Airport Pavement Management System

Assessing current condition and estimating remaining life from aircraft demand

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ABSTRACT

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Road pavements management system (PMS) is a well-established approach that could benefit airports. For the implementation of an Airport Pavement Management System (APMS), there is a need to assess current pavement condition by considering observed distress levels and to match such condition to an apparent age, hence enabling the estimation of remaining life.

Traditionally the use of a global pavement condition indicator (PCI) is deployed by airport agencies. The estimation of PCI is done manually utilizing reference charts and tables. Automating this estimation is an imperative need. Furthermore, being able to predict the consumption of life by current and future aircraft demand (frequency and distribution) is key to airport operations.

AASHTO's mechanistic empirical method was recalibrated to match fatigue after 20 years of operations of a case study on Mashhad International Airport in Iran. The method considers the fatigue damage analysis and includes various factors like aircraft traffic and their loadings and pavement structural parameters.

One of the objectives of this research was to automate the estimation of pavement condition index (PCI) based on observed distresses, facilitating the identification of damage and the association of remedial work. The second objective was to predict the pavement's remaining life by using the fatigue damage analysis technique by enabling the ability to predict pavement performance and the assumption that a pavement fails when the load repetition exceeds a certain threshold. By connecting both approaches, better decisions for the type of intervention and the timing of the intervention can be done.

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Secondly, I want to express my deep gratuity to my friend Dr. Hooman Hajikarimi for his consistent support in providing me with some of the datasets from the Mashhad Airport pavements that I know how hard was it to collect all those data.

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Finally, I must express my very profound gratitude to my wife, who has suffered lots of hardships during this journey. There will never be the right word to express my appreciation for her everlasting love, support and encouragement throughout my life and through the process of researching and writing this thesis.

DEDICATION

To my father's soul and my beloved family

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LIST OF ABBREVIATIONS

APMS	Airport Pavement Management System
ASR	Reactivity of Alkali-Silica
CDV	Corrected Deduct Value
DV	Deduct Value
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FOD	Foreign Object Damage
GIS	Geographic information system
HMA	Hot Mix Asphalt
IRI	International Roughness Index
M&R	Maintenance and Rehabilitation
PCI	Pavement Condition Index
PMS	Pavement Management System
PSI	Present Serviceability Index
TDV	Total deduct value

CHAPTER 1
INTRODUCTION

1.1. Background

Pavements, like other infrastructure, have a limited lifespan and will deteriorate over time due to repetitive loads and climatic reasons. When pavement failure happens, reconstruction would be required, which is laborious, time-consuming, and costly, as well as the use of more natural resources.

A pavement typically functions well for most of its life before reaching "critical condition" and rapidly deteriorating. Maintaining and preserving a good-condition pavement vs rehabilitating a fair-to-poor-condition pavement is four to five times less expensive and extends the pavement's functional life. The amount of years a pavement remains in "good" condition before deteriorating rapidly is determined by a variety of factors, including construction type and quality, traffic volume and pattern, climate condition, and maintenance. (FAA, AC 150/5380-7B). As a result, reliable prediction of pavement network performance is critical for effective pavement maintenance.

In order to decrease the costs of rehabilitation and reconstruction of the pavements and assist policy and decision-makers in obtaining optimum strategies for maintaining pavement in serviceable condition over a given period of time, a set of procedures defined to collect, analyze and report the pavement data which is named Pavement Management System (PMS). Airport pavement, as well as road pavements, requires the implementation of a system to prevent pavement failure or more extension of distresses. This matter is more vital in airports since the severe deteriorations can cause hazardous accidents for aircraft.

Appropriate pavement performance prediction models should be related to several pavement parameters, such as pavement condition indicators, pavement age, traffic, and pavement type. The application of pavement performance indicators which are currently used, such as the Pavement Condition Index (PCI), International Roughness Index (IRI), and Present Serviceability Index (PSI), affects the accuracy of pavement performance prediction models.

1.2. Problem Statement

Current airport pavement management systems (APMS) follow visual inspections of observed distresses, manually combined to produce a pavement condition indicator and associate this to the required remedial works. Such approach fails to forecast the deterioration rate and remaining life of the pavement, and are uncapable of incorporating the impact of the composition and frequency of aircrafts to be received by the runway in the future.

1.3. Research Objective

The overall goal of this research is to enhance airport pavement management systems.

First, by automating the estimation of pavement condition (through observed distresses) and facilitating the matching of remedial works.

Second by explicitly enabling the consideration of aircraft composition and frequency, such that the effect of each aircraft operation is directly linked to the remaining life of the pavement.

1.4. Scope and Limitations

Securing the data was not an easy task given the confidentiality of the information, including an airport's flexible and rigid pavement distress data, flight statistics at the time of inspection, geotechnical test results for pavement design, and airport maps.

The main limitation in this thesis was counting with 20 years of aircraft operations (type of aircraft and frequency of operations). Landing gear configuration was taken as given by the manufacturer of the aircraft and tire contact pressure was taken from secondary literature sources. Soil baring capacity was only available at given borehole points.

The mechanistic-empirical equation for the allowable number of repetitions is only applicable for the case study and can be used as a seed value for other calibrations elsewhere.

1.5. Research Significance

The following contributions were made to this research:

1- Developing a tool to automate the calculation of flexible and rigid pavement PCI.
2- Adaptation of the AASHTO highways mechanistic equation towards runway pavements
3- Enabling a method to estimate the Allowable Number of loads before fatigue damage
4- Enabling a method to test future scenarios for receiving new aircraft or altering the frequency of aircraft operations with direct measurement on the life of the pavement.

1.6. Organization of the Thesis

This thesis is presented in six chapters as follows. Chapter 1 defines the problem and presents the objectives of the research and the structure of the thesis. Chapter 2 contains a review of the state of the practice in the importance and history of the Pavement management system, Pavement condition Indicators and using fatigue damage method in order to predict pavement remaining life. Chapter 3 presents the methodology of the project in both two approaches. Chapter 4 is specified for the automation and presentation of PCI calculation for the case study of Mashhad International Airport. Chapter 5 implements an equation for Mashhad airport pavement fatigue damage and prediction of pavement remaining life based on chapter 4 PCI results. Chapter 6 presents the conclusions and makes recommendations for future research.

CHAPTER 2
LITERATURE REVIEW

2.1. **Airport Pavement Management**

Although pavement management systems (PMS) date back to the 1960s, they have been used in airports runways since the 1980s. It is well acknowledged that runways, like highways, are prone to deterioration, which, if not monitored, can cause safety threats to aircraft operations (taking off or landing) (Alessandro Di Graziano et al,2021)

An Airport Pavement Management System (APMS) is a set of procedures for managing the maintenance and rehabilitation of runways, taxiways and apron pavements. An APMS includes deterioration modeling and a decision-support system (Paola Di Mascio et al,2019). In theory An APMS must facilitate the Investigation of pavement deteriorating patterns resulting in more accurate prediction of future pavement conditions and remaining pavement life.

The purpose of implementing a pavement management system is to assist decision-makers in establishing economically feasible methods to keep pavements in serviceable condition over a specific time period and provides a consistent, objective, and systematic approach for setting priorities, timelines, and resource allocation (Paola Di Mascio et al,2019) to identify the most cost effective decisions regarding particular M&R treatments and their appropriate timing, while also knowing the long-term consequences of those decisions(TRB,2008). Because of a more effective means of allocating available funding, this ability may eventually contribute to an improvement in the pavement management system. A life-cycle cost analysis for multiple options can be performed by estimating the rate of deterioration to find the ideal time to apply the best M&R alternative and avoid greater M&R expenditures in the future.

A pavement typically functions well for most of its life before reaching "critical condition" and rapidly deteriorating **(Figure1).** Maintaining and keeping a good-condition pavement vs rehabilitating a fair-to-poor-condition pavement is four to five times less expensive and extends the pavement's life span. The amount of years a pavement remains in "acceptable" condition before deteriorating rapidly is determined by a variety of factors, including construction type and quality, pavement use, climate, and maintenance (FAA, PMP, 2014)

The ability to predict future pavement conditions as a function of time and the relative cost of rehabilitation at varying stages over its life is one of the most important features of an APMS. (Alessandro Di Graziano et al,2019).

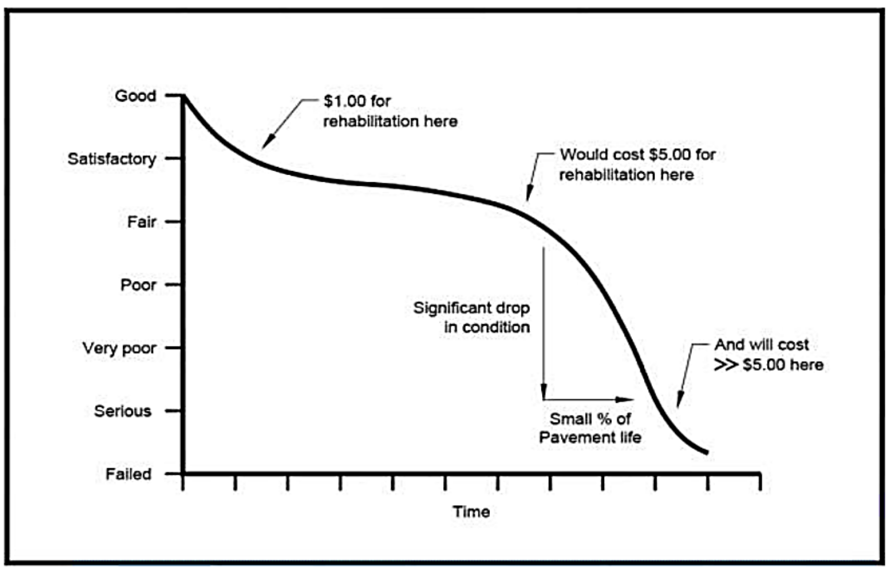


Figure1. **Typical pavement condition life cycle (Source: FAA, PMP, 2014)**

2.2. **Pavement Distresses**

Pavement data collection basically includes identifying and measuring pavement distresses. The first step in developing an inventory of on-site inspections is to have a standard definition of distress type to classify deteriorations for flexible and rigid pavement. In this regard various institutions, provide some procedures and adequate information in order to categorize pavement deterioration which is produced by loading, environmental factors, or a combination thereof, appears on the pavement surface (FAA, 2014). T**able 1** and **table 2**, summarize the main distress experienced by pavements, which are used in the process of calculating the pavement condition index.

