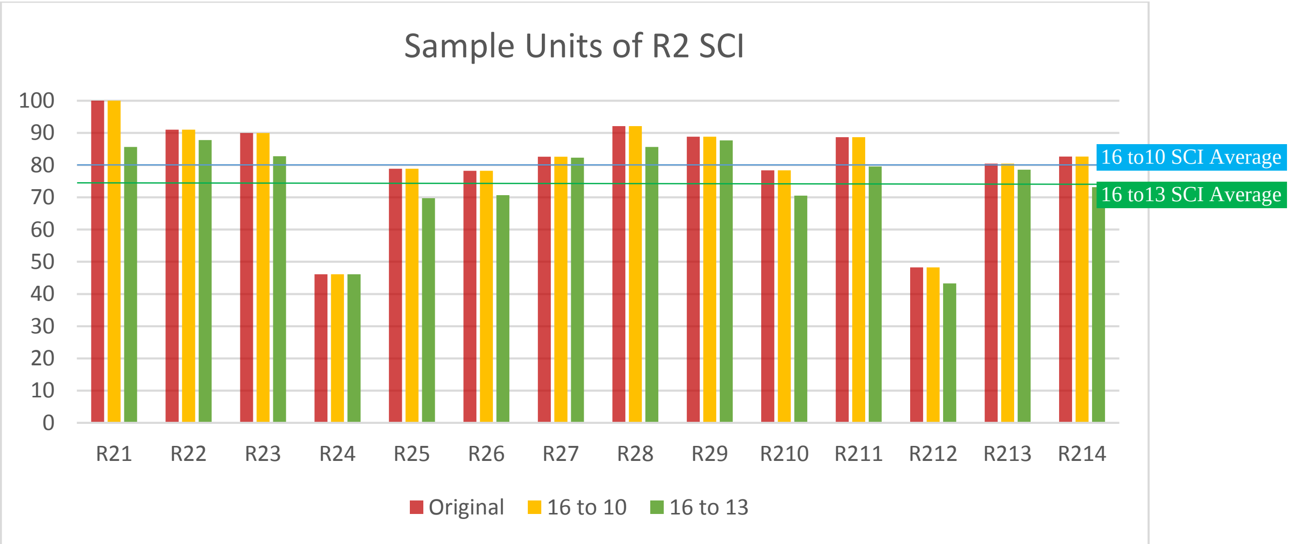

FIGURE 5.10 – SCI SAMPLES UNITS OF THE SECTION R2

Presented the iteration procedure, the PCI and SCI results obtained in both sections, R2 and R4 were analyzed and compared as follows.

5.5.1 Influence of Considering Alkali-Silica Reaction distress Compared to other Similar Distresses

As the title suggests, has been changed every slab at the unit samples with ASR to potential distresses that it can be confused with, in case not performing laboratory tests for confirmation of ASR presence, such as the three distresses mentioned before or a combination of them: Scaling/Map Cracking (16 to 10), Shrinkage Cracking (16 to 13), Shrinkage Cracking and Scaling/Map Cracking (16 to 13 and 10) and finally Shrinkage Cracking and Longitudinal, Transverse and Diagonal (L/T/D) cracks (16 to 13 and 3).

The reason to change ASR to two different distresses it is due to the fact that Shrinkage Cracking does not have a severity level defined, so, in the case where ASR was moderate severity level it has been changed to Scaling/Map Cracking in one case and in other case to L/T/D, both at moderate severity level. The results obtained are presented in figure 5.11:

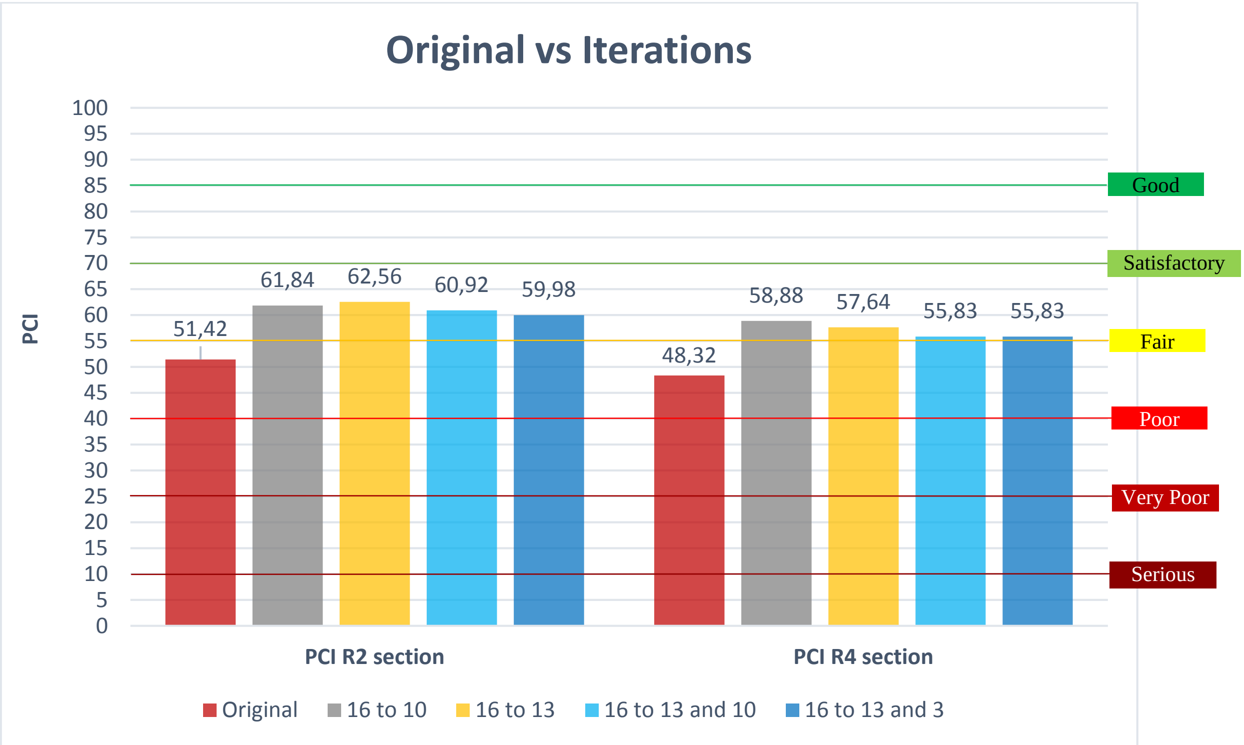

FIGURE 5.11 – COMPARISON OF ORIGINAL PCI WITH THE PCI WITHOUT ASR

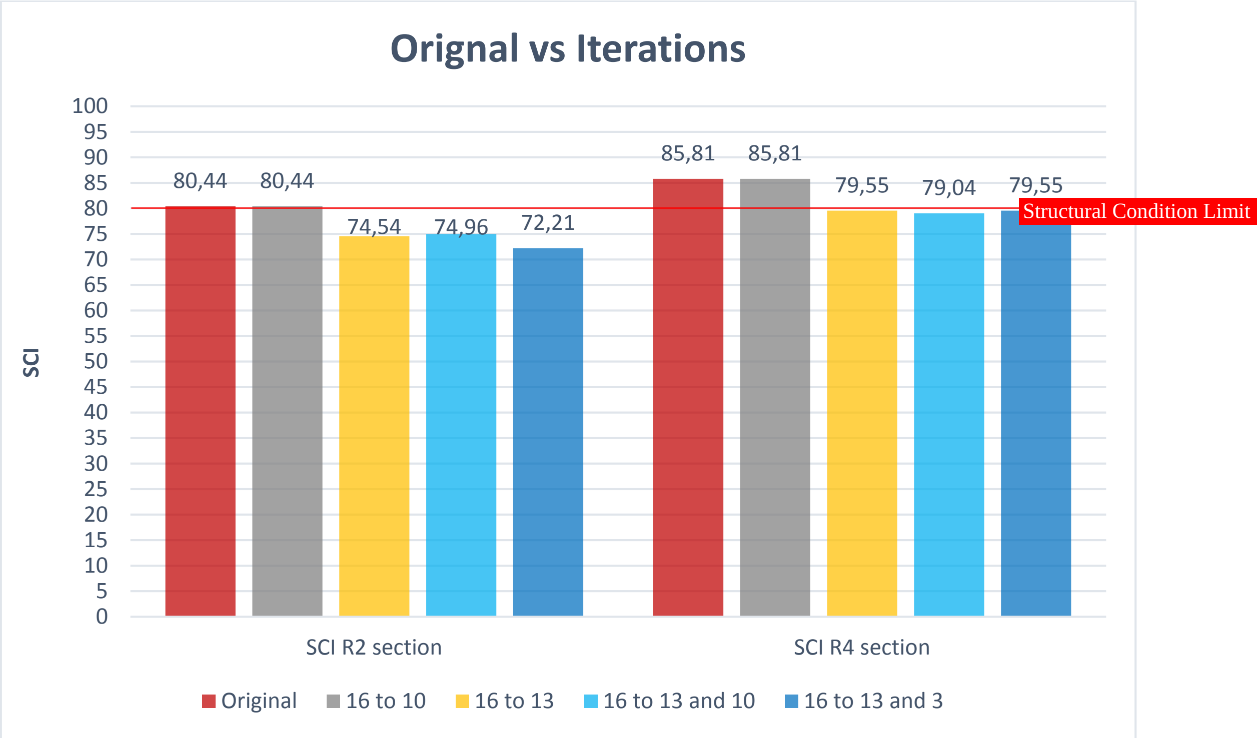

FIGURE 5.12 – COMPARISON OF ORIGINAL SCI WITH THE SCI WITHOUT ASR

In this first approach, when ASR was replaced with other distresses, as explained before, the PCI increases as presented in figure 5.11. When looking at the PCI rating scale in figure 5.1, it is possible to classify the original state of the pavement as poor and after the changes it is noticeable that it increases to fair, which accordingly with the airport management pavement system (APMS) is the minimum PCI level to maintain the pavement without a major rehabilitation (FAA, 2006). Although, the structural condition of the pavement (figure 5.12) slightly decreases after these changes, this is due the fact that ASR is not considered (yet) a structural condition distress, while shrinkage cracking, which was one of the iterated distress, is. As it is possible to notice by the figure 6.12 only the iterations with Shrinkage Cracking (13) affected the structural condition of the pavement. The fact of changing ASR to another distress which it can be mistaken with, improved the state of the pavement from needing a major rehabilitation to the state where the rehabilitations can be four to five times cheaper, however, the structural condition of the pavement got slightly worse which creates an ambiguity.

5.5.2 Study of the Influence of Possible Maintenance/Rehabilitations Measures on the PCI Evaluation

In this part of the process the original PCI from the survey suffered a few alterations to simulate possible maintenance and rehabilitation (M&R) actions in the pavement. For example, all Joint Sealant Damage distresses were eliminate to simulate a new joint sealant (Just JS) replacement as well as the distresses which can be fixed with a sealant, such as low severity L/T/D cracks, Corner and Joint Spalling at low severity levels. In the cases where Corner and Joint Spalling presented moderate severity these were considered rehabilitated by patching in addition to the cracks already sealed (JS and Patch) so they appear in the PCI evaluation as replaced by Small Patch. For the higher levels of distress which were L/T/D cracks, ASR and Scaling/Map Cracking the entire PCC slab was considered to be rehabilitated by being replaced as well as the joint sealant in the sample unit. In one case, just ASR and Scaling/Map Cracking in moderate severity were rehabilitated (Slab Replacement 10 and 16), and in other case, due its structural effects was also rehabilitated L/T/D cracks (Slab Replacement 3, 10 and 16).