Table1. **Flexible Pavement Distresses (Source : FAA, 2014)**

Distress	Type	Definition
Longitudinal and transverse cracks	crack	This cracking is not due to loading and form by surface shrinkage and expansion. Thermal variations, bad lane join construction and age hardening of asphalt material can cause that..
Block cracking		These cracks split the pavement into blocks that can be as little as 1 foot by 1 foot (0.3 m × 0.3 m) or as large as 10 feet by 10 feet (3 m by 3 m). Daily temperature cycling, which leads to daily stress/strain cycling triggers this type of cracks.
Reflection cracking		Vertical or horizontal movement caused by moisture fluctuations or traffic loads. These cracks can arise on asphalt pavement overlay when cracks or joints in the previous pavement have not been completely fixed.
Alligator or fatigue cracking		An interconnection crack generated by fatigue failure of the HMA surface under repetitive traffic pressure at the bottom of the HMA surface (or stabilized base), where the tensile stress and strain are the highest under a wheel load. These cracks are generating multiple-sided sharp angled pieces that build a pattern resembling alligator skin. The longest side of the pieces is less than 2 feet (0.6 m)
Slippage cracks		Deforming or sliding the pavement due to braking or turning wheels. The main reasons for that are low-strength surface mix or a poor bonding between surface and the under layer.
Raveling	***Disintegration***	When the asphalt binder has severely aged and stiffened, the aggregate particle dislodged and slightly more pieces break away, and the pavement becomes rough and jagged, potentially becoming a significant source of FOD.
Weathering		Wearing away of the asphalt binder and fine aggregate material from the pavement surface. The loss of fine aggregate matrix is visible and may be followed by color fading of the asphalt pavement
Potholes		When part of the pavement material breaking away and creating a hole due to pavement surface fracture. The majority of potholes are produced by pavement surface fatigue
Asphalt stripping		In this distress the bituminous binder stripes due to penetration of moisture into the HMA.

		In addition the water-vapor cyclic pressures in Asphalt mixture can cause removing the binder rom aggregates.
Jet blast Erosion		The aircraft engine jet blast can cause burning bituminous binder of asphalt surface and make it dark. The localized burned area can vary in depth up to 1/2-inch (13 mm).
Patching		Some parts of the pavement can be replaced with new layers. When patched sections start to deteriorate, the quality of ride is being effected and raises the possibility of FOD.
Rutting	***Distortion***	A depression in the wheel path's surface is called rutting. This type of distress is produced by a persistent deformation in any of the pavement layers or subgrade as a result of material consolidation or displacement caused by traffic loads
Corrugation		Lack of mix stability or a poor bond between material layers cause plastic surface movement indicated by ripples across the surface
Shoving		The localized bulging of a pavement surface is known as shoving. It can be caused by a lack of stability in the mix, shear movement at an interlayer, or lateral stresses generated during expansion by adjacent PCC pavement
Depression		Can occur as a result of higher traffic than the pavement was designed to withstand, localized settling of the underlying pavement layers, or poor construction procedures.
Swelling		upward bulge in the pavement's surface is often induced by frost activity in the subgrade around different material types or by swelling soil
Polished aggregate	***Loss of skid resistance***	Repeated traffic applications produce aggregate polishing for extremely small or low quality asphalt materials with no angular particles.
Contaminants		The accumulation of rubber particles, oils, or other foreign elements on a pavement surface reduces its skid resistance
Bleeding		Formation of a layer of bituminous material on the pavement surface that resembles a shiny, glass-like, reflecting surface that generally becomes fairly sticky. It happens when hot weather causes asphalt binder to fill gaps in the mix and then extend out onto the pavement's surface.
fuel/oil Spillage		Constant fuel/oil spillage on an HMA surface softens the asphalt

Table2. **Rigid Pavement Distresses (Source : FAA, 2014)**

Distress	**Type**	**Definition**
Longitudinal, transverse, and diagonal cracks	***Cracking***	A combination of repeated loads and shrinking stresses can cause cracks. poor construction methods, underlying pavement layers that are fundamentally insufficient for the imposed load, or pavement overloads can separate the slab into two or three pieces
Corner breaks		Load repetition on slab corners due to lack of support, and curling stresses. A corner break varies from a corner spall in that it runs vertically through the whole thickness of the slab, whereas a corner spall crosses the joint at an angle
Durability "D" cracking		a pattern of cracks running near and parallel to a joint or linear crack forms because the concrete is unable to endure environmental conditions such as freeze-thaw cycles.
Shrinkage cracking		This type of cracking that develops during the setting and curing of the concrete do not walk the whole length of the slab.
Shattered slab /intersecting cracks		Crossing cracks that split it up into four or more parts. This is mainly due to traffic saturation and/or insufficient foundation support.
Joint seal damage	***Joint seal damage***	Any situation that causes incompressible foreign material, such as soil or stones, to collect in the joints or allows water to infiltrate. Foreign material accumulation prevents the slabs from expanding and may result in buckling, shattering, or spalling and also water can penetrate through the pavement layers which causes pumping or foundation deterioration
Scaling, map cracking, and crazing	***Disintegration***	The erosion and loss of the wearing surface can occur on a surface that has been deteriorated by incorrect curing or finishing or freeze-thaw cycles. Map cracking, also known as crazing, is a network of thin hairline cracks that run exclusively through the top surface of the concrete.
Reactivity of Alkali-Silica (ASR)		ASR is generated by an expansion reaction between alkalis and certain reactive silica minerals, which results in the formation of a gel that absorbs water, causing it to expand and potentially harm the concrete and surrounding structures.

Joint spalling		The breaking of the slab edges within 2 feet (0.6 m) of the side of the joint does not continue vertically through the slab but normally meets the joint at an angle.
Corner spalling		ravelling or breakdown of the slab within 2 feet (0.6 m) of the corner that varies from a corner break in that it often angles downward to cross the joint, whereas a break continues vertically through the slab with the same reason that generate joint spalling
Blow-ups		Occurs at a transverse crack or joint that is not broad enough to allow the concrete slabs to expand mostly common in thin pavement portions.
Pop outs		A little portion of pavement that separates off the concrete surface. This is induced by freeze-thaw action along with expanding aggregates, and it can be caused by ASR Moreover it can happen by a big piece of aggregate breaking free from the concrete surface or by clay balls in the concrete mix.
Patching		When the deteriorated pavement has been removed and replaced with new material.
Pumping	***Distortion***	By displacement of the slab during the loading, water and underlying material are ejected via joints. The ejected water brings gravel, sand, clay, or silt particles with it, resulting in a gradual loss of pavement support that can triggers cracking.
Settlement or faulting		slab level variation at a joint or crack resulting by upheaval or non-uniform consolidation of the underlying pavement layer(s) material
Polished aggregates	***Loss of skid resistance***	Using aggregates which are naturally polished or crushing naturally polished stones results in rough angular faces with high skid resistance
Contaminants		the accumulation of rubber particles in pavement grooves reduces the efficacy of the grooves and increases the chance of hydroplaning

2.3. Aggregated Pavement condition indicators

Structural degradation of Pavement condition is a function of cumulative traffic loading, and is conditioned by the pavement structure, and the environmental exposure. (1994, Haas and colleagues)

However, surface condition (i.e., distress type, severity and density) and structural strength must be investigated in order to clearly establish the required maintenance and rehabilitation interventions. In addition, roughness and skid resistance are also used as measures of safety for landing and taking off operations and used in combination with the surface condition and the structural strength for programming maintenance and rehabilitation interventions.

Typically, network-level pavement management includes a visual inspection of the pavement's condition. Pavement management at the project level can include assessing strength, roughness, and skid resistance which may obtained by destructive testing (such as coring and boring) or non-destructive testing. (TRB, 2008)

For convenience of communicating results to stakeholders, airport agencies had adopted an aggregated condition index to communicate the summation of all pavement distress indicators into a single number, called Pavement Condition Index (PCI) (Haas, R., Hudson and W. R., & Zaniewski, J. ,1994), which levels are linked to required treatments (FHWA, 2003). The approach used to establish PCI must be practical and repeatable to ensure that APMS recommendations are trustworthy and condition ratings do not differ between inspectors.

(TRB, 2008) (Piryonesi et al, 2017)

The Pavement Condition Index (PCI), generated by the US Army Corps of Engineers, is a very comprehensive pavement indicator (Shahin, M. Y., & Kohn, S. D. ,1979).

The PCI method is based on a visual inspection of the type, extent, and severity of pavement distress. The PCI is an indicator of the current condition of the pavement based on the distress observed on the pavement's surface, which also reflects structural integrity and surface operating condition (roughness and safety). The PCI is monitored to determine the pace of pavement deterioration in addition to M&R requirements and priorities.

As shown in **Table 3**, this allows for the early identification of serious intervention needs. Moreover, PCI provides information on pavement performance for assessment or improvement of the pavement design and maintenance methods.

Table3. **Typical Pavement M&R Strategies based upon PCI Value (Source: Shahin M.Y., and Walther J.A. , 1990).**

PCI	Rating	Strategy
85-100	Good	Routine Maintenance
70-85	Satisfactory	Preventive Maintenance
55-70	Fair	Minor Rehabilitation
40-55	Poor	Minor Rehabilitation
25-40	Very Poor	Minor Rehabilitation
10-25	Serious	Reconstruction
0-10	Failed	Reconstruction

As a result, the PCI is a numerical index ranging from 0 to 100 that is used to describe the overall condition of a pavement section's surface, with 100 being the best possible condition and 0 indicating the worst possible condition.

In order to get a set of PCIs for the desired pavement, a full pavement distresses inspection is usually necessary. In terms of pavement performance rating, the PCI has been the most unique indicator. It has also seen widespread use in network-level pavement management. (Shahin M.Y., and Walther J.A. , 1990).

The process of calculating the PCI is standardized and documented by the ASTM. The first step in generating the PCI is to extract the distress data. Based on its influence on pavement performance and riding quality, each distress is classified as Low (L), Moderate (M), or High (H) (H). The Federal Highway Administration (FHWA) provided a complete distress identification manual in 2003. (FHWA, 2009). The amount of distress within a pavement section is measured in square meters (square feet), linear meters (feet), or the number of occurrences, depending on the type of distress. In contrast, longitudinal and transverse cracking are measured in linear meters (feet). (ASTM, 2007)

Distress Density is the proportion of distress within a certain region. It is calculated by dividing the total amount of each distress type at each severity level by the section's entire area.