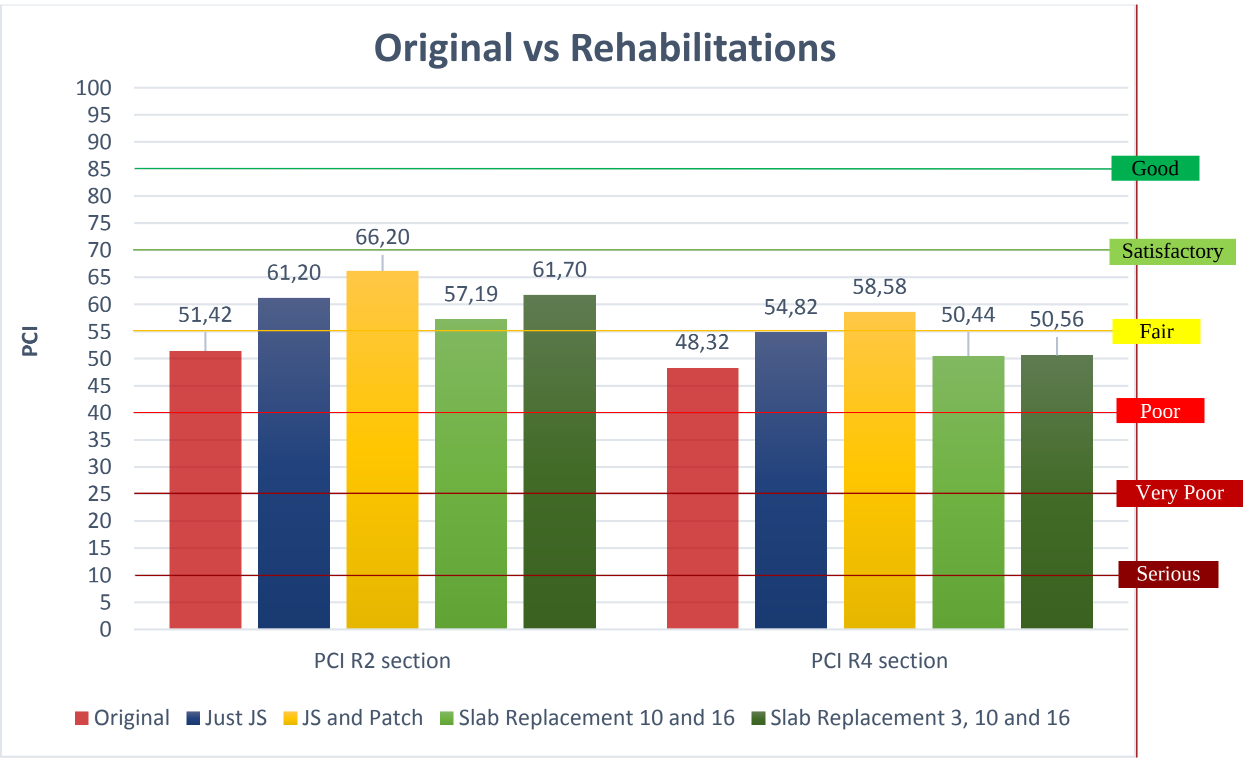

FIGURE 5.13 – ORIGINAL PAVEMENT CONDITION AND REHABILITATIONS

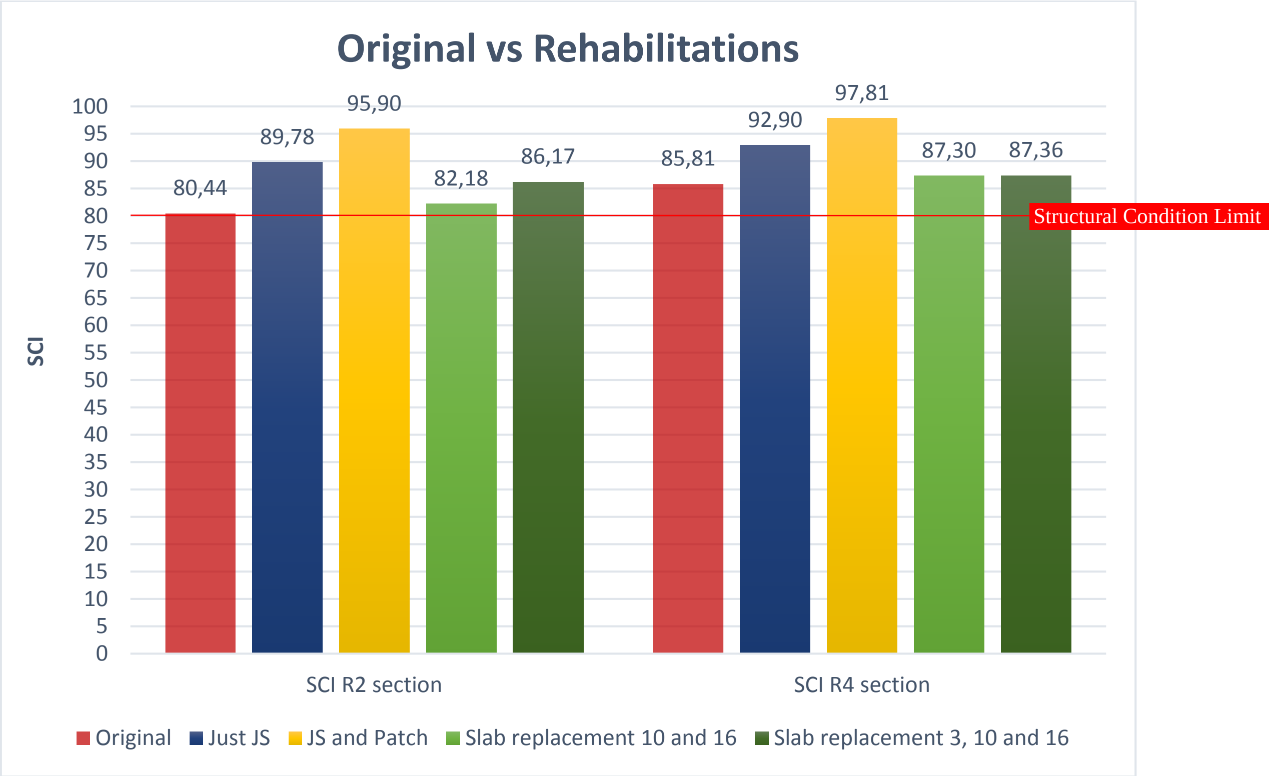

FIGURE 5.14 – ORIGINAL STRUCTURAL PAVEMENT CONDITION AND REHABILITATIONS

On this next iteration (figure 5.13), was simulated a rehabilitation of the original pavement state. As it is possible to see, the pavement condition improved, however, only at section R2 it got significantly better, while section R4 still remained in a poor condition. Accordingly with the Airport Pavement Management System (APMS), this fact is due the pavement already reached the poor state of use, and the rehabilitation procedures were not enough to rehabilitate the pavement to a satisfactory level, by this and proving the statement of APMS, the rehabilitation procedures have to be bigger and consequently more costly. On other hand, the structural condition index (SCI) of both section increased (figure 5.14) after the rehabilitation interventions. This is due the fact that most of the cracks were fixed by joint sealant and patching, such as L/T/D, Corner and Joint Spalling at low severity and moderate levels, respectively. As a method of maintenance/rehabilitations these are expensive, and the costs depends on the depth of the interventions made in the pavements, being the joint sealant the cheapest and the slab replacement or total reconstruction the most expensive. However, in a long term point of view the pavement will maintain its condition at a higher level for longer period, continuing to provide a satisfactory level of use (figure 5.15).

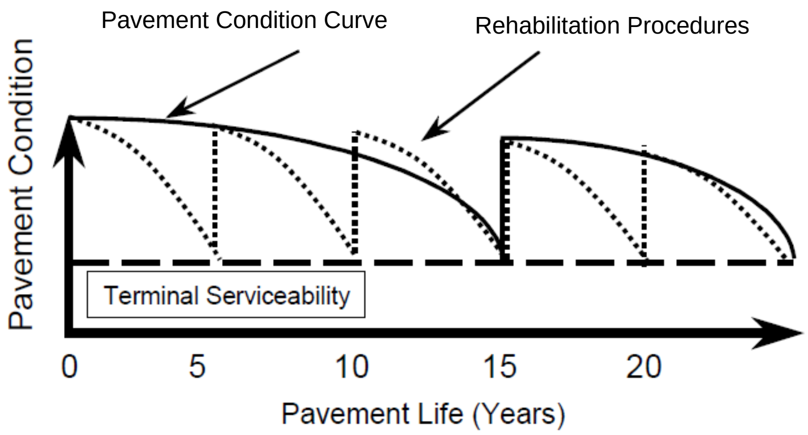

FIGURE 5.15 – DURABILITY OF A PAVEMENT IN LONG-TERM WITH REHABILITATIONS STRATEGIES (WALLS & SMITH, 1998)

5.5.3 The Influence of Maintenance/Rehabilitations on the Alkali-Silica Reaction Iterations

In this procedure, were combined the ASR iterations as made before with the rehabilitations as well, a part of slab replacement which is a last measure in case of pavement distresses due its costs.

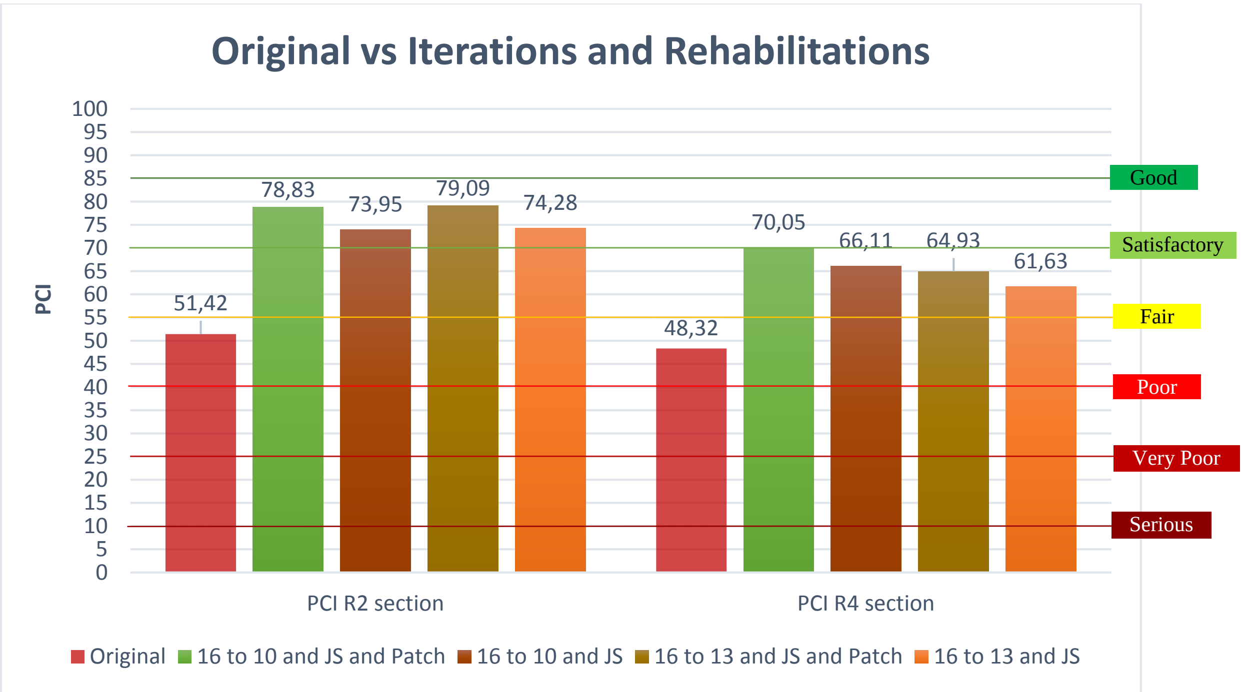

FIGURE 5.16 – ORIGINAL PAVEMENT CONDITION WITH THE ITERATIONS AND REHABILITATIONS

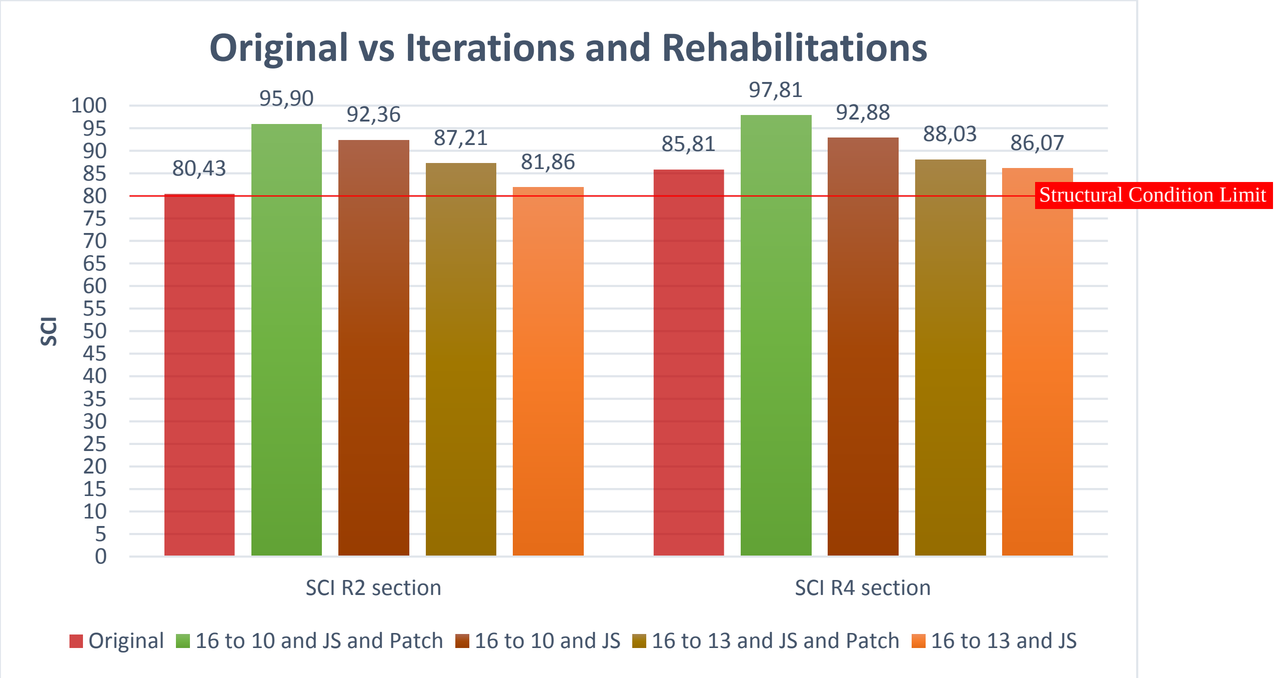

FIGURE 5.17 – ORIGINAL STRUCTURAL PAVEMENT CONDITION WITH ITERATIONS AND REHABILITATIONS

In this final approach (figure 5.16 and 5.17) where the previous iterations were combined, the PCI and SCI levels increased significantly, passing the pavement state from poor to satisfactory. In this PCI level the pavement is already in a comfortable state of use merely with sealing joints and patches with no need to major rehabilitations. The fact of changing a distress such as ASR to Scalling/Map Cracking (16 to 10) or Shrinkage Cracking (16 to 13) in addiction with a simple maintenance such as sealing joints, cracks and patching, made a considerable improvement in the pavement either at the level of PCI as the SCI.

5.6 Results Analysis

The fact of changing the ASR to the distresses mentioned before in the first approach, improved the pavement condition index in average of 16.16% in the section R2 and 15.3% in the section R4. However, the structural condition index decreased in average of 6.09% and 5.62% in sections R2 and R4, respectively.

In the second approach, the procedures of maintenance and rehabilitation improved the sections R2 and R4 in average of 16.49% and 9.85%, respectively in PCI and 9.13% and 6.05%, respectively in SCI.

Finally, the ASR iterations in combination with maintenance/rehabilitation procedures, improved the pavement condition in average of 32.82% and 26.43% in the sections R2 and R4, respectively. The structural improvements were in average of 9.97% and 8.91% in the sections R2 and R4, respectively. This fact, prove the subjectivity of the PCI evaluation, when preparing maintenance and rehabilitation programs and also highlight the effect of ASR distress in a pavement when is or not registered.

By the deterioration curve, a pavement just needs major rehabilitations after reaches the PCI level of 55 (fair) and below, before that, a good maintenance of the pavement is enough to ensure the good behavior of the pavement. That maintenance includes the capability of iterate the pavement distress as done in this study case in aid to taking further decisions. Taking this study case as an example, with this iteration process from the automation of the PCI was possible to conclude that the alkali-silica reaction has an important weight in the PCI level of this sections, such important that the rehabilitation procedures simulated, when comparing to the ASR iterations are almost insignificant. Therefore, and to validate the presence of Alkali-Silica Reaction the laboratory testing of cores is advised.

When looking at the PCI scale rate, it is notable that after the failed condition, which is until PCI level 10, the following PCI levels change from 15 to 15. By this, and with the automation of PCI calculation and an engineer judgment when a pavement condition index (PCI) improves at least 15 PCI points when changed by another distress taking a core to proper testing is advised.

6 Conclusions and Future Developments

On the present study it was intended to present, improve and reduce the subjectivity of the Pavement Condition Index (PCI) methodology, as well as to address the Structural Condition Index (SCI) (Rollings, 1988), and to automate the calculation process. Beside the development and implementation of automation of PCI/SCI calculation, and due to its time effectiveness and precision in the data processing, it was also possible to study the effect of Alkali-Silica Reaction (ASR) distress on the PCI results. The ASR can be confirmed only with laboratory tests, that have to be performed on cores extracted from pavement, and its symptoms on pavement surface are similar to other distresses, less severe for the pavement condition evolution in time.

The PCI evaluation assesses the condition of the pavements based on distresses observed and does not include tests for structural or functional measurement of these characteristics. Nevertheless when performed systematically, it provides an indication of pavement condition evolution in time. This evaluation procedure has widespread acceptance not only in North America but also throughout the world due to reduced costs. While the methodology enables trained and experienced inspectors to gather consistent and repeatable data pertaining to the pavement system, there are limitations to the procedure, particularly when the collected data are used in pavement maintenance programs (PMP). Nevertheless, due to the fact that is a visual inspection procedure, there are some common misapplications that need to be addressed such as subjectivity in the distress evaluation or the fact that the structural condition cannot be assess directly. With few adjustments, some of these limitations can be overcome, making the PCI procedure even more valuable. Some of those limitations can be reduced, such as the subjectivity of the PCI calculation due the abacus consultation and others improved with the introduction of structural condition evaluation.

The fact that two different persons can read slightly different values from an abacus of the same distress, at the same level of severity and density, results in cumulative errors that affects the final PCI value. Year by year this lack of accuracy in the inspection of the same pavement, mainly when the team that performs the inspection is changed, can results in higher errors and, consequently influence the overall state evaluation and the planning and choice of maintenance measures that, are required to rehabilitate the pavement. Also it will influence the maintenance decisions that depend of the PCI evaluation through time, such as airport management pavement system (APMS).

With the automation of the PCI calculation presented on this study, the lack of accuracy is reduced. The same distress, with the same density and severity level, will have the same value, not depending on the person that performs the calculations.

Also, with all the information gathered in this study, from detailed description of rigid pavement distresses to the automation of the PCI/SCI calculation was possible to create a data base for a tablet application (AirPav Inspector) to aid the visual inspection and replace the common data sheet survey used generally in the airports PCI evaluation. Consequently, this will contribute for an easier and confident way to collect the data, time and cost effective, by reducing the time needed in to the office to introduce the data collected in situ and to calculate the PCI/SCI.

In this way, and using the automation of PCI/SCI was possible to study and analyze a real airport rigid pavement with possible Alkali-Silica Reaction (ASR) distress present at the pavement. The study was performed by selecting the two weakest sections of the airport, from PCI/SCI point of view. Both sections present ASR, so the study of its influence in the pavement evaluation was performed by replacing the ASR distress with others that have similar symptoms on pavement surface, and to study the impact on the final PCI/SCI value. As was possible to verify along the iterations, the ASR highly influence the PCI final value has no effect in the pavement structural condition index (SCI).

Also, a study regarding the maintenance effect on the final PCI/SCI value was performed. Thus several measures were considered to be applied to the existing pavement, from sealing joints (less expensive) to slab replacement (most expensive). With rehabilitations such as sealants, patches and replacement of the slab, the PCI did not increase significantly when comparing for example with the ASR iterations. Accordingly with the APMS when a pavement reaches the poor condition, the rehabilitation procedures get four to five times more expensive to rehabilitate the pavement, this fact, may look like rehabilitations at this point is too expensive, although, in a long-term point of view, the pavement will remain longer in that condition.

However, the SCI of the pavement increased because one of the iterated distresses was Shrinkage Cracking which accordingly with (Rollings, 1988) can be considerate a structural distress in long term. This fact, creates an ambiguity and makes the assessment of the pavement condition a harder job when having this possible decision between ASR and other resembling distress. Therefore, a confirmed diagnosis from laboratory testing of cores as to be taken to ensure the presence and extent of ASR.

By this, and combining the results of the laboratory tests, the symptoms from the site investigation and the pavement condition index, should be developed a test to verify and classify the ASR distress as a structural distress, also should be developed a non-destructive analysis to evaluate the ASR without the need of laboratory testing. This non-destructive analysis may pass for a development of a device inserted within the PCC slab to monitor the evolution of ASR since its early stages. Also, as future developments, an entire autonomy of PCI calculation for the AirPav Inspector without the use of the MS Excel automation will be developed and a cloud to synchronize all the data collect during the visual inspection with the AirPav Inspector to a computer data base should be taken into consideration.

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Appendix

Appendix I

Severity Levels of Distresses for Pavement Condition Index Evaluation

General

This chapter presents the levels of severity of each distress mentioned before accordingly with the (ASTM - D5340, 2011), (ASTM - D6433, 2011) and FAA website as well as the way they can be measured during the visual inspection. All the figures shown as example in this chapter for each distress are courtesy of the FAA website (FAA, 2014).

The levels of severity are separated by their level impact on the ride quality by:

- Low: No reduce of speed is necessary for comfort and safety;
- Moderate: Some reduce in speed is necessary for safety and comfort;
- High: Speed must be reduced considerably for safety and comfort.

Airport Rigid Pavement Distresses and their Severity Levels

Each of the distresses has been regrouped according to the style of distress into the following categories:

- Cracking
- Joint Deficiencies
- Surface Defects
- Other Distresses

Cracking

a) Longitudinal, Transverse and Diagonal Cracks.

Severity Levels:

- Low

Crack has little or minor spalling (no foreign object debris (FOD) potential). If non-filled, it has a mean width less than approximately 3 mm. A filled crack can be of any width, but the filler material must be in satisfactory condition; or the slab is divided into three pieces by low-severity cracks

LOW SEVERITY L/T/D

- Moderate

One of the following conditions exists:

1. Filled or non-filled crack is moderately spalled (some FOD potential);
2. A non-filled crack has a mean width between 3 and 25 mm;
3. A filled crack is not spalled or only lightly spalled, but the filler is in unsatisfactory condition;
4. The slab is divided into three pieces by two or more cracks, one of which is at least medium severity.

MODERATE SEVERITY L/T/D

- High

One of the following conditions exists:

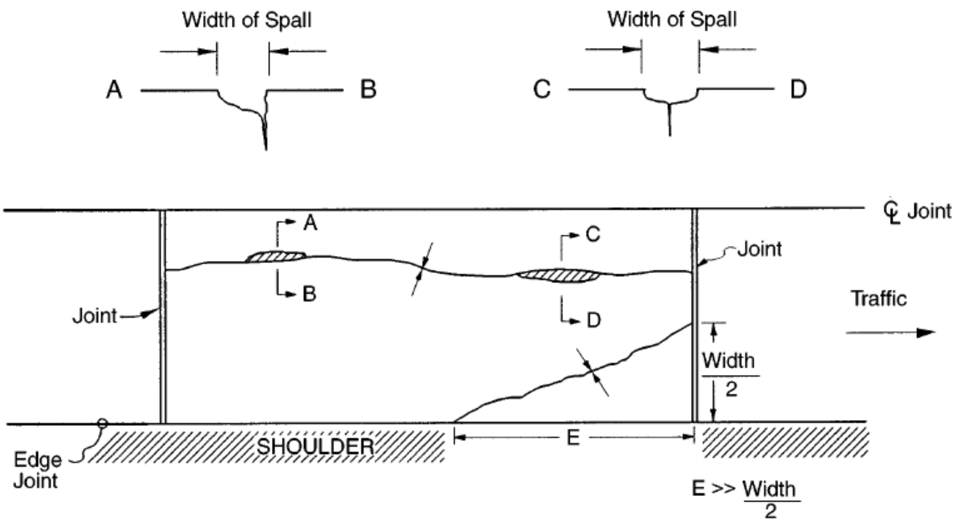
1. Filled or non-filled crack is severely spalled, causing definite FOD potential;
2. A non-filled crack has a mean width greater than approximately 25 mm, creating a tire damage potential;
3. The slab is divided into three pieces by two or more cracks, one of which is at least high severity.

HIGH SEVERITY L/T/D

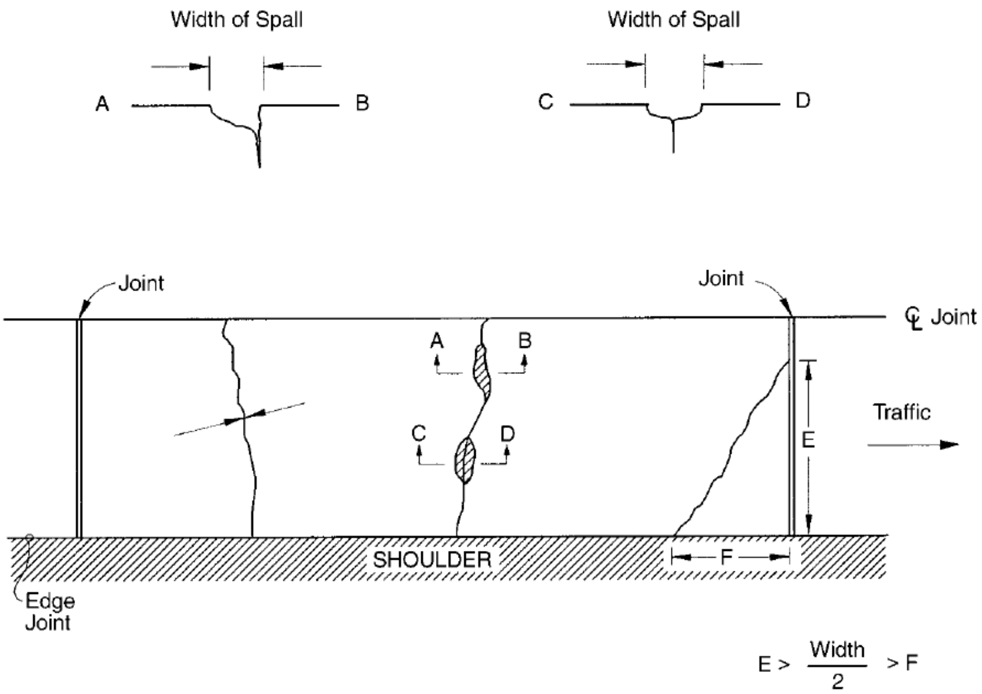
How to measure it:

Once the severity has been identified, the distress is recorded as one slab. Hairline cracks that are only a few cm long and do not extend across the entire slab are rated as shrinkage cracks, if the slab is divided into four or more pieces by cracks, refer to the distress type given for Shattered Slab.

Cracks used to define and rate corner breaks, durability "D" cracks, patches, shrinkage cracks, and spalls are not recorded as Longitudinal, Transverse and Diagonal (L/T/D) cracks.



MEASURE OF LONGITUDINAL CRACKING (MILLER & BELLINGER, 2003)



MEASURE OF TRANSVERSE CRACKING (MILLER & BELLINGER, 2003)

b) Durability "D" Cracking.

Severity Levels:

- Low

"D" cracking is defined by hairline cracks occurring in a limited area of the slab, such as one or two corners or along one joint. Little or no disintegration has occurred. No FOD potential.

LOW SEVERITY "D" CRACKING

- Moderate

"D" cracking has developed over a considerable amount of slab area with little or no disintegration or FOD potential; or "D" cracking has occurred in a limited area of the slab, such as one or two corners or along one joint, but pieces are missing and disintegration has occurred. Some FOD potential.

MODERATE SEVERITY "D" CRACKING

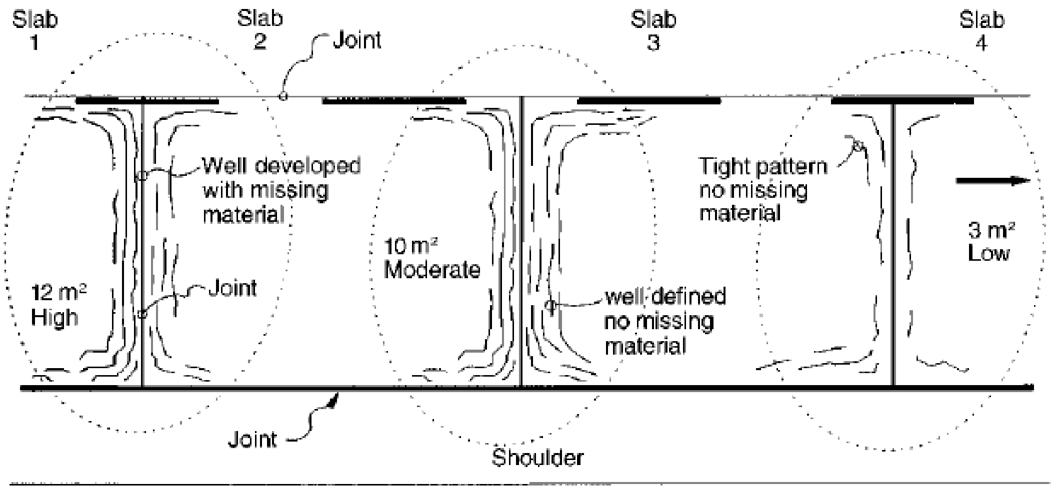
- High

"D" cracking has developed over a considerable amount of slab area with disintegration or FOD potential.

HIGH SEVERITY "D" CRACKING

How to measure it:

When the distress is located and rated at one severity, it is counted as one slab. If more than one severity level is found, the slab is counted as having the higher severity distress. For example, if low and medium durability cracking are located on one slab, the slab is counted as having medium only. If "D" cracking is counted, scaling on the same slab should not be recorded.