The "Pavement Section" is a section of pavement with similar construction, maintenance, use history, and condition. A section's traffic volume, structure, and geometric qualities should be comparable. The PCI calculation is based on deducting values, which are weighting factors ranging from 0 to 100 that reflect the effect of each distress on pavement condition.

A deduct value of 0 indicates that distress has no influence on the structural integrity of the pavement or the operational condition of the surface, whereas a deduct value of 100 shows that the distress is highly significant.

Deduct Value (DV) is the number of distresses used to calculate a combined condition index for pavement sections. According to ASTM 6433-07, there are distress deduct value curves for determining deduct value for each distress type and severity level. (ASTM, 2007)

Deduct values can be obtained from the Figures provided by ASTM (ASTM, 2007)

It is worth mentioning that using these figures is time consuming and can cause human error.

For adjustment of the cumulative deduct value or the total deduct value (TDV), Corrected Deduct Value (CDV) is defined. The CDV adjusts the TDV to fit for a range of 0-100 by using a set of CDV-TDV adjustment curves. The maximum of CDV (maxCDV) is used to calculate PCI (PCI=100-maxCDV). If there is only one deduct value, then the TDV is used in place of the maxCDV in determining the PCI (ASTM, 2007).

However, The DV and CDV curves lacked mathematical formulae and the procedure is time-consuming and may cause visual errors.

Instead of using manual calculation, Piryonesi et al. developed a Python program to calculate the PCI from the distresses in accordance with the ASTM standard. All deduct value graphs and correction curves were digitized and mathematically modelled for this purpose. After discovering the mathematical purpose of curves, a Python program was used to implement them. Data points also can be used for each curve in this study, and nonlinear regression analysis can be performed to determine the optimal DV mathematical functions for each DV curve (Piryonesi et al, 2017).

After obtaining the pavement condition index for all the required segments, the next step is presenting them for intervention decision making. Shanshan Tu et al. (2019) employed GIS technology to display the results and extract the necessary information more easily. In this research, an airport pavement management system (APMS) based on a 3D geographic information system (GIS) was presented, which plays an important role in improving airport pavement maintenance and rehabilitation efficiency

PMS is a scientific strategy that can assist an aviation agency in making better use of limited maintenance and rebuilding budgets. The system, which makes use of GIS technology, dramatically increases an agency's capacity to find and track pavement distress, evaluate pavement condition, and maximize performance.

As shown in **Figure 2**, pavement performance data such as PCI of the apron on the map can be displayed using different colors to represent the corresponding value of PCI on the map (the red parts will warn the agency and require maintenance as soon as possible), which is used to assist administrators in making an optimal decision. (Shanshan Tu , 2019). It is crucial to identify and repair damaged sections as soon as possible. The methodology allows the airport agency to select where and when to maintain within financial constraints.

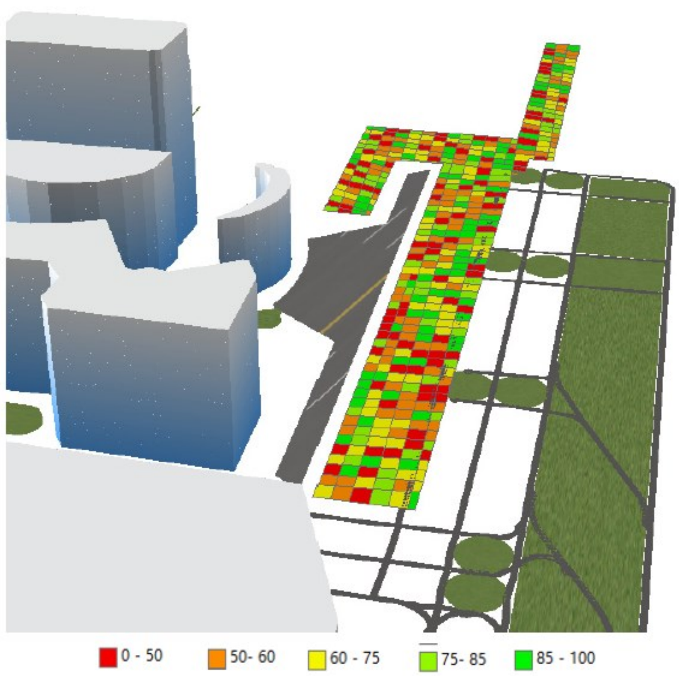


Figure2. **Display of PCI of the apron (Shanshan Tu et al 2019)**

2.4. **Old Airport Pavement design methods**

International aviation organizations have developed various design methods for airport pavements. For instance, ICAO, FAA and Transport Canada have released their design manual. In the old publications of FAA advisory circular, rigid pavements was recommended to design based on Westergaard theory of edge loaded slabs as described in AC 150.5320- 6D. FAA also used Three-Dimensional Finite Element method and failure model to design rigid pavements. For flexible pavements, CBR method which is basically an empirical method was utilized as described in AC 150.5320-6D. In the current methods the flexible pavement design guidance in the AC 150/5320-6G is based on layered elastic theory and the rigid pavement is based on both layered elastic theory and three-dimensional finite element theory. "For flexible pavement design, FAARFIELD uses the maximum vertical strain at the top of the subgrade and the maximum horizontal strain at the bottom of all asphalt layers as the predictors of pavement structural life. For rigid pavement design, FAARFIELD uses the horizontal stress at the bottom of the concrete panel as the predictor of the pavement structural life."(FAA, 2021)

In the old design method which has been canceled by FAA, the aircraft type that produces the greatest pavement thickness and was not necessarily the heaviest aircraft in the forecast, was the design aircraft. Later FAARFIELD was developed and calibrated specifically to produce pavement thickness designs consistent with previous methods based on a mixture of different airplanes rather than an individual airplane (FAA, 2009). "FAARFIELD is based on the cumulative damage factor (CDF) concept in which the contribution of each aircraft type in a given traffic mix is summed to obtain the total cumulative damage from all aircraft operations in the traffic mix." (FAA, 2021) Therefore, the influence of any single aircraft could be taken in to account in the process of pavement failure.

2.5. **Modern Mechanistic Empirical Pavement Performance Prediction**

Pavement performance prediction can follow modern mechanistic empirical models (Gupta et al., 2012) where non-structural factors such as the number of load repetitions are combined with structural response parameters (stresses and strains, layer materials and thicknesses, drainage, etc.) to create a model that can predict the consumption of the runway pavement life and forecast the progression of rut depth and roughness (IRI) distresses over time under cumulative traffic loading and/or environment effects (Archilla and Madanat 2000).

The main merit of mechanistic-imperial models is their capability to extrapolate predictions beyond the data range and conditions in which they were calibrated, resulting in deterministic performance projections (Prozzi, 2001). Their significant drawback is that it is not possible to evaluate the accuracy of the predictions when these models are employed outside of the initial data range for which they were calibrated (Prozzi, 2001).

In pavement analysis, loads on the pavement surface produce two strains that are believed to be critical for design purposes. These are the horizontal tensile strain (εt) at the bottom of the asphalt layer and the vertical compressive strain (εv) at the top of the subgrade layer. **(Figure3).**

If the horizontal tensile strain (εt) is excessive cracking of the surface layer will occur, and the pavement distresses due to fatigue. If the vertical compressive strain (εv) is excessive, permanent deformation occurs on the surface of the pavement structure from overloading the subgrade, and the pavement distresses due to rutting. (Yang H. Huang ,2004)

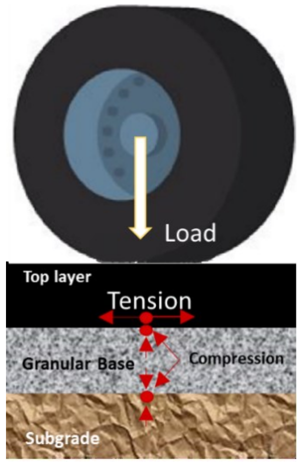


Figure3. **Two strains produced by loads on the pavement surface**

Several fatigue and rutting models have been created to determine the relationship between the asphalt modulus and/or the observed stresses and the number of load repetitions before pavement failure.

Failure is expected when the cumulative damage ratio, D_f, equals or exceeds 100 percent, according to the following expression (Hesham et al, 1998):

$$D_f = \sum_{i=1}^{k} \frac{n}{N_{fi}} \leq 1$$

K = Number of loading groups (axle-load/type combinations).
n= Cumulative number of passages of load group *i.*
N_{fi}=Allowable number of passages to failure of load group *i*

The tensile strain at the bottom of the asphalt layer has been used as a design criterion to prevent fatigue cracking. (Yang H. Huang, 2004) Huang (1973a) developed charts for determining the critical tensile strain at the bottom of layer 1 for a two-layer system.

The mechanistic-empirical method has the potential to be used to obtain a tool to inspect future scenarios of aircraft traffic for a given airport and to predict the ability of the runway to withstand such future aircraft traffic and the consumption of remaining life of the pavement. For this purpose, the MEPDG can be calibrated first to the observed deterioration history of a given airport under historical aircraft traffic loading. Once calibrated, the same equations can be used to forecast the impact of any current or future combination of aircraft traffic, where aircraft traffic encompasses both the amount and configuration of the loading as well as the number of load repetitions. (Pietro Pezzano,2016).

For the forces exerted on the pavement by airplanes it is required to estimate the axle loads and tire pressures, their configurations, the repetition of loads (frequency) and the distribution of traffic across the pavement.

Simply put, the MEPDG structural model considers that each load causes a certain amount of irreparable damage. This damage accumulates throughout the pavement's life, and when it reaches a certain threshold, the pavement is considered to have reached the end of its functional service life. Therefore, pavement structural design requires quantification of all expected loads that a pavement will encounter over its design life. (Pietro Pezzano et al, 2016)

To estimate the critical strains that produce in airport pavement layer, it is important to establish an equivalent axle load factor (EALF) between the 80 kN standard axle load for vehicles and the axle of the airport fleet. Airplanes do not have aligned axles like vehicles, thus while designing, we must take into account that the most loaded area of the runway is where the heaviest loaded gear generates the greatest weigh. (Pietro Pezzano et al, 2016)

The FAARFIELD Airplane window provides a good tool to obtain the characteristics of most airplanes in the world because it offers around 200 different aircraft models, their axle load distribution, wheel spacing, and tire pressure. (Pietro Pezzano et al, 2016)

CHAPTER 3
METHODOLOGY

Deterioration models predict the decay of pavement condition as a response to air traffic, environmental exposure, and pavement structural capacity (Gulen et al. 2001).