DURABILITY CRACKING AT A JPCP (MILLER & BELLINGER, 2003)

c) Corner Breaks.

Severity Levels:

- Low

Crack has little or minor spalling (no FOD potential). If nonfilled, it has a mean width less than approximately 3 mm. A filled crack can be of any width, but the filler material must be in satisfactory condition. The area between the corner break and the joints is not cracked.

LOW SEVERITY CORNER BREAK

- Moderate

One of the following conditions exists:

1. Filled or nonfilled crack is moderately spalled (some FOD potential);
2. A nonfilled crack has a mean width between 3 and 25 mm;
3. A filled crack is not spalled or only lightly spalled, but the filler is in unsatisfactory condition;
4. The area between the corner break and the joints is lightly cracked lightly cracked means one low-severity crack dividing the corner into two pieces.

MODERATE SEVERITY CORNER BREAK

- High

One of the following conditions exists:

1. Filled or nonfilled crack is severely spalled, causing definite FOD potential;
2. A nonfilled crack has a mean width greater than approximately 25 mm, creating a tire damage potential;
3. The area between the corner break and the joints is severely cracked.

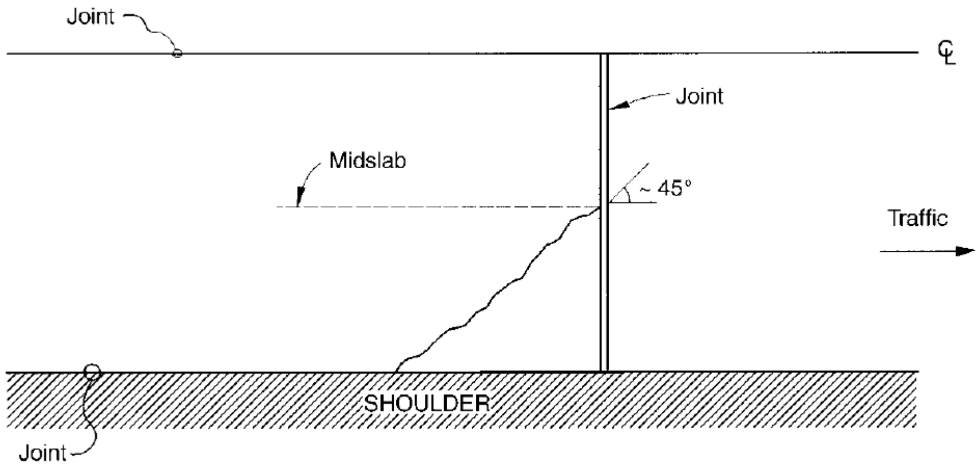
HIGH SEVERITY CORNER BREAK

How to measure it:

A distress slab is recorded as one slab if it contains a single corner break, contains more than one break of a particular severity, or contains two or more breaks of different severities. For two or more breaks, the highest level of severity should be recorded. For example, a slab containing both light and medium-severity corner breaks should be counted as one slab with a medium corner break. Crack widths should be measured between vertical walls, not in spalled areas of the crack.

If the corner break is faulted 3 mm or more, increase severity to the next higher level. If the corner is faulted more than 13 mm, rate the corner break at high severity. If faulting in corner is incidental to faulting in the slab, rate faulting separately.

The angle of crack into the slab is usually not evident at low severity. Unless the crack angle can be determined, to differentiate between the corner break and corner spall, use the following criteria. If the crack intersects both joints more than 60 cm from the corner, it is a corner break. If it is less than 60 cm, unless you can verify the crack is vertical, call it a spall.



IDENTIFYING A CORNER BREAK DISTRESS (MILLER & BELLINGER, 2003)

d) Corner Spalling

Severity Levels:

- Low

One of the following conditions exists:

1. Spall is broken into one or two pieces defined by low-severity cracks (little or no FOD potential);
2. Spall is defined by one medium-severity crack (little or no FOD potential).

LOW SEVERITY CORNER SPALLING

- Moderate

One of the following conditions exists:

1. Spall is broken into two or more pieces defined by medium severity crack(s), and a few small fragments may be absent or loose;
2. Spall is defined by one severe, fragmented crack that may be accompanied by a few hairline cracks;
3. Spall has deteriorated to the point where loose material is causing some FOD potential.

MODERATE SEVERITY CORNER SPALLING

- High

One of the following conditions exists:

HIGH SEVERITY CORNER SPALLING

1. Spall is broken into two or more pieces defined by high-severity fragmented crack(s) with loose or absent fragments;
2. Pieces of the spall have been displaced to the extent that a tire damage hazard exists;
3. Spall has deteriorated to the point where loose material is causing high FOD potential

How to measure it:

If one or more corner spalls having the same severity level are located in a slab, the slab is counted as one slab with corner spalling. If more than one severity level occurs, it is counted as one slab having the higher severity level.

A corner spall smaller than 76 mm wide measured from the edge of the slab, and filled with sealant is not recorded.

e) Shattered Slab

Severity Levels:

- Low

Slab is broken into four or five pieces predominantly defined by low-severity cracks.

LOW SEVERITY SHATTERED SLAB

- Moderate

Slab is broken into four or five pieces with over 15% of the cracks of medium severity (no high-severity cracks); slab is broken into six or more pieces with over 85% of the cracks of low severity.

MODERATE SEVERITY SHATTERED SLAB

- High

At this level of severity, the slab is called shattered:

1. Slab is broken into four or five pieces with some or all cracks of high severity; or
2. Slab is broken into six or more pieces with over 15% of the cracks of medium or high severity.

HIGH SEVERITY SHATTERED SLAB

How to measure it:

No other distress such as scaling, spalling, or durability cracking should be recorded if the slab is medium- or high-severity level since the severity of this distress would affect the slab's rating substantially. Shrinkage cracks should not be counted in determining whether or not the slab is broken into four or more pieces. If all pieces or cracks are contained within a corner break, the distress is categorized as a severe corner break.

f) Shrinkage Cracking.

Severity Levels:

No degrees of severity are defined. It is sufficient to indicate that shrinkage cracks exist.

NO SEVERITY LEVELS DEFINED TO SHRINKAGE CRACKING

How to measure it:

If one or more shrinkage cracks exist on one particular slab, the slab is counted as one slab with shrinkage cracks.

Joint Deficiencies

a) Joint Seal Damage

Severity Levels:

- Low

Joint seal damage is at low severity if a few of the joints have sealer which has debonded from, but is still in contact with, the joint edge. This condition exists if a knife blade can be inserted between sealer and joint face without resistance.

LOW SEVERITY LEVEL JOINT SEAL DAMAGE

- Moderate

Joint seal damage is at medium severity if a few of the joints have any of the following conditions:

MODERATE SEVERITY LEVEL JOINT SEAL DAMAGE

1. Joint sealer is in place, but water access is possible through visible openings no more than 3 mm wide. If a knife blade cannot be inserted easily between sealer and joint face, this condition does not exist;
2. Pumping debris are evident at the joint;
3. Joint sealer is oxidized and “lifeless” but pliable (like a rope), and generally fills the joint opening;
4. Vegetation in the joint is obvious, but does not obscure the joint opening.

- High

Joint sealer is in generally poor condition over the entire surveyed sample with one or more of the above types of damage occurring to a severe degree. Sealant needs immediate replacement. Joint seal damage is at high severity if 10% or more of the joint sealer exceeds limiting criteria listed above, or if 10% or more of sealer is missing.

HIGH SEVERITY LEVEL JOINT SEAL DAMAGE

How to measure it:

Joint seal damage is not counted on a slab-by-slab basis, but is rated based on the overall condition of the sealant in the sample unit (20 slabs).

Joint sealer is in satisfactory condition if it pre-vents entry of water into the joint, it has some elasticity, and if there is no vegetation growing between the sealer and joint face.

Pre-molded sealer is rated using the same criteria as above except as follows:

1. Pre-molded sealer must be elastic and must be firmly pressed against the joint walls;
2. Pre-molded sealer must be below the joint edge. If it extends above the surface, it can be caught by moving equipment such as snow plows or brooms and be pulled out of the joint. Pre-molded sealer is recorded at low severity if any part is visible above joint edge. It is at medium severity if 10% or more of the length is above joint edge or if any part is more than 12 mm above joint edge. It is at high severity if 20% or more is above joint edge or if any part is more than 25 mm above joint edge, or if 10% or more is missing.

Rate joint sealer by joint segment. Sample unit rating is the same as the most severe rating held by at least 20% of segments rated.

Rate only the left and up-station joints along sample unit boundaries.

In rating oxidation, do not rate on appearance, rate on resilience. Some joint sealer will have a very dull surface, and may even show surface cracks in the oxidized layer. If the sealer is performing satisfactorily and has good characteristics beneath the surface, it is satisfactory.

b) Joint Spalling

Severity Levels:

- Low

Spall over 0.6 m long:

LOW SEVERITY LEVEL OF SPALLING L/T JOINTS

1. Spall is broken into no more than three pieces defined by low or medium severity cracks; little or no FOD potential exists;
2. Joint is lightly frayed; little or no FOD potential. Spall less than 0.6 m long is broken into pieces or fragmented with little FOD or tire damage potential exists. Lightly frayed means the upper edge of the joint is broken away leaving a spall no wider than 25 mm and no deeper than 13 mm. The material is missing and the joint creates little or no FOD potential.

- Moderate

Spall over 0.6 m long:

MODERATE SEVERITY LEVEL OF SPALLING L/T JOINTS

1. Spall is broken into more than three pieces defined by light or medium cracks;
2. Spall is broken into no more than three pieces with one or more of the cracks being severe with some FOD potential existing;
3. Joint is moderately frayed with some FOD potential. Spall less than 0.6 m long: spall is broken into pieces or fragmented with some of the pieces loose or absent, causing considerable FOD or tire damage potential.

Moderately frayed means the upper edge of the joint is broken away leaving a spall wider than 25 mm or deeper than 13 mm.

- High

Spall over 0.6 m long:

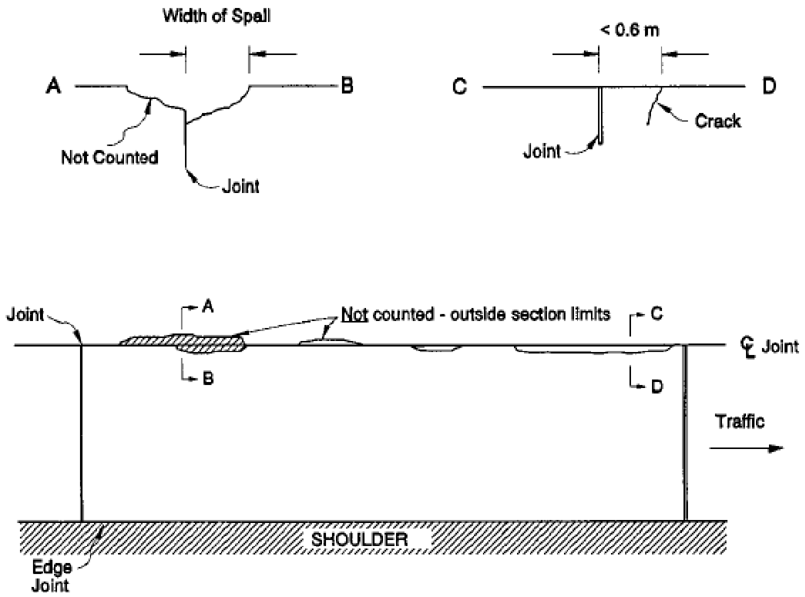
HIGH SEVERITY LEVEL OF SPALLING L/T JOINTS

1. Spall is broken into more than three pieces defined by one or more high-severity cracks with high FOD potential and high possibility of the pieces becoming dislodged;
2. Joint is severely frayed with high FOD potential.

How to measure it:

If the joint spall is located along the edge of one slab, it is counted as one slab with joint spalling. If spalling is located on more than one edge of the same slab, the edge having the highest severity is counted and recorded as one slab. Joint spalling can also occur along the edges of two adjacent slabs. If this is the case, each slab is counted as having joint spalling. If a joint spall is small enough, less than 76 mm wide, to be filled during a joint seal repair, it should not be recorded.

NOTE: If less than 0.6 m of the joint is lightly frayed, the spall should not be counted.



MEASURE OF JOINT SPALLING (MILLER & BELLINGER, 2003)

Sufarce Defects

a) Map Cracking and Scaling

Severity Levels:

- Low

Minimal loss of surface paste that poses no FOD hazard. No FOD potential.

LOW SEVERITY LEVEL OF MAP CRACKING AND SCALING

- Moderate

The loss of surface paste that poses some FOD potential including isolated fragments of loose mortar, exposure of the sides of coarse aggregate (Less than a quarter of the width of coarse aggregate), or evidence of coarse aggregate coming loose from the surface.

MODERATE SEVERITY LEVEL OF MAP CRACKING AND SCALING

- High

The high severity is associated with low durability concrete that will continue to pose a high FOD hazard; normally the layer of surface mortar is observable at the perimeter of the scaled area, and is likely to continue to scale due to environmental or other factors. Indication of high severity FOD is that routine sweeping is not sufficient to avoid FOD issues.

HIGH SEVERITY LEVELS OF MAP CRACKING AND SCALING

How to measure it:

If two or more levels of severity exist on a slab, the slab is counted as one slab having the maximum level of severity. For example, if both low-severity crazing and medium scaling exist on one slab, the slab is counted as one slab containing medium scaling. If “D” cracking is counted, scaling is not counted.

b) Alkali-Silica Reaction (ASR)

Severity Levels:

- Low

Minimal to no FOD potential from cracks, joints or ASR-related popouts; cracks at the surface are tight (predominantly 1.0 mm or less), little to no evidence of movement in pavement or surrounding structures or elements.

LOW SEVERITY LEVEL OF ASR

- Moderate

Some FOD potential; but increased sweeping or other FOD removal methods may be required. May be evidence of slab movement or some damage (or both) to adjacent structures or elements. Medium ASR distress is differentiated from low by having one or more of the following: increased FOD potential, crack density increases, some fragments along cracks or at crack intersections present, surface popouts of concrete may occur, pattern of wider cracks (predominantly 1.0 mm or wider) that may be subdivided by tighter cracks.