This research proposes the automation of the calculation of Pavement Condition Index (PCI) following the American Standard of Testing Materials (ASTM) method (ASTM, 2007). The automation takes the form of an Excel macro that facilitates the calculations of PCI from pavement distress data. The PCI is used to identify the recommended maintenance and rehabilitation method **(Figure 4).** In addition, this research proposes an adaptation of the mechanistic empirical pavement method in order to estimate the remaining life of a pavement with explicit capabilities to entertain any scenario of future expected air traffic. **(Figure 4)**

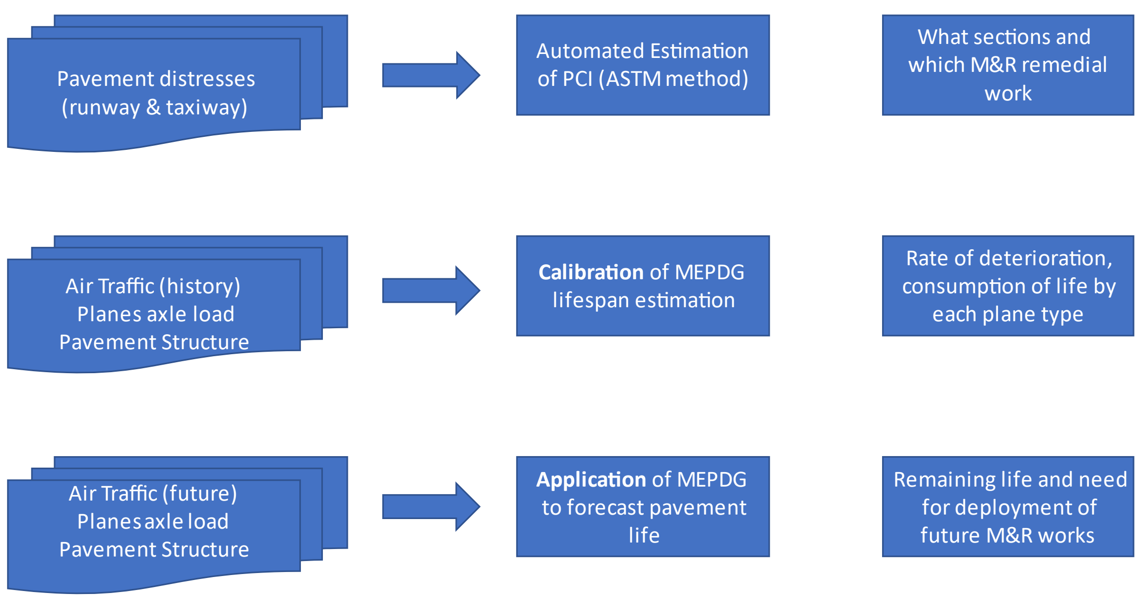


Figure4. **Summary of the Methodology proposed in this thesis**

The fatigue damage analysis comprising estimates the pavement performance and the remained life by applying the pavement failure criteria.

3.1.Background and Definitions

3.1.1. Pavement condition indicator

The PCI is a numerical index between 0 and 100 that is used to indicate the general condition of the surface of a pavement section, with 100 representing the best possible condition and 0 representing the worst possible condition. This PCI rating scale is shown in **Figure 5**. (Wesołowski.M & Iwanowski.P ,2020)

Figure5. **Standard PCI rating scale (after ASTM 2007)**

Pavement condition surveys are required to assess the level of distresses in order to obtain the pavement condition index (PCI) for the pavement section of interest. The PCI has been the most common index in terms of pavement performance rating. (Shahin and Walther, 1990).

The procedure to perform pavement condition surveys and the PCI calculation method have been standardized by ASTM for Airfields, roads and parking lot pavements (ASTM, 2007).

ASTM (2007) provides the basic definitions for the calculation of PCI, which are reproduced for convenience in the following paragraphs, as they will be required moving forward in this study:

*“**Pavement Section** - A homogeneous pavement area having uniform construction, maintenance, usage history, and condition. A section should have similar traffic volume, structure and geometric characteristics. A completed distress identification manual was provided by Federal Highway Administration (FHWA) in 2003 (FHWA, 2009). Depending on the distress type, the extent of distress within a pavement section is quantified either in square meters (square feet), linear meters (feet), or the number of occurrences.*

For instance, fatigue and block cracking are measured in square meters (feet), while longitudinal and transverse cracking is measured in linear meters (feet). (ASTM, 2007)

***Distress Density** - Percentage to indicate the ratio of distress within an area. It is obtained by dividing the total quantity of each distress type at each severity level by the total area of a pavement section.*

***Deduct Value (DV)** - Statistical weight number of distresses to determine a combined condition index for pavement sections. According to ASTM 6433-07, for each distress type and severity level, there is a distress deduct value curves for deduct value determination (ASTM, 2007).*

***Corrected Deduct Value (CDV)** - Adjustment of the cumulative deduct value or the total deduct value (TDV). The CDV adjusts the TDV to fit for a range of 0-100 by using a set of CDV-TDV adjustment curves. The maximum of CDV (maxCDV) is used to calculate PCI (PCI=100-maxCDV). If there is only one deduct value, then the TDV is used in place of the maxCDV in determining the PCI (ASTM, 2007)”.*

Dynamic segmentation must be observed when dividing entire airport pavements into sections. Sections must consider the pavement structure and surface type, the history of maintenance, the drainage quality, the traffic level and the purpose of the pavement, among others.

Several sections must be selected in order to collect distress data to establish the pavement PCI, and they are known as sample units. However, it is not the purpose of this research to revise the sampling method. The reader is directed to Shahin and Walther (1990) for further details on the estimation of the minimum number of samples required in each section.

The present ASTM PCI approach offers an objective analysis of pavement quality, but it may be laborious for large airport networks. Even for a tiny airport pavement network, there are several calculations that must be performed. Therefore, it is advantageous to create a tool that automates the PCI calculation of airport sections.

The first step to advance this research is to develop an automated approach to replace the manual procedure presented in ASTM (2007) and this is accomplished with a programmed Excel spreadsheet template with multiple sheets which import distress data collected by third parties and directly calculate the PCI for various test sections.

The following sections explain the development of mathematical formulae based on current DV curves provided in the ASTM 6433-07 procedure, followed by an explanation of how these equations are used in an Excel template for automating PCI calculations.

For the DV curves, no mathematical formulae were known. In this work, data points for each curve were obtained and nonlinear regression analyses were performed to determine the suitable DV mathematical functions for each curve. The similar methodology was used to the CDVs.

3.1.2. Damage Analysis

For damage analysis approach as a mechanistic empirical method, failure criteria and equation recommended by institutes to calculate the number of load repetition until the pavement fails are the main basics to define.

There are two failure criteria that originated in the Asphalt Institute and that were adopted on the AASHTO MEPDG: the rutting and the cracking. This research uses cracking as the limiting failure criteria to estimate the lifespan of an airport pavement. The approach is based on the elastic strain "ε_t" at the bottom of the pavement top layer and makes a comparison of the number of observed load repetitions versus the allowable number of repetitions (*Nf*) for each given aircraft. The equation to calculate the maximum allowable Number of loads before fatigue damage is:

$$N_f = f_1 \ (\varepsilon_t)^{-f_2} \ (E_1)^{-f_3}$$

Where:

N_f : Number of load repetition until the pavement fails.

ε_t : The critical tensile strain.

f_1, f_2, f_3: Correlation coefficients to fit empirical field data to the mechanistic model.

E_1: Modulus of elasticity of the pavement top layer.

3.2. Pavement Condition inspection

Pavement surface damages are visually inspected to determine the PCI indicator. Distress type, density, and severity are considered during the review. The airport elements are divided into research samples i.e., runways, taxiways and aprons. The elements are then separated into individual samples. (Wesołowski.M, Iwanowski.P, 2020)

Each sample unit has its own data sheet (**appendix A**). Data Sheets are used to record the type and severity of distress for each sample unit. All types of distress are defined by a unique code, which is shown in **Tables 4** and **Table 5** for flexible and rigid airfield pavements, respectively. For example, number 41 (Alligator Cracking, Low Severity) is measured in meters, so 40 represents 40 meters of low severity cracking, and so on. In rigid pavements, the inspection is carried out by reporting the distress observed in each slab on the concrete pavement field inspection data sheet.

For example, code 62L specifies that a slab has a low-severity corner break. Load, climate, and other factors are used to categorize distress causes (**Tables 4 and 5**).

Table 6 in **Section 3.3.2** provides an example that illustrates the use of codes to calculate PCI for a sample unit.

Table4. **Flexible pavement distress classification**

code	Distress	Cause
41	Alligator Cracking	Load
42	Bleeding	Other
43	Block cracking	Climate
44	Corrugation	Other
45	Depression	Other
46	Jet blast	Other
47	Joint reflection/cracking	Climate
48	Longitudinal and transverse cracking	Climate
49	Oil spillage	Other
50	Patching	Other
51	Polished aggregate	Other
52	Weathering and raveling	Climate
53	Rutting	Load
54	Shoving	Other
55	Slippage cracking	Other
56	Swelling	Other

Table5. **Rigid pavement distress classification**

code	Distress	Cause
61	Blowup/buckling	Load
62	Corner break	Load
63	Linear cracking	Climate
64	Durability "D" cracking	Climate
65	Join seal damage	Other
66	Patching small	Other
67	Patching large/utility cut	Other
68	Pop outs	Other
69	Pumping	Other
70	Scaling/crazing	Other
71	Settlement	Other
72	shattered slab	Load
73	shrinkage cracking	Other
74	join spalling	Other
75	corner spalling	Other

3.3.Calculating the PCI

For each inspected sample unit, the PCI is determined based on ASTM standard test method for Airport Pavement Condition Index Survey (ASTM, 2007). The PCI for the whole pavement section cannot be calculated without first computing the PCI for the sample unit. As discussed in **Section 3.1**, the PCI calculation is based on deduct values, which are weighting factors ranging from 0 to 100 that reflect the effect of each distress on pavement condition. (Paola Di Mascio & Laura Moretti , 2019).