MODERATE SEVERITY LEVEL OF ASR

- High

One or both of the following exist:

1. Loose or missing concrete fragments and poses high FOD potential;
2. Slab surface integrity and function significantly degraded and pavement requires immediate repairs; may also require repairs to adjacent structures or elements.

HIGH SEVERITY LEVEL OF ASR

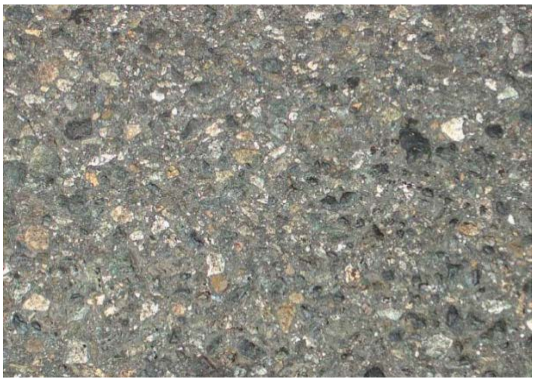
How to measure it:

No other distresses should be recorded of the slab has a high severity level of ASR.

c) Polished Aggregate

Severity Levels:

Not applicable. However, the degree of polishing may be reflected in a reduction of surface friction.



NO SEVERITY LEVEL DEFINED TO POLISHED AGGREGATE DISTRESS (PAVEMENT INTERACTIVE, 2014 B)

How to measure it:

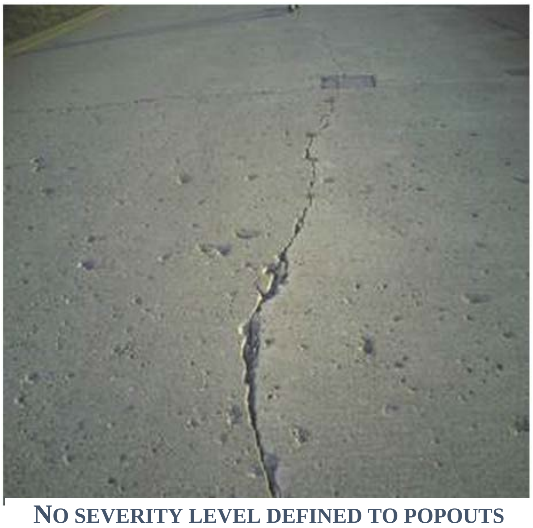
Record square meters of affected surface area.

NOTE: Diamond grinding also removes the surface mortar and texturing. However, this condition should not be recorded as polished aggregate, but instead, be noted by a comment.

d) Popouts

Severity Levels:

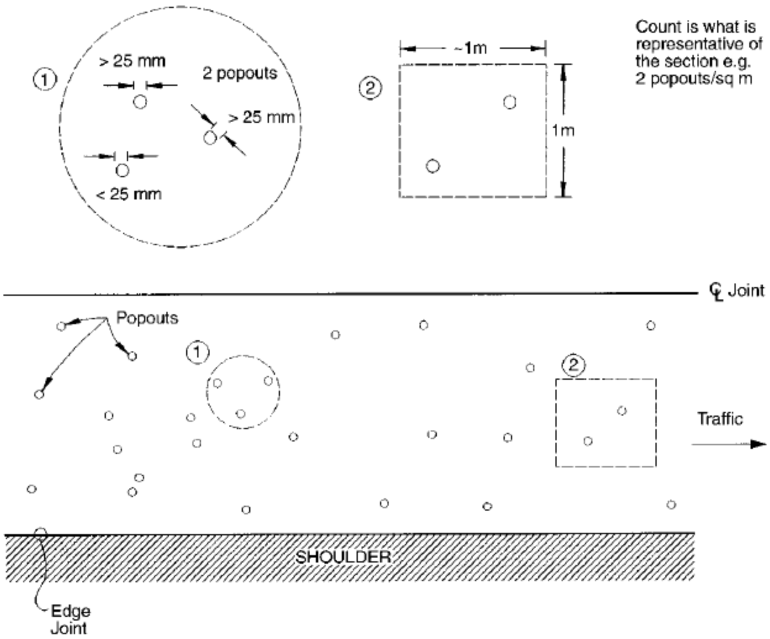
No degrees of severity are defined for popouts. However, popouts must be extensive before they are counted as a distress; that is, average popout density must exceed approximately three popouts per square meter over the entire slab area.



NO SEVERITY LEVEL DEFINED TO POPOUTS

How to measure it:

The density of the distress must be measured. Per (ASTM - D5340, 2011), to count a slab as having this type of distress, an average greater than three Popouts per square meter is needed. If there is any doubt about the average being greater than three popouts per square meter, at least three random 1 m^2 areas should be checked. When the average is greater than this density, the slab is counted.



MEASURE PER SQUARE METER OF POPOUTS (MILLER & BELLINGER, 2003)

Miscellaneous Distresses

a) Blowup

Severity Levels:

- Low

Buckling or shattering has not rendered the pavement inoperable, and only a slight amount of roughness exists.

LOW SEVERITY LEVEL OF BLOWUPS

- Moderate

Buckling or shattering has not rendered the pavement inoperable, but a significant amount of roughness exists

MODERATE SEVERITY LEVEL OF BLOWUPS

- High

Buckling or shattering has rendered the pavement inoperable.

HIGH SEVERITY LEVEL OF BLOWUPS

How to measure it:

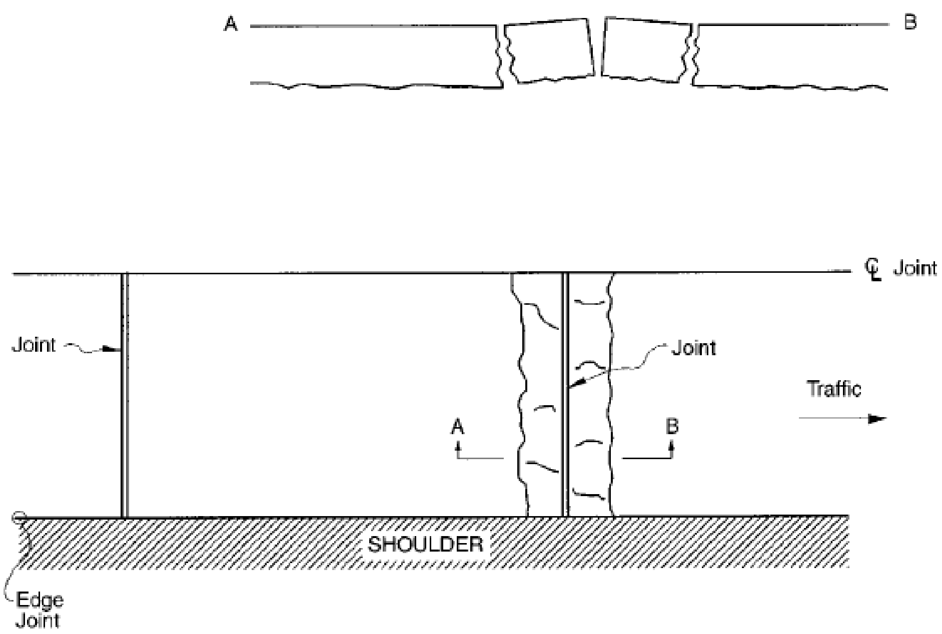
A blowup usually occurs at a transverse crack or joint. At a crack, it is counted as being in one slab, but at a joint, two slabs are affected and the distress should be recorded as occurring in two slabs.

Record blowup on a slab only if the distress is evident on that slab. Severity may be different on adjacent slabs. If blowup has been repaired by patching, establish severity by determining the difference in elevation between the two slabs.

At the present time, no significant research has been conducted to quantify severity levels for blowups. Future research may provide measurement guidelines:

DIFFERENCE IN ELEVATION OF BLOWUPS

Severity Levels	Runways and High-Speed taxiways	Aprons and Other Taxi ways
Low	< 13 mm	From 6 to 25 mm
Moderate	From 13 to 25 mm	From 25 to 51 mm
High	Inoperable	Inoperable



BLOWUP DISTRESS (MILLER & BELLINGER, 2003)

b) Faulting

Severity Levels:

Severity levels are defined by the difference in elevation across the fault and the associated decrease in ride quality and safety as severity increases

HIGH SEVERITY LEVEL OF BLOWUPS

DIFFERENCE IN ELEVATION OF FAULTING

Severity Levels	Runways/Taxiways	Aprons
Low	< 6 mm	From 3 to 13 mm
Moderate	From 6 to 13 mm	From 13 to 25 mm
High	> 13 mm	> 25 mm

How to measure it:

In counting settlement, a fault between two slabs is counted as one slab. A straightedge or level should be used to aid in measuring the difference in elevation between the two slabs.

Construction-induced elevation differential is not rated in PCI procedures. Where construction differential exists, it can often be identified by the way the high side of the joint was rolled down by finishers (usually within 150 mm of the joint) to meet the low-slab elevation.

c) Patching

e.1) Small Patch

Severity Levels:

- Low

Patch is functioning well with little or no deterioration.

LOW SEVERITY LEVEL OF SMALL PATCHING

- Moderate

Patch that has deterioration or moderate spalling, or both, can be seen around the edges. Patch material can be dislodged with considerable effort (minor FOD potential).

MODERATE SEVERITY LEVEL OF SMALL PATCHING

- High

Patch deterioration, either by spalling around the patch or cracking within the patch, to a state that warrants replacement

LOW SEVERITY LEVEL OF SMALL PATCHING

e.2) Large Patch

Severity Levels:

- Low

Patch is functioning well with very little or no deterioration.

LOW SEVERITY LEVEL OF LARGE PATCHING

- Moderate

Patch deterioration or moderate spalling, or both, can be seen around the edges. Patch material can be dislodged with considerable effort, causing some FOD potential.

MODERATE SEVERITY LEVEL OF LARGE PATCHING

- High

Patch has deteriorated to a state that causes considerable roughness or high FOD potential, or both. The extent of the deterioration warrants replacement of the patch.

HIGH SEVERITY LEVEL OF LARGE PATCHING

How to measure it:

If one or more small patches having the same severity level are located in a slab, it is counted as one slab containing that distress. If more than one severity level occurs, it is counted as one slab with the higher severity level being recorded. If a crack is repaired by a narrow patch (that is, 100 to 250 mm wide), only the crack and not the patch should be recorded at the appropriate severity level.

d) Pumping

Severity Levels:

No degrees of severity are de- fined. It is sufficient to indicate that pumping exists.

NO DEFINED LEVELS OF PUMPING

How to measure it:

Slabs are counted as follows: one pumping joint between two slabs is counted as two slabs. However, if the remaining joints around the slab are also pumping, one slab is added per additional pumping joint.

Visual Inspection Guidelines for PCI of Airport Pavements

This section presents some guidelines details for airport visual inspection that have to be taken into consideration in order to reduce the subjectivity of this methodology. Sometimes a small detail is the difference between choose one or another distress type and like that compromise the PCI rate overall.

The following distresses are numerated accordingly with the norm (ASTM - D5340, 2011):

1. Blowup

Measurement Detail: At a crack, it is counted as being in one slab, but at a joint, two slabs are affected and the distress should be recorded as occurring in two slabs. Severity may be different on adjacent slabs. If blowup has been repaired by patching, establish severity by determining the difference in elevation between the two slabs.

2. Corner Breaks

Measurement Detail: For example, a slab with dimensions of 7.5 by 7.5 m that has a crack intersecting the joint 1.5 m from the corner on one side and 5m on the other side is not considered a corner break, it is a diagonal crack. However, a crack that intersects 2 m on one side and 3 m on the other is considered a corner break.

A corner break differs from a corner spall in that the crack extends vertically through the entire slab thickness, while a corner spall intersects the joint at an angle.

3. Longitudinal, Transverse and Diagonal Cracks

Measurement Detail: Cracks used to define and rate corner breaks, “D” cracks, patches, shrinkage cracks, and spalls are not recorded as L/T/D cracks.

4. Durability “D” Cracking

Measurement Detail: If “D” cracking is counted, scaling/map cracking on the same slab should not be recorded.

5. Joint Seal Damage

Measurement Detail: Joint sealer is in satisfactory condition if it prevents entry of water into the joint, it has some elasticity, and if there is no vegetation growing between the sealer and joint face.

6. Small Patch

Measurement Detail: If a crack is repaired by a narrow patch 1 cm to 2.5 cm wide, only the crack and not the patch should be recorded at the appropriate severity level.

7. Large Patch

Measurement Detail: Same as Small Patch.

8. Popouts

Measurement Detail: When the average is greater than three popouts per square meter, the slab is counted.

9. Pumping

Measurement Detail: One pumping joint between two slabs is counted as two slabs. However, if the remaining joints around the slab are also pumping, one slab is added per additional pumping joint.

10. Map Cracking/Scaling

Measurement Detail: If “D” cracking is counted, scaling/map cracking is not counted.

11. Faulting

Measurement Detail: Construction-induced elevation differential is not rated in PCI procedure.

12. Shattered Slab

Measurement Detail: Shrinkage cracks should not be counted in determining whether or not the slab is broken into four or more pieces.

13. Shrinkage Cracking

Measurement Detail: Hairline cracks that do not extend across the entire slab.

14. Joint Spalling

Measurement Detail: If a joint spall is small enough, less than 76 mm wide, to be filled during a joint seal repair, it should not be recorded as well as if less than 0.6 m of the joint is lightly frayed.

15. Corner Spalling

Measurement Detail: A corner spall smaller than 76 mm wide measured from the edge of the slab, and filled with sealant is not recorded.

16. Alkali-Silica Reaction

Measurement Detail: Age of concrete when distress developed, generally ASR distresses are observed in a few to many years after construction, in contrast to plastic shrinkage cracking which occurs the day of construction and is apparent within the first year. ASR is differentiated from "D" Cracking in that ASR has cracks perpendicular at the joint faces.

White, brown, gray or other colored gel or staining may be present at the crack surface.