A deduct value of 0 indicates that distress has no influence on the structural integrity of the pavement or the operational condition of the surface, whereas a deduct value of 100 shows that the distress is highly significant (ASTM, 2007)

Deduct values can be obtained from the Figures provided by ASTM (2007). However, that procedure is time-consuming, and its automation is needed. For this purpose, each curve was digitalized, and an equation was derived using a best fit approach. **Appendix B** contains all of the equations derived in the calculation of deduct values estimated as part of this research. In addition, a Visual Basic Macro was coded in Excel to automate the calculation of PCI (**appendix C**).

3.3.1 Asphalt surfaced pavements (ASTM, 2007)

Step 1- Determine deduct values

a. Add the totals for each distress category as shown in **Table 6** at each severity level and write them on the survey form under "total." Depending on the type of distress, quantities of distress are measured in square feet or square meters (depending on the country), linear feet or meters, or the number of occurrences.
b. To calculate the percentage of density per sample unit for each distress type and severity, divide the quantity of each distress type at each severity level by the total area of the sample unit, then multiply by 100. (This is done automatically in the excel file)

c. Using the distress deduct value curves, determine the deduct value for each distress type and severity level combination. The figures of deducting curves are provided in **appendix D** for Asphalt airfields.

Table6. **Example of an asphalt pavement sample unit condition**

Sample Area =5000 m^2		**Date**= / /				Sketch:		
Section = 1		**Sample unit =**						
Distress code	Distress type	Distress severity	Quantity			Total	Density	Deduct Value
48	Longitudinal and transverse cracking	L*	10	20	17	47	0.940	3.12
48	Longitudinal and transverse cracking	M	7	9		16	0.320	6.22
41	Alligator Cracking	L	53			53	1.060	21.27
45	Depression	L	10	5		15	0.300	0.90
53	Rutting	L	20	45	10	75	1.500	17.14
53	Rutting	M	25			25	0.500	20.24

Note:* L= Low, M=Medium, H=High

Step2- Determining the maximum allowable number of deducts

a. If only one individual deduct value (or none) is greater than 5, the total deduct value is used in place of the maximum corrected deduct value (CDV) in step 4 and the PCI computation is completed. Otherwise, the rest of the step2, steps 3 and 4, should be followed.

b. The individual deduct values are listed in descending order. In **Table 7,** the values would be sorted as follows: 21.27; 17.14; 6.22; 3.12 and 0.9.

c. The allowable number of deducts (m) is determined by using the following formula: m_i=1+(9/95)(100-HDV_i), where: m_i= Allowable number of deducts, including fractions, for sample unit *i* and HDV_i= Highest individual deduct value for sample unit *i*. For example, in **Table 7,** *m* is 8.45

d. The number of individual deduct values is reduced to *m*, including the fractional part. If less than *m* deduct values are available, then all of the deduct values are used.

Step3- Determining the maximum corrected deduct value (CDV)

a. The number of deduct value greater than 5 are determined and entered in (q)
b. The total deducts value by adding all individual deduct values is calculated.
c. The CDV is determined from q, and total deduct value by looking up the appropriate correction curve. Correction curves are provided in **appendix F**.
d. Reduce the smallest individual deduct value that is greater than 5 (just for airfields and unsurfaced roads) to 5.0
e. The maximum CDV is the largest of the CDVs determined.

Step4- Calculate PCI by subtracting the maximum CDV from 100.

For example, the PCI calculation for **Table 7** would be PCI=100-43=57, where 43 is the roundup of 42.13, which is the maximum CDV.

Table7. **PCI calculation sheet for the example sample unit**

	Deduct Values										**Total**	**q**	**CDV**
1	21.27	20.24	17.14	6.22	3.12	0.90					68.88	4.00	35.45
2	21.27	20.24	17.14	5.00	3.12	0.90					67.67	3.00	42.13
3	21.27	20.24	5.00	5.00	3.12	0.90					55.52	2.00	36.80
4	21.27	5.00	5.00	5.00	3.12	0.90					40.29	1.00	40.29
User will add as needed													

3.3.2 Concrete surfaced pavements (ASTM, 2007)

Step 1- Determine deduct values

a. Add up the number of slabs in which each is a unique combination of distress type and severity level happens.
b. Simply divide the number of slabs from step (a) by the total number of slabs in the sample unit, then multiply by 100 to obtain the percentage of density per sample unit for each distress type and severity combination.
c. Determine the deduct values for each distress type and severity combination.
   The figures of deduct curves are provided in **appendix E** for cement concrete airfields.

Table8. **Example of a cement concrete pavement sample unit condition**

Number Of Slabs=20	Section = 1	Date= / /	Sample unit =	Sketch:		
Distress code	Distress type	Distress severity	No of Slabs	Total	Density	Deduct Value
65	Join seal damage*	H	*	0	0	12.00
62	Corner break	L	2	2	10	8.21
62	Corner break	M	1	1	5	8.74
63	Linear cracking	L	3	3	15	11.04
63	Linear cracking	M	3	3	15	24.07
72	shattered slab	L	1	1	5	10.66
74	join spalling	L	2	2	10	3.30
75	corner spalling	L	3	3	15	5.56
75	corner spalling	M	1	1	5	4.20

Note: * Number of slabs in join seal damage is not effective

Step2- Determining the maximum allowable number of deducts

This step is the same as for asphalt surface pavement outlined in **section 3.3.1 (Step c)**. For the example in **Table 8**, based on the highest deduct value (HDV) of 24.07, m is calculated as m = 1.0 + 9/95(100-24) = 8.2. There are nine deducts; the ninth smallest deduct (=3.3) is multiplied by 0.2 and reduced to 6.6.

Step3- Determining the maximum corrected deduct value (CDV)

Determine the maximum CDV by following the procedures in section 3.5.1 (Step 3) but using the appropriate curve at the end of **Appendix F** (for concrete Airfields).

Step4- Calculate PCI by subtracting the maximum CDV from 100.

Table 9 summarizes the PCI calculation for the example of PCC pavement data given in **Table8**, PCI= 100-59=41, where 59 is the round-up of 58.9.

Table9. **PCI calculation sheet for example sample unit**

	Deduct Values										Total	q	CDV
1	24.07	12.00	11.04	10.66	8.74	8.21	5.56	4.20	0.64	0	85.11	7	54.2
2	24.07	12.00	11.04	10.66	8.74	8.21	5.00	4.20	0.64	0	84.55	6	56.9
3	24.07	12.00	11.04	10.66	8.74	5.00	5.00	4.20	0.64	0	81.34	5	56.7
4	24.07	12.00	11.04	10.66	5.00	5.00	5.00	4.20	0.64	0	77.60	4	54.7
5	24.07	12.00	11.04	5.00	5.00	5.00	5.00	4.20	0.64	0	71.95	3	54.1
6	24.07	12.00	5.00	5.00	5.00	5.00	5.00	4.20	0.64	0	65.91	2	56.2
7	24.07	5.00	5.00	5.00	5.00	5.00	5.00	4.20	0.64	0	58.91	1	58.9
It can be added as required…													

3.3.3 Calculation of the PCI for a Section (ASTM, 2007)

The PCI of a section is calculated by averaging the PCIs of sample units examined if all inspected sample units are picked using the systematic random strategy or because they are representative of the section and are of similar size. If the inspected sample units were not of equal size, an area-weighted average should be employed, as illustrated in the equation below.

$$PCI_s = PCI_r = \frac{\sum_{i=1}^{R} \mathrm{PCI}_{ri} \times A_{ri}}{\sum_{i=1}^{R} A_{ri}}$$

PCI_s= PCI of the pavement section

PCI_r= Area weighted average PCI of random (or representative) sample unit

PCI_{ri}= PCI of random sample unit *i*

R = Total number of inspected random sample units

A_{ri} = Area of random sample unit *i*,

In **appendix G** the template for PCI calculation is presented.

3.4. Damage analysis under long term performance of the pavement

The pavement condition index method (PCI) based on current distress observations reflects only the extent of damage from previous aircraft demand (history to date) but ignores the effect of changing demand moving towards the future. Therefore, such approach is unable to estimate the impact of future changes on aircraft operations or test scenarios of increased or altered demand on the runway pavement remaining life and how that could accelerate its deterioration. A damage analysis approach is needed to predict the pavement life due to fatigue damage.

It is well known from the literature that pavement structural models are based on the specific amount of irreversible damage produced by every load application. This damage accumulates over the pavement's life, and when it reaches a certain maximum value, the pavement is deemed to be at the end of its usable service life [Pietro Pezzano, Nicola Brusa and David Crowther].

As observed the Elastic modulus can be thought of as a constant amount for a given runway and it is the elastic strain the element that contributes the most to the allowable number of loads. Hence the need to recalibrate the elastic strain coefficient "f_2". Flight statistics of the pavement design period are required to calibrate f_2. In addition, there is a need to estimate the critical tensile strain from every aircraft and its associated landing gear and tire contact pressure. Other amounts required are the modulus of elasticity of the pavement top layer. The f_1 and f_3 are kept constant and based on the calibrated amounts for highways. Future research can study the need to calibrate them over the basis of a dataset of runways with different elastic modulus. In Asphalt Institute pavement design method, f1 and f2 are 0.0796 and 0.854 respectively.

The number of flights in an airport based on the fleet type can be predicted for the pavement design life period. In this report, 20 years is considered. Obtaining the growth rate for every single aircraft requires a separate study.

As it has been noticed in FAA advisory circular for a proper pavement design, materials, construction, and maintenance, any pavement type the desired pavement service life can be provided and historically, airport pavements have performed well for 20 years. (FAA, 2016)

Geotechnical tests can demonstrate the modulus of elasticity of the pavement's different layers.

The critical tensile strain (e) is obtained by the following equation:

$$\varepsilon_t = \frac{q}{E1} * F_e$$

E1: Modulus of elasticity of the top layer

Fe: the strain factor from the figure below.

q: Contact pressure from a single wheel load.