Road Rigid Pavement Distresses and Severity Levels

This section covers the road distresses according with the same criteria mentioned before, with the exception of the Longitudinal, Transverse and Diagonal cracks, which are defined separately for reinforced and non-reinforced concrete pavements. Following the same group categories comes:

Cracking

a) Longitudinal, Transverse and Diagonal Cracks.

Severity Levels:

- Low

Nonfilled cracks smaller than 13 mm wide at JPCP or between 3 and 25 mm at JRCP and CRCP. Filled cracks of any width with the filler in satisfactory condition. No faulting exists.

EXAMPLE OF A LOW SEVERITY L/T/D ON A ROAD

- Moderate

One of the following conditions exists to JPCP:

1. Nonfilled crack with a width between 13 and 50 mm;
2. Nonfilled crack of any width smaller than 50 mm with faulting smaller than 10 mm, or filled crack of any width with faulting smaller 10 mm.

EXAMPLE OF A MODERATE SEVERITY CRACK ON A ROAD

One of the following conditions exists to JRCP or CRCP:

1. Nonfilled crack with a width between 25 and 75 mm and no faulting;
2. Nonfilled crack of any width smaller than 75 mm with faulting smaller than 10 mm, or filled crack of any width with faulting smaller 10 mm.

- High

Nonfilled crack with a width bigger than 50mm at JPCP or bigger than 75 mm at JRCP and CRCP, or any crack width filled or nonfilled with a faulting bigger than 10 mm.

HIGH SEVERITY CRACK AT A ROAD

How to measure it:

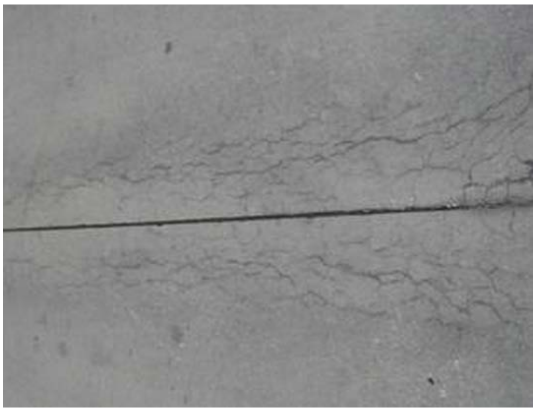
Once the severity has been identified, the distress is recorded as one slab. If two medium severity cracks are within one slab, the slab is counted as having one high-severity crack. Slabs divided into four or more pieces are counted as Divided Slabs. In reinforced slabs, cracks smaller the 3 mm wide are counted as shrinkage cracks. Slabs longer than 9 m are divided into approximately equal length "slabs" having imaginary joints assumed to be in perfect condition.

b) Durability "D" Cracking

Severity Levels:

- Low

"D" cracks cover less than 15% of slab area. Most of the cracks are tight, but a few pieces may be loose and or missing.



LOW SEVERITY DURABILITY CRACKING

- Moderate

One of the following conditions exists: "D" cracks cover less than 15% of the area and most of the pieces are loose and or missing, or "D" cracks cover more than 15% of the area. Most of the cracks are tight, but a few pieces may be loose and or missing.

MODERATE DURABILITY CRACKING

- High

"D" cracks cover more than 15% of the area and most of the pieces have come out or could be removed easily.

HIGH SEVERITY DURABILITY CRACKING

How to measure it:

When the distress is located and rated at one severity, it is counted as one slab. If more than one severity level exists, the slab is counted as having the higher severity distress. For example, if low and medium "D" cracking are on the same slab, the slab is counted as medium- severity cracking only.

c) Corner Breaks

Severity Levels:

- Low

A low severity corner break has a crack smaller than 13 mm, cracks of any width with satisfactory filler; no faulting. The area between the break and the joints is not cracked or may be lightly cracked.

EXAMPLE OF THE LOW CORNER BREAK

- Moderate

The break is defined by a moderate severity crack, or the area between the break and the joints, or both, has a moderate crack. A moderate severity crack is a nonfilled crack between 13 and 50 mm, a nonfilled crack smaller than 50 mm with faulting smaller than 10 mm, or any filled crack with faulting smaller than 10 mm.

EXAMPLE OF A MODERATE CORNER BREAK

- High

The break is defined by a high severity crack, or the area between the break and the joints, or both, is highly cracked. A high severity crack is a nonfilled crack bigger than 50 mm wide, or any filled or nonfilled crack with faulting bigger than 10 mm.

EXAMPLE OF HIGH SEVERITY CORNER BREAK

Note: To reinforced pavements check the L/T/D cracks.

How to measure it:

Distressed slab is recorded as one slab if it contains:

1. A single corner break.
2. More than one break of a particular severity.
3. Two or more breaks of different severities.

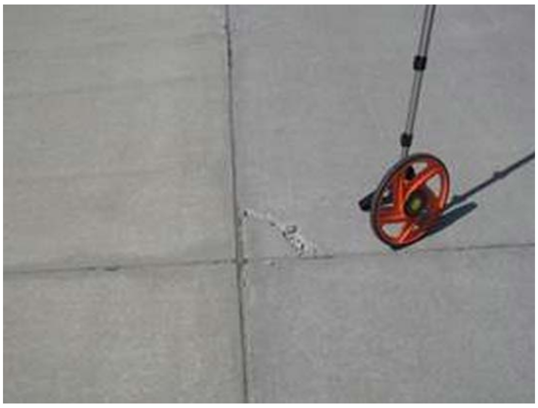
For two or more breaks, the highest level of severity should be recorded. For example, a slab containing both low- and medium-severity corner breaks should be counted as one slab with a medium corner break.

d) Corner Spalling

Severity Levels: The following table lists severity levels for corner spalling.

SEVERITY LEVELS FOR CORNER SPALLING

Width of the spall	Dimensions of Sides Spall	
	130x130 to 300x300 mm	Bigger than 300x300 mm
Low (<13mm)	Low	Low
Moderate (13 to 50mm)	Low	Moderate
High (>50mm)	Moderate	High



EXAMPLES OF CORNER SPALLING DISTRESS, LOW, MODERATE AND HIGH SEVERITY LEVELS RESPECTIVELY STARTING IN THE UPPER LEFT FIGURE

How to measure it:

If one or more corner spalls with the same severity level are in a slab, the slab is counted as one slab with corner spalling. If more than one severity level occurs, it is counted as one slab with the higher severity level.

Corner spalling with an area of less than 65 cm^2 from the crack to the corner on both sides should not be counted.

e) Divided Slab

Severity Levels: The following table lists severity levels for Divided Slabs

SEVERITY LEVELS OF DIVIDED SLABS

Severity of Majority of Cracks	Number of Pieces in Cracked Slab		
	4 to 5	6 to 8	More than 8
Low (<13mm)	Low	Low	Moderate
Moderate (13 to 50mm)	Low	Moderate	High
High (>50mm)	Moderate	High	High

EXAMPLES OF DIVIDED SLAB, LOW, MODERATE AND HIGH SEVERITY LEVELS RESPECTIVELY STARTING IN THE UPPER LEFT FIGURE

How to measure it:

If the divided slab is moderate or high severity, no other distress is counted for that slab.

f) Shrinkage Cracks

Same as presented previously for airport pavements on Shrinkage Cracking distress.

Joint Deficiencies

a) Joint Seal Damage

Same as presented previously for airport pavements on Joint Seal Damage distress.

b) Joint Spalling

Severity Levels: The following table lists severity levels for Joint Spalling.

SEVERITY LEVELS FOR JOINT SPALLING

Spall Pieces	Width of Spall	Length of Spall	
		Smaller than 0.6m	**Bigger than 0.6m**
Tight - Cannot be easily removed (maybe a few pieces missing)	Smaller than 100 mm	Low	Low
	Bigger than 100 mm	Low	Low
Loose: Can be removed and some pieces are missing; if most or all pieces are missing, spall is shallow, less than 25 mm.	Smaller than 100 mm	Low	Moderate
	Bigger than 100 mm	Low	Moderate
Missing: Most or all pieces have been removed	Smaller than 100 mm	Low	Moderate
	Bigger than 100 mm	Moderate	High

Note: See figure 3.27 for better understanding.



EXAMPLES OF JOINT SPALLING DISTRESS ON ROADS, FROM LEFT TO RIGHT, LOW, MODERATE AND HIGH SEVERITY LEVELS RESPECTIVELY

<u>How to measure it:</u>

A frayed joint where the concrete has been worn away along the entire joint is rated as low severity.

If spall is along the edge of one slab, it is counted as one slab with joint spalling. If spalling is on more than one edge of the same slab, the edge having the highest severity is counted and recorded as one slab. Joint spalling also can occur along the edges of two adjacent slabs. If this is the case, each slab is counted as having joint spalling.

Surface Defects

a) Map Cracking and Scaling

Severity Levels:

- Low

Crazing or map cracking exists over most of the slab area; the surface is in good condition, with only minor scaling present.

LOW SEVERITY MAP CRACKING EXAMPLE

- Moderate

Slab is scaled but less than 15% of the slab is affected.

MODERATE SEVERITY MAP CRACKING EXAMPLE

- High

Slab is scaled over more than 15% of its area.

HIGH SEVERITY MAP CRACKING EXAMPLE

How to measure it:

A scaled slab is counted as one slab. Low severity crazing only should be counted if the potential for scaling appears to be imminent or a few small pieces come out.

b) Polished aggregate

Severity Levels:

No degrees of severity are de- fined; however, the degree of polishing should be significant before it is included in the condition survey and rated as a defect.

EXAMPLE OF MAP CRACKING AND SCALING DISTRESS

How to measure it:

A slab with polished aggregate is counted as one slab.

c) Popouts

Exactly as presented previously for airport pavements on Popouts distress

Other Distresses

a) Blowup

Severity Levels:

The severity levels of roads blowup are the same for airports as the reader can see previously, with the slightly difference that the road can stay operable at all severity levels. Higher the level, bigger the discomfort for the passengers.

How to measure it:

At a crack, a blowup is counted as being in one slab, however, if the blowup occurs at a joint and affects two slabs, the distress should be recorded as occurring in two slabs. When a blowup renders the pavement impassable, it should be repaired immediately.

b) Faulting

Severity Levels:

As previously faulting is defined by the difference of elevation across the joint.

EXAMPLE OF FAULTING

DIFFERENCE OF ELEVATION AT THE JOINTS TO DEFINE FAULTING ON ROADS

Severity Level	Difference of Elevation
Low	Between 3 and 10 mm
Moderate	Between 10 and 20 mm
High	More than 20 mm

How to measure it:

Faulting across a joint is counted as one slab. Only affected slabs are counted. Faults across a crack are not counted as distress but are considered when defining crack severity.

c) Patching

c.1) Small Patch

Severity Levels:

- Low

Patch is functioning well with little or no deterioration.

EXAMPLE OF SMALL CORNER PATCH

- Moderate

Patch is moderately deteriorated. Patch material can be dislodged with considerable effort.

EXAMPLE OF A MODERATE SMALL PATCH

- High

Patch is badly deteriorated. The extent of deterioration warrants replacement.

HIGH SEVERITY SMALL PATCH

c.2) Large Patch

Severity Levels:

- Low

Patch is functioning well, with little or no deterioration.

LOW SEVERITY LARGE PATCH

- Moderate

Patch is moderately deteriorated, or moderate spalling can be seen around the edges, or both. Patch material can be dislodged with considerable effort.

MODERATE SEVERITY LARGE PATCH

- High

Patch is badly deteriorated. The extent of the deterioration warrants replacement.

HIGH SEVERITY LARGE PATCH

How measure it:

If a single slab has one or more patches with the same severity level, it is counted as one slab containing that distress. If a single slab has more than one severity level, it is counted as one slab with the higher severity level.

d) Pumping

Exactly as presented previously for airport pavements on Pumping distress.

e) Lane/Shoulder Drop

Severity Levels:

- Low

The difference between the pavement edge and shoulder is between 25 and 50 mm.

LOW SEVERITY LANE/SHOULDER DROP

- Moderate

The difference in elevation is between 50 and 100 mm.

MODERATE SEVERITY LANE/SHOULDER DROP.

- High

The difference in elevation is bigger than 100 mm.

HIGH SEVERITY LANE/SHOULDER DROP

f) Punchout

Severity Levels: The following table lists severity levels for Punchout distress.

SEVERITY LEVELS OF PUNCHOUT.

Severity of Majority of Cracks	Number of Pieces		
	2 to 3	4 to 5	More than 5
Low	Low	Low	Moderate
Moderate	Low	Moderate	High
High	Moderate	High	High

EXAMPLES OF PUNCHOUT DISTRESS AT HIGH SEVERITY

How to measure it:

If a slab contains more than one punchout or a punchout and a crack, it is counted as shattered.

g) Railroad Crossing

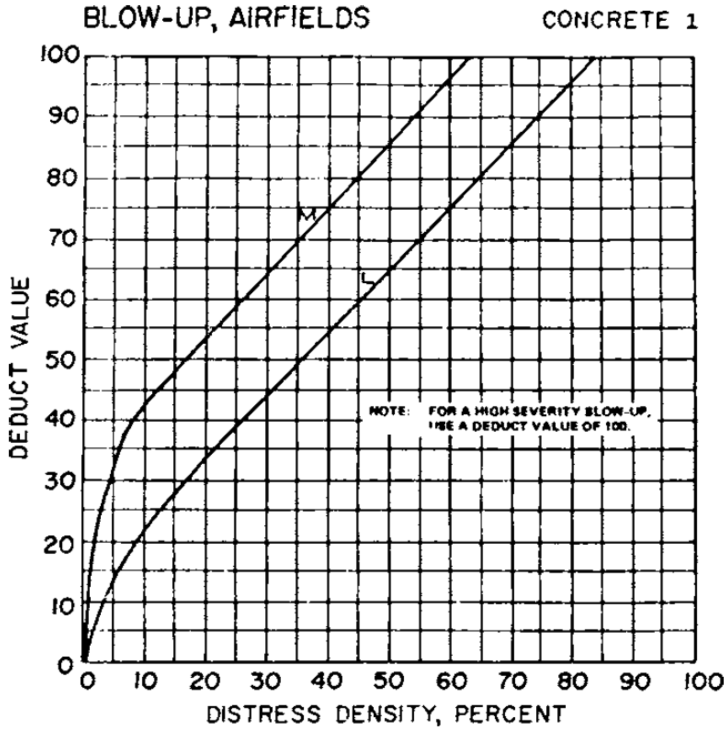
Severity Levels: The Railroad crossing severity levels are distinguished by the ride quality, by another words, if it causes low severity ride quality it is a low severity rail road crossing, and so on.