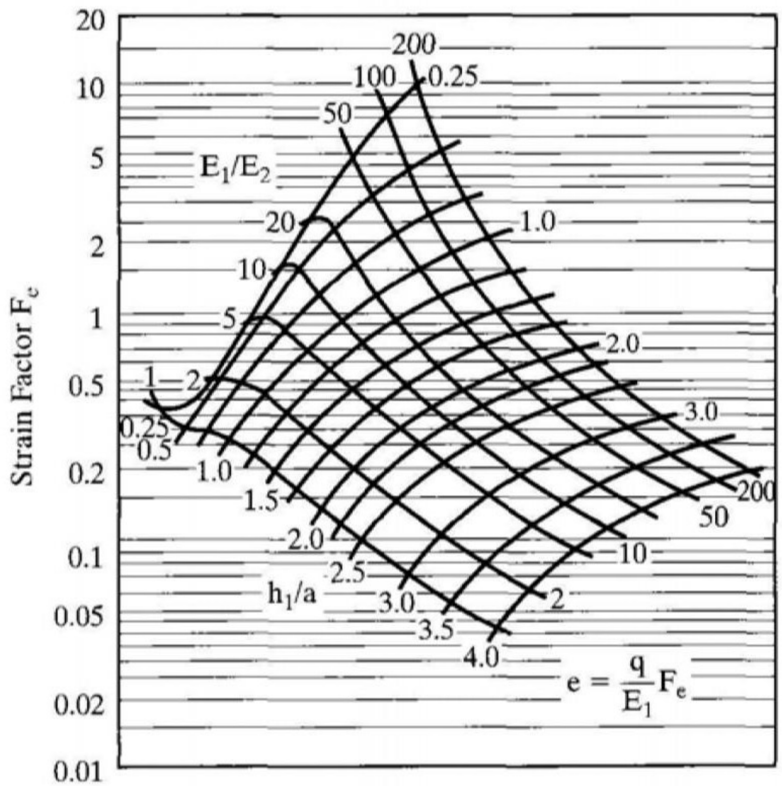


Figure6. **Strain factor for single wheel(Yang H. Huang ,2004)**

In this figure, the following parameters are required:

E2: Modulus of elasticity for the silty clay soil

h1: Existing or new Pavement Top layer thickness

a: The contact radius

Contact pressure from a single wheel load (q)

$$q = \frac{Qw}{\pi a2}$$

The load acting on the single wheel (Qw) is obtained from the following equation:

$$Qw = \frac{Qg}{r}$$

r: Number of wheels of the leg of the main gear under consideration.

Q_g is the distribution of the load between the aircraft gears and calculates from the following equation:

$$Q_g = r \times \frac{0.825 + 0.025 \times N}{R} \times Qt$$

Q_t = total maximum weight of the aircraft (KN).

N = number of landing gears.

R = total number of wheels of the main gear.

r = number of wheels of the leg of the main gear under consideration.

An essential input element in pavement design is traffic load. The magnitude and configuration of the loads, number of wheels and gears, the percentage of load on the main gear and tire pressure are utilized to find load distribution, especially the load on the main single wheel.

Because aircrafts do not have aligned axles like trucks, we must design for the most heavily loaded stretch of the runway, where the most load comes from the most heavily loaded gear.

For example, **figure 7** and **figure 8** show the wheel configuration of some aircrafts.

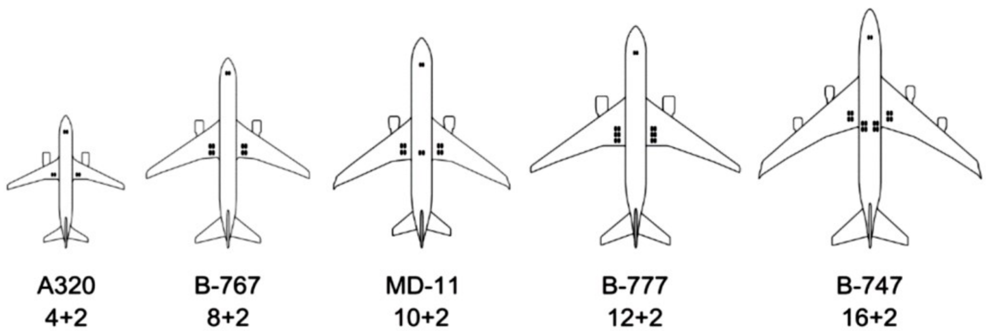


Figure7. **Aircraft wheel configuration(Wikimedia Commons,2022)**

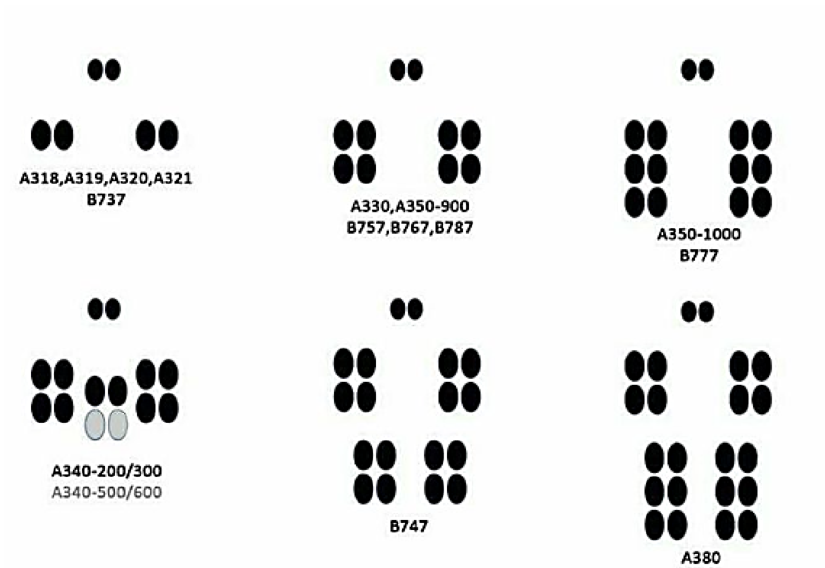


Figure8. **Aircraft wheel configuration(COM FAA,2014)**

The distribution of loads on an aircraft's wheels is not the same since the loads on the main gear are more than on the front gear. **Appendix H** contains some aircraft's loads and weights characteristics comprising maximum take-off weight, gross weight, the portion of loads applied to the main gear, main wheel load and tire pressure.

The contact area of the wheel on the pavement is obtained by dividing the main wheel load and tire pressure and by having the area of contact, the radius of contact can be easily calculated.

After calculating f_2, using the above procedures, the equation for calculating N_f can be used in order to predict the allowable number of flights during the design period for every single aircraft.

3.5. Estimating the pavement remaining life

The estimation of remaining service life is produce by a detailed fatigue damage analysis for the given number of repetitions of observed aircraft and considering the pavement structural capabilities. By calibrating the equation of fatigue damage analysis, number of load repetition (N) over allowable number of load repetition (Nf) can be calculated for all pavement life spans from1 year, 2 years, 3 years up to 20 years.

$$N_f = f_1 (\varepsilon_t)^{-f_2} (E_1)^{-f_3}$$

The Elastic modulus E_1 is a given and measurable property of the top pavement layer and the critical tensile strain (e) is obtained by the following equation:

$$\varepsilon_t = \frac{q}{E1} * F_e$$

Where the contact pressure from a single wheel load (q) is:

$$q = \frac{Qw}{\pi a2}$$

The load acting on the single wheel (Qw) is obtained from the following equation:

$$Qw = \frac{Qg}{r}$$

Qg is the distribution of the load between the aircraft gears and calculates from the following equation:

$$Q_g = r \times \frac{0.825 + 0.025 \times N}{R} \times Qt$$

The above equations can be used to obtain the tensile strain in order to calibrate the coefficient f_2 which is the most important parameter in the estimation of the pavement structural response, to obtain the calibrated f_2 coefficient for rigid and flexible pavements, use the below equation:

$$f_2 = \frac{-\log(N_f/f_1 \times \varepsilon_t^{(-f_3)})}{\log(\varepsilon_t)}$$

The total *n* over *Nf* for the fleet shows the portion of deterioration and failure have occurred during that specific period. Therefore, the results produce an indication of the rate of deterioration of the pavement structure which can be associated to the progression of PCI through time. At any given point on time, the calculated pavement PCI obtained from the first method can be used to find the corresponding apparent age and the pavement remaining life **(Figure 9).**

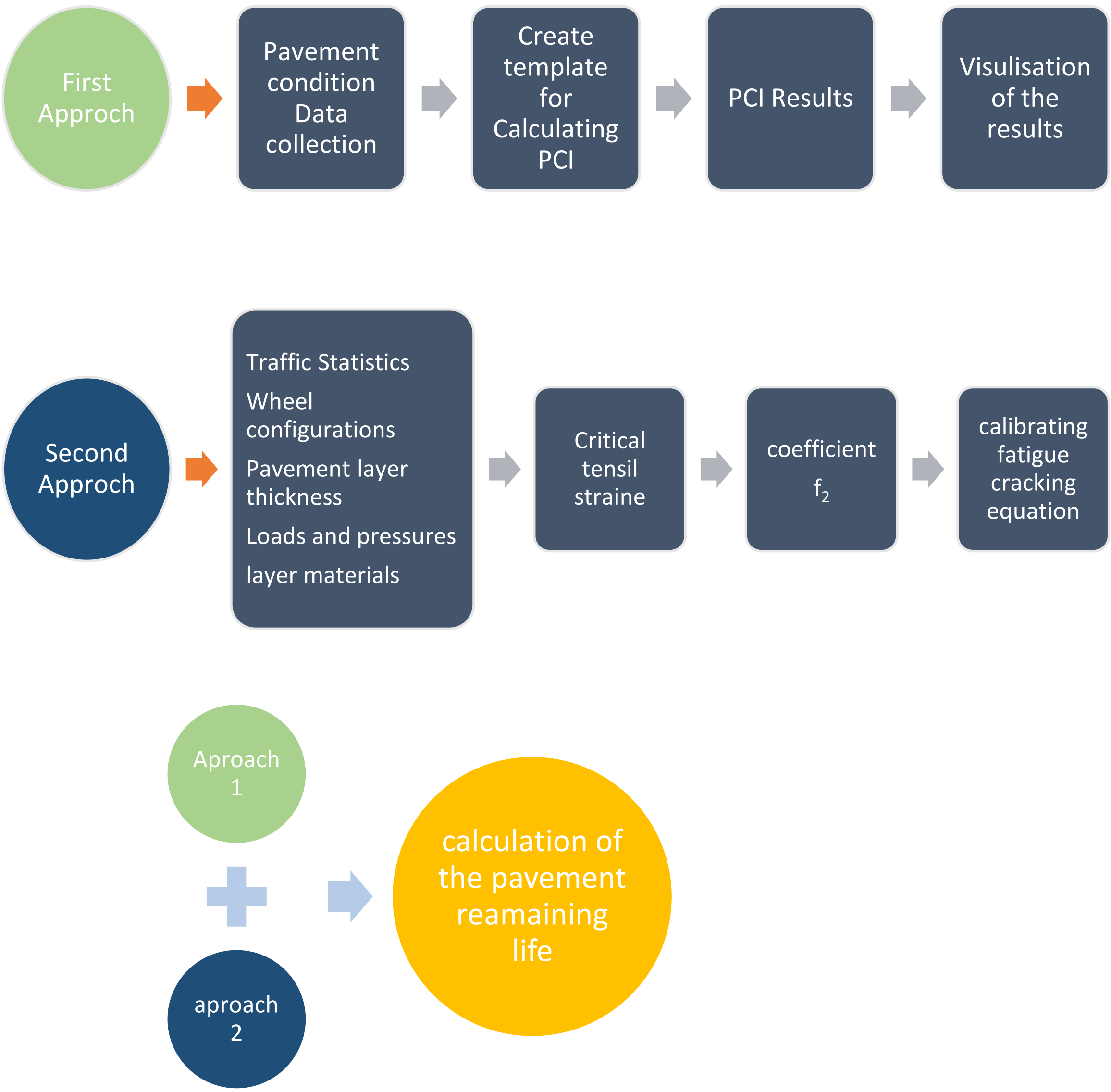


Figure9. **Flowchart for the conducted methodology of the research**

CHAPTER 4
CASE STUDY 1: PCI OF MASHHAD INTERNATIONAL AIRPORT

This chapter presents a case study of an airport Pavement Management System for Iran's Mashhad International Airport. Raw data on existing pavement distresses, traffic load statistics, and geotechnical test results were acquired from local sources and used for the calculation of pavement condition indicators.

4.1. Location and Backgrounds

Mashhad International Airport (Hasheminejad Airport (IATA: MHD, ICAO: OIMM), lies one mile south of Mashhad city in Khorasan-Razavi Province, Iran. The coordination of the airport reference point is 36° 14′ 6″ N, 59° 38′ 27″ E.

Mashhad Airport was first constructed in 1951 and has been expanding for the past 70 years. Moreover 10 million domestic and international travellers pass through the airport each year.

- **Physical characteristics**

The airport has two bituminous asphalt paved runways with the direction of 13R-31L, a length of 3,920 meters and 45 meters in width. A rigid paved apron with the dimensions of 170 meters by 1,591 meters and an area of 270,470 square meters is located southeast of the second runway. Each concrete slab is 7.5 by 7.5 meters. **Figure 10** illustrates the airport airside and landside land uses.

Figure10. **Mashhad International Airport overview[Google Map]**

➢ **Traffic**

Table 10 includes a summary of arrivals and departures and the fleet distribution for 2016. This statistic is needed to design and evaluate the aircraft gear load pressure on the pavement.

Table10. **Fleet distribution for 2016 (AIC, 2016)**

No.	Aircraft type	Arrival & Departure	No.	Aircraft type	Arrival & Departure
1	MD83	12,609	14	A300	1,529
2	MD82	11,098	15	A310	592
3	MD88	5,259	16	A319	1,111
4	F100	4,754	17	A320	11,233
5	A306	4,557	18	A321	494
6	B737-300	2,811	19	B747	435
7	B734	2,244	20	ATR72	345
8	B735	1,411	21	TU154M	219
9	B738	2,227	22	A343	174
10	B739	132	23	B77W	152
11	A332	1,209	24	BAE	3,388
12	B752	1,113	25	AN74	50
13	B727	1,475			

The following graphs present the flight statistics of Mashhad Airport between the years 2008 and 2016, including take off & landing maneuvers, Airport Passengers Statistics and Airport Fleet share. **(Figures 11 to 13)**

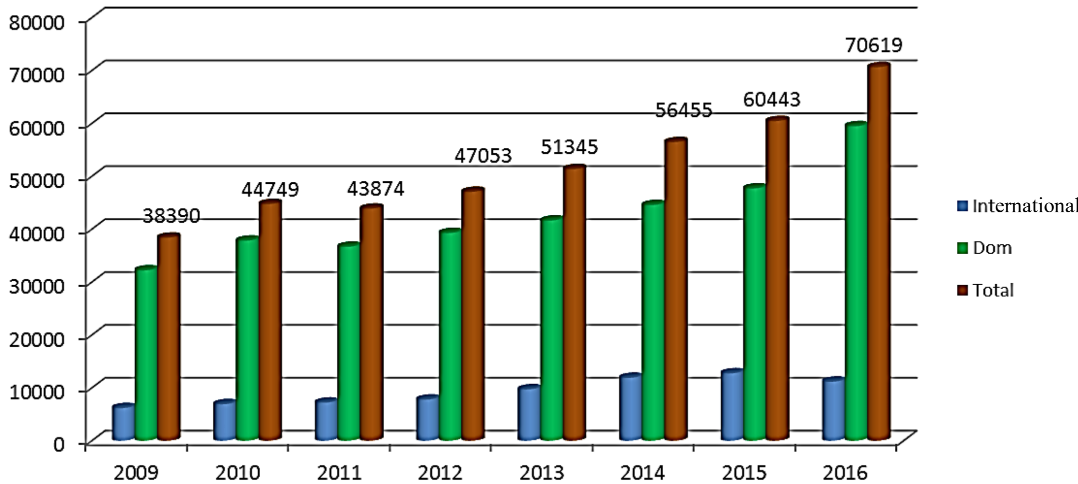


Figure11. **Take off & landing maneuver 2008-2016 (Fleet)**

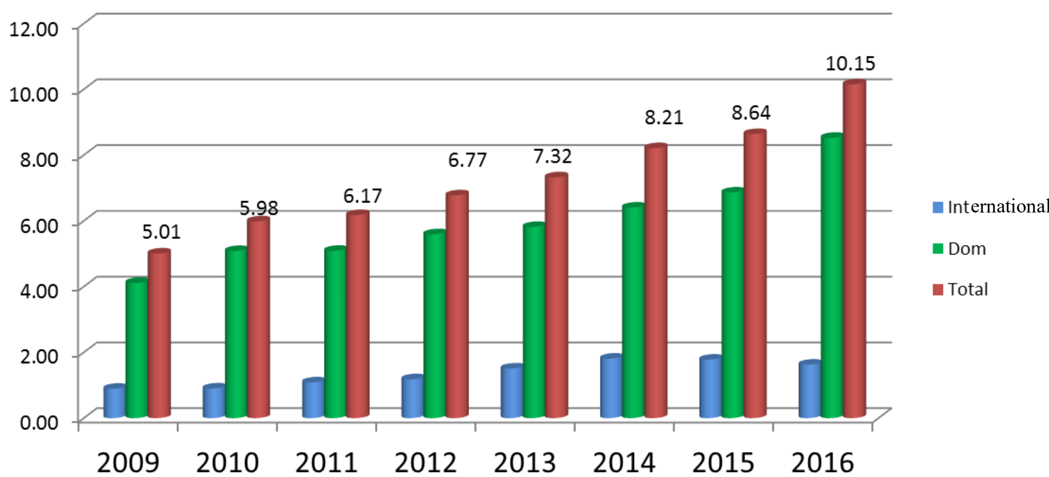


Figure12. **Airport Passenger Statistics 2008 – 2016 (Million Passenger)**

%

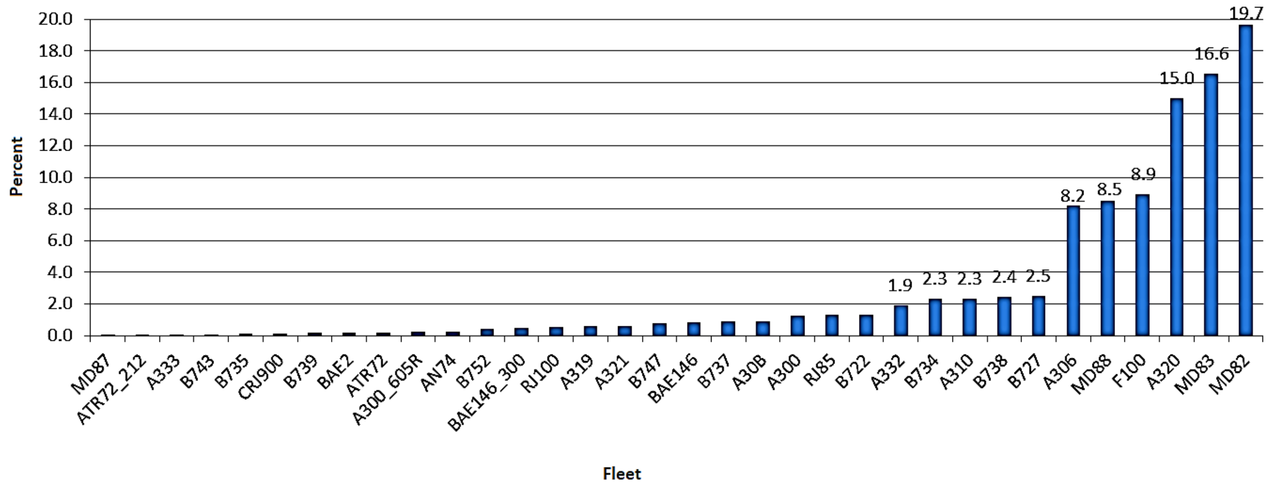


Figure13. **Mashhad Airport Fleet share (Percent in 2016)**

4.2. Observed distresses

The data on airfield surface distresses containing asphalt and concrete pavements (flexible and rigid) was collected through visual inspection done in 2016, with the pavements being divided into different sections based on the history of pavement construction and maintenance, traffic loads, drainage systems, and current pavement condition. As stated in **appendix A**, pavement specialists assessed the airport surface and filled- up the datasheets in order to calculate the pavement condition index (PCI).

4.2.1. *Apron*

Rigid paved apron is divided into sample units by splitting it into 22 rows of slabs by 223 columns of slabs.

To obtain an overview of the severity, density and distribution of distresses, the inspection results were transferred onto zoning maps to enhance the visualization, as shown in **Figures 14 to 17** for four different distress types (Longitudinal, Transverse and diameter crack, scaling, map cracking and crazing, join seal damage and shrinkage cracks). As seen in the Figures, most of the distresses are concentrated on the eastern half of the apron which was built more than 50 years ago. Scaling, map cracking and crazing are the most distresses in the apron, but visual observations show that some severe settlements have appeared in some slabs since 2015.