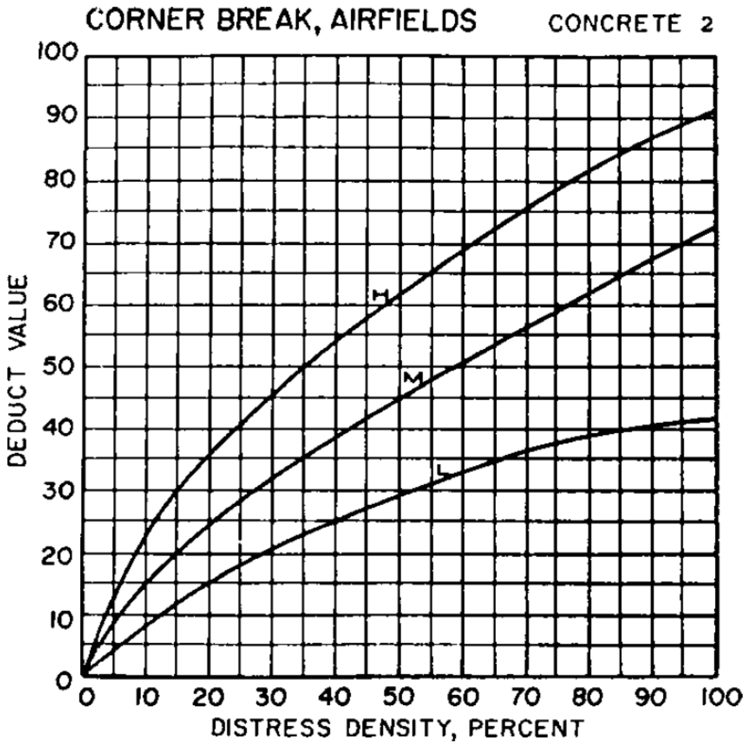
How to measure it:

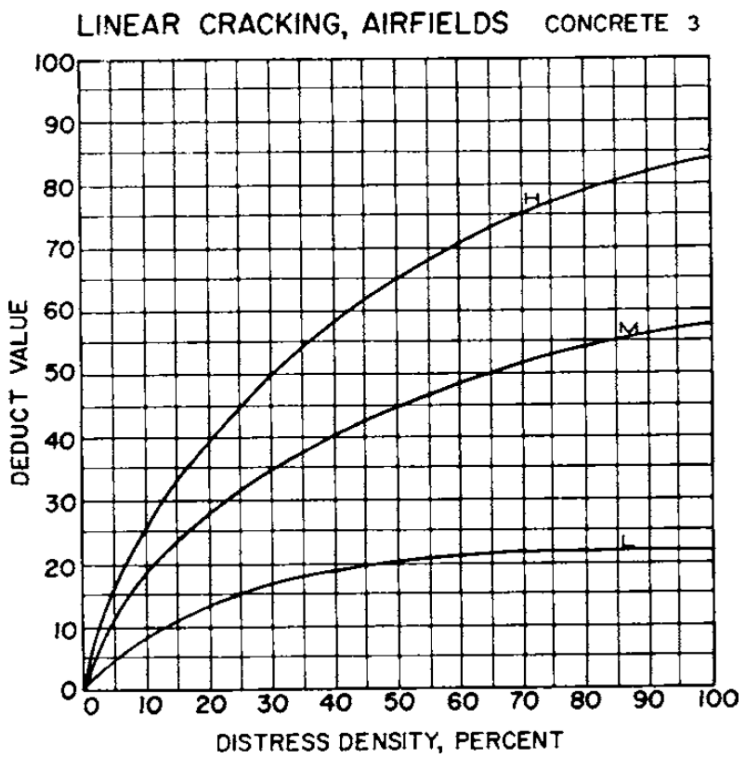
The number of slabs crossed by the railroad tracks is counted. Any large bump created by the tracks should be counted as part of the crossing.

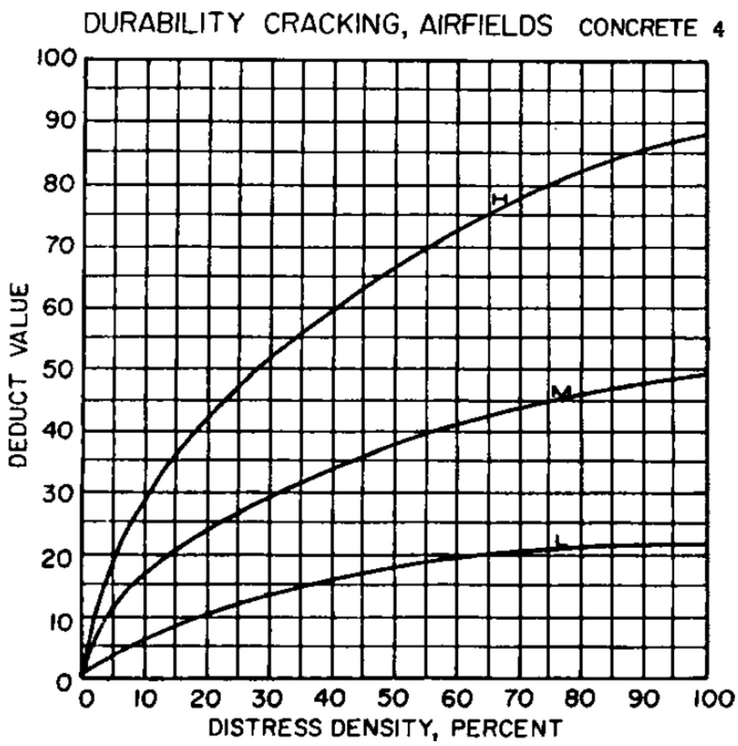
Appendix II

Severity Level Distresses Curves for the Calculation of the DV



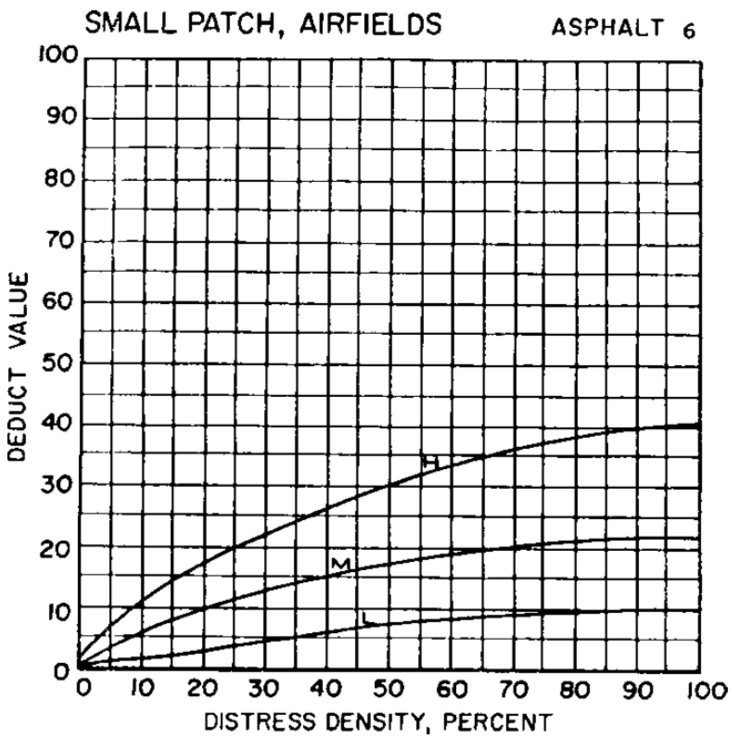



LINEAR CRACKING, AIRFIELDS CONCRETE 3
DEDUCT VALUE
DISTRESS DENSITY, PERCENT
H
M
L
0
10
20
30
40
50
60
70
80
90
100

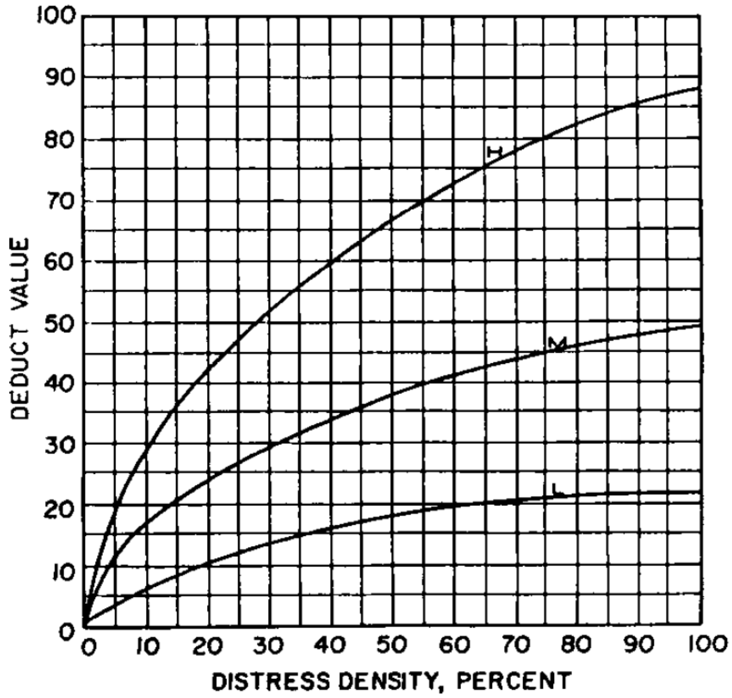

DURABILITY CRACKING, AIRFIELDS CONCRETE 4
DEDUCT VALUE
DISTRESS DENSITY, PERCENT
H
M
L
0
10
20
30
40
50
60
70
80
90
100

5 – Joint Seal Damage

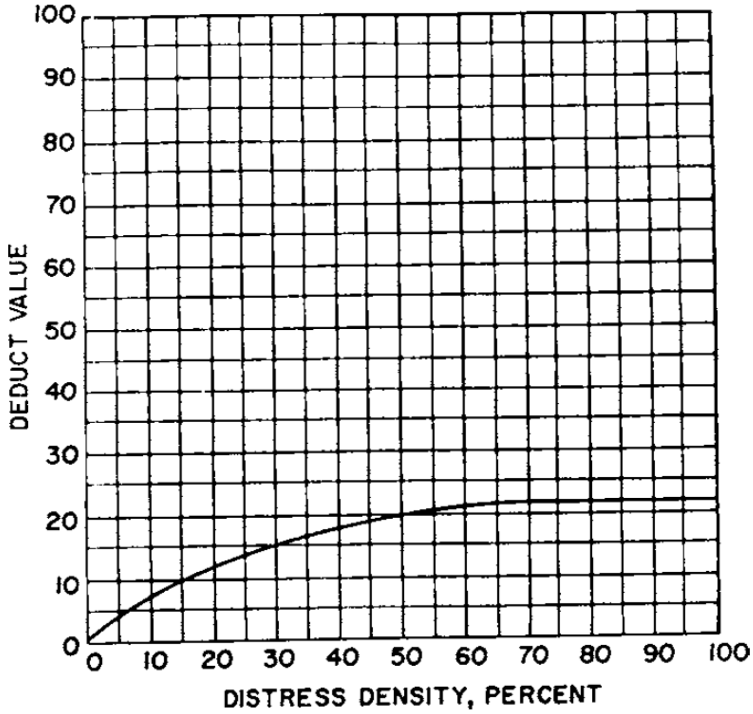
L	2
M	7
H	12

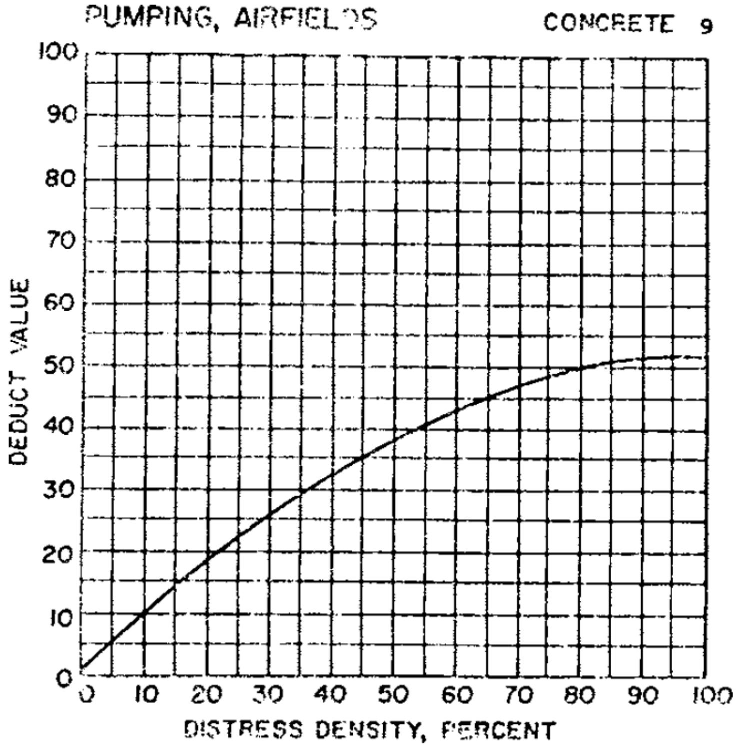


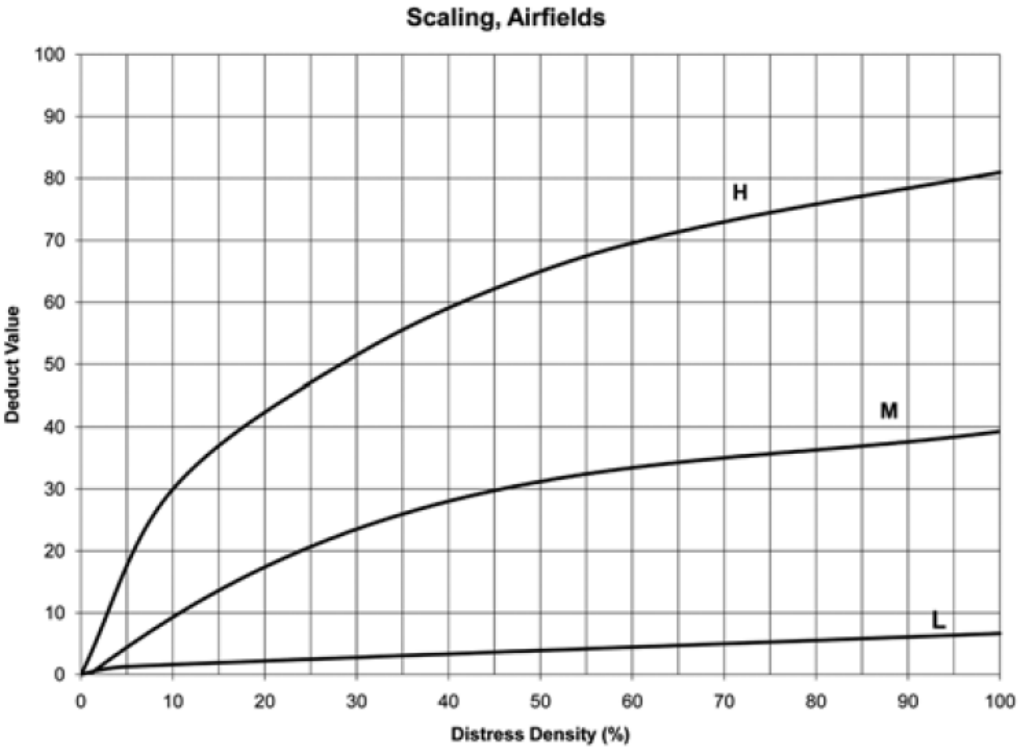
PATCHING/UTILITY CUT, AIRFIELDS CONCRETE 7

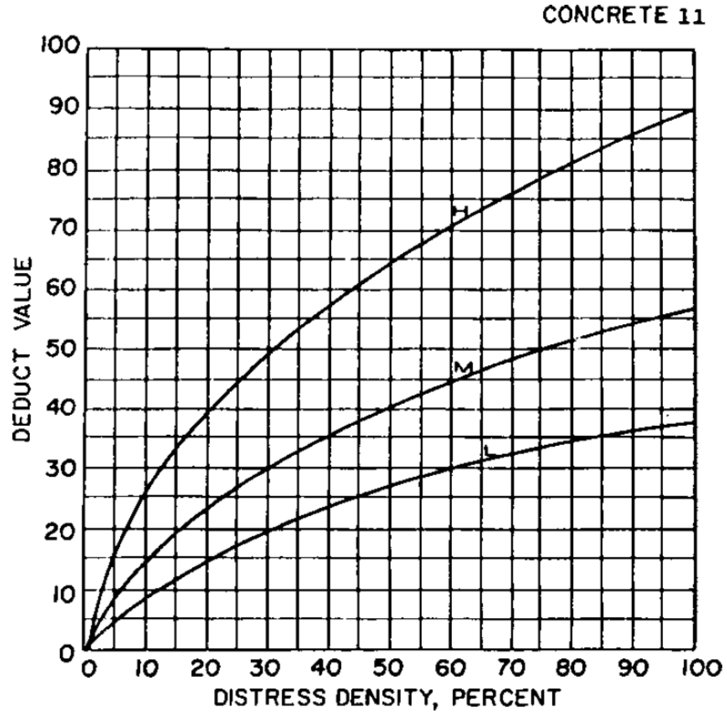


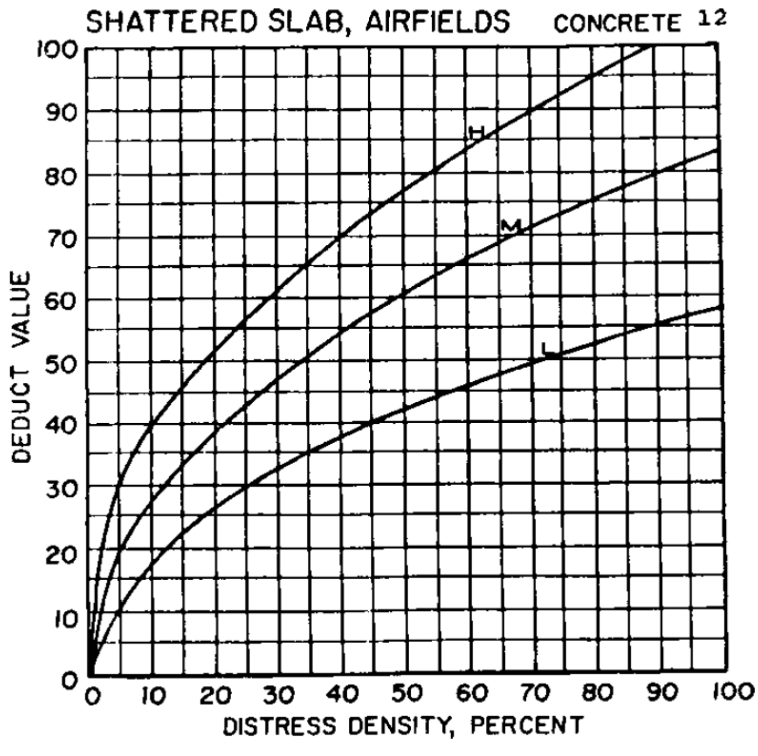
POPOUTS, AIRFIELDS CONCRETE 8

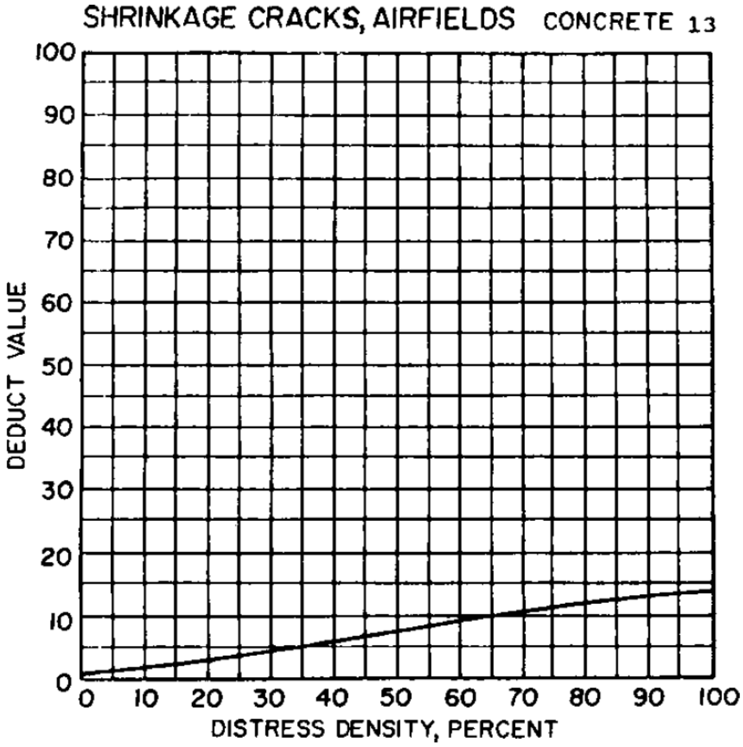


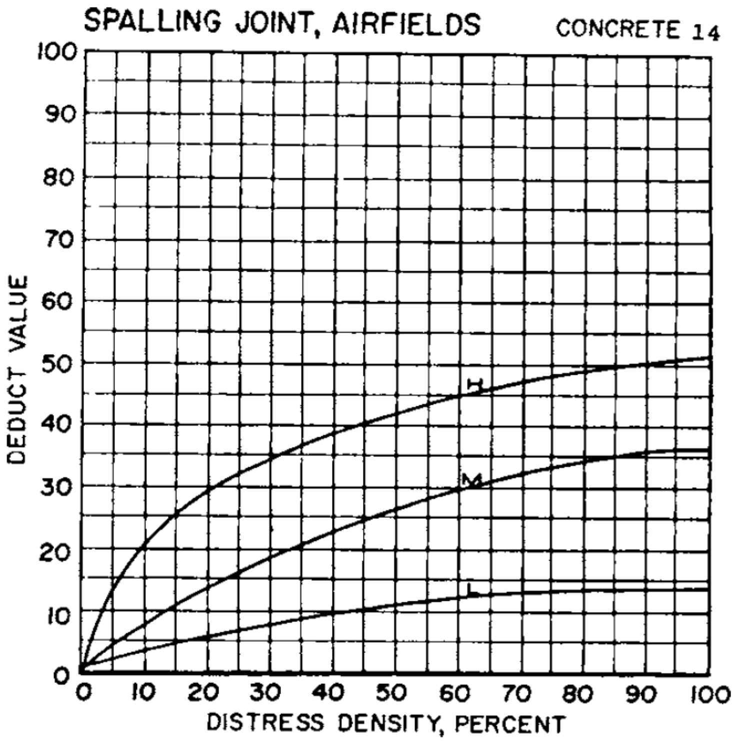

PUMPING, AIRFIELDS
CONCRETE 9
DEDUCT VALUE
DISTRESS DENSITY, PERCENT

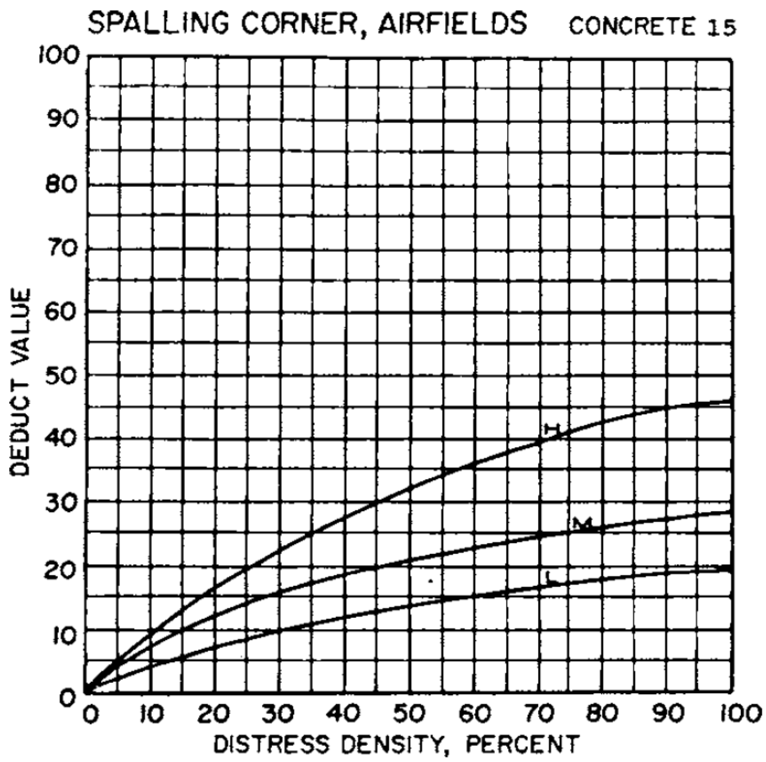

Scaling, Airfields
Deduct Value
Distress Density (%)
H
M
L

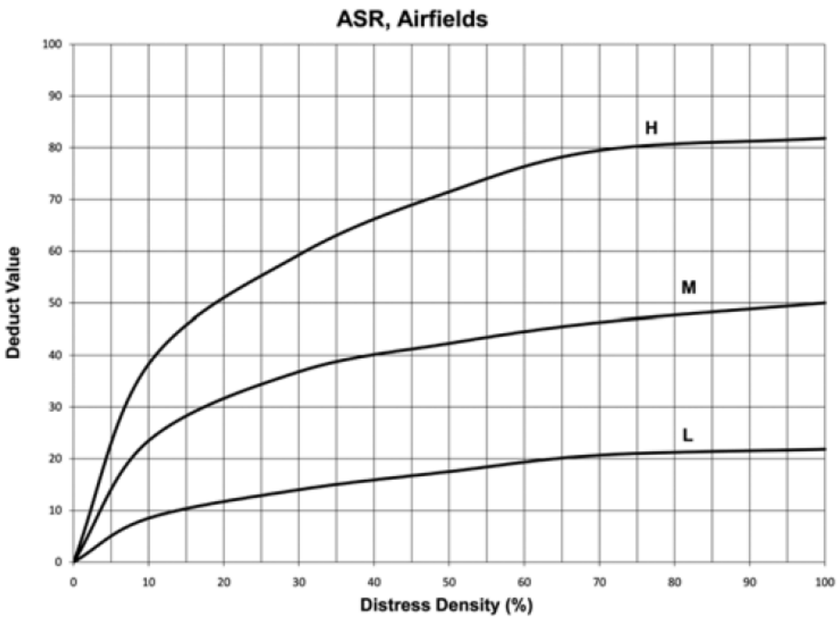

CONCRETE 11
DEDUCT VALUE
DISTRESS DENSITY, PERCENT
H
M
L
0
10
20
30
40
50
60
70
80
90
100


SHATTERED SLAB, AIRFIELDS
CONCRETE 12
DEDUCT VALUE
DISTRESS DENSITY, PERCENT
H
M
L
0
10
20
30
40
50
60
70
80
90
100


SHRINKAGE CRACKS, AIRFIELDS
CONCRETE 13
DEDUCT VALUE
DISTRESS DENSITY, PERCENT
0
10
20
30
40
50
60
70
80
90
100


SPALLING JOINT, AIRFIELDS
CONCRETE 14
DEDUCT VALUE
DISTRESS DENSITY, PERCENT
H
M
L
0
10
20
30
40
50
60
70
80
90
100


SPALLING CORNER, AIRFIELDS
CONCRETE 15
DEDUCT VALUE
0
10
20
30
40
50
60
70
80
90
100
H
M
L
DISTRESS DENSITY, PERCENT


ASR, Airfields
Deduct Value
0
10
20
30
40
50
60
70
80
90
100
H
M
L
Distress Density (%)

Appendix III

PCC Correction Curves for the Calculation of the CDV