4.2.2. *Runway*

Only the main runway and the western stopway have been inspected **.** The runway has been divided into 4-meter by 100-meter blocks, with a total of 773 sections as shown in **Figure 18**.

4.2.3. *PCI results*

To improve the visualization of the PCI, the apron sample units were aggregated on blocks of 5 by 5 slabs, which means that there are 25 slabs in each section.

The PCI for all sections was calculated in Excel using a macro for coding the distresses. The pavement condition index of each section is colour-coded following the traffic-light standard where: Gray is the worst condition, Green is the good condition. Colour codes facilitate the selection of maintenance and rehabilitation**. Figure 19** shows the colour-coded PCI for the apron. Likewise, for the flexible pavement, the PCI of the main runway was calculated in the same way as the apron. The calculated PCI is shown in colours in **figure 20.**

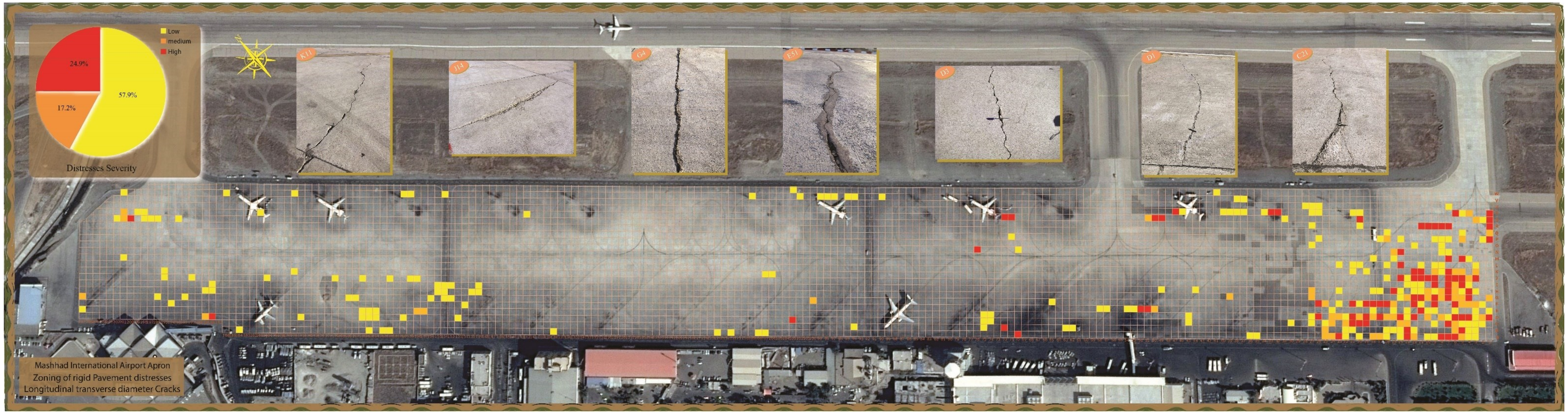


Figure14. **Zoning Map for the slabs distress severity containing Longitudinal, Transverse and diameter crack**

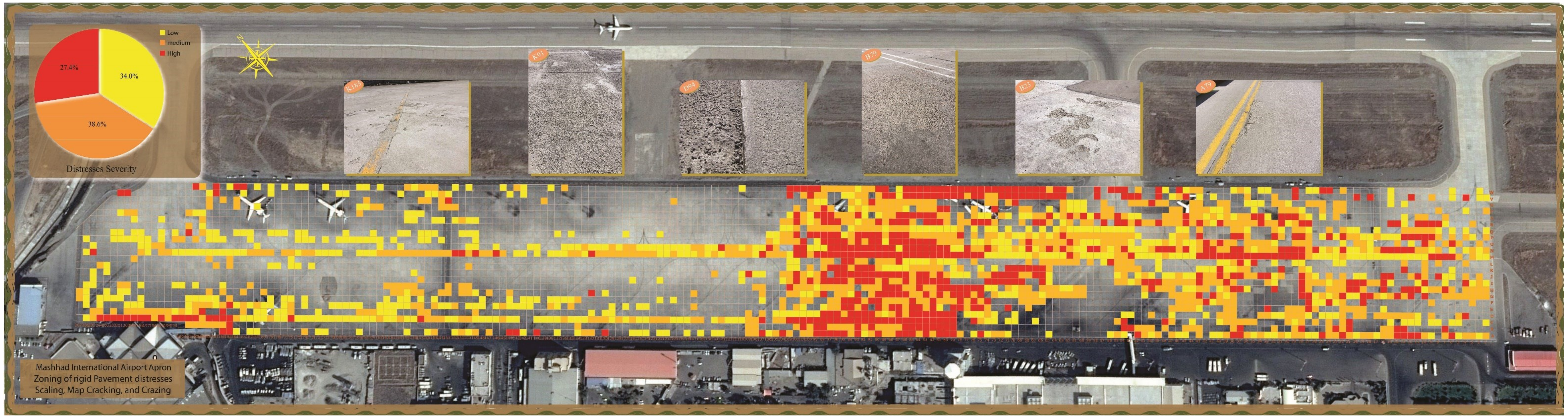


Figure15. **Zoning Map for the slabs distress severity containing scaling, map cracking and crazing**

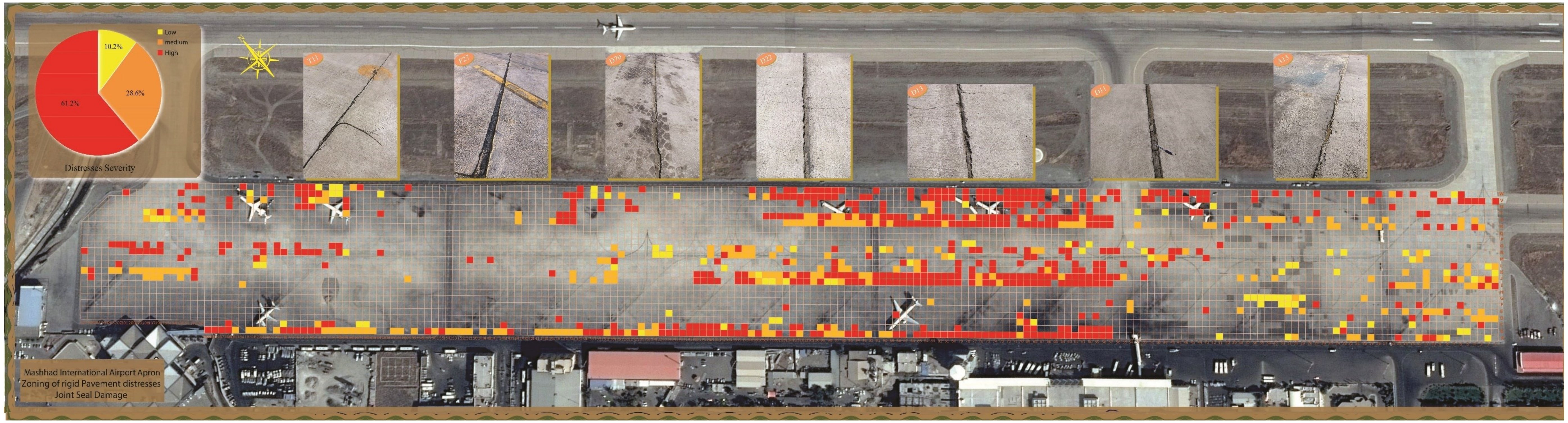


Figure16. **Zoning Map for the slabs distress severity containing join seal damage**

Figure17. **Zoning Map for the slabs distress severity containing shrinkage cracks**

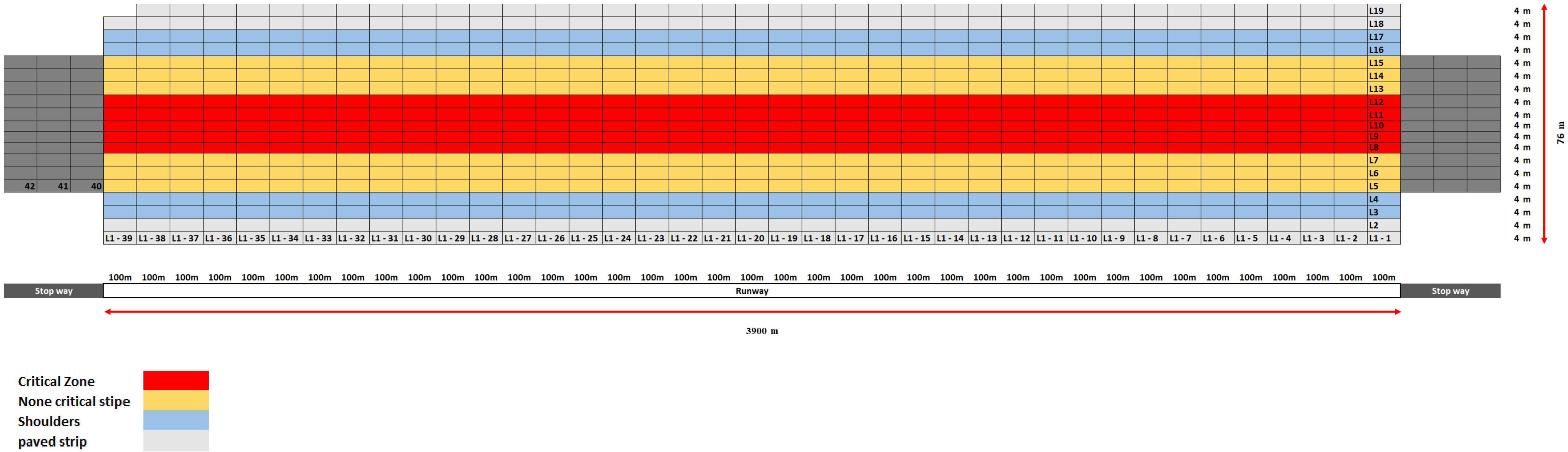


Figure18. **Sections of runway 31R-13L**

PCI	Rating
100	Good
85	Satisfactory
70	Fair
55	Poor
40	Very Poor
25	Serious
10	Failed
0	

Figure19. **PCI calculated for Apron and PCI rating scale**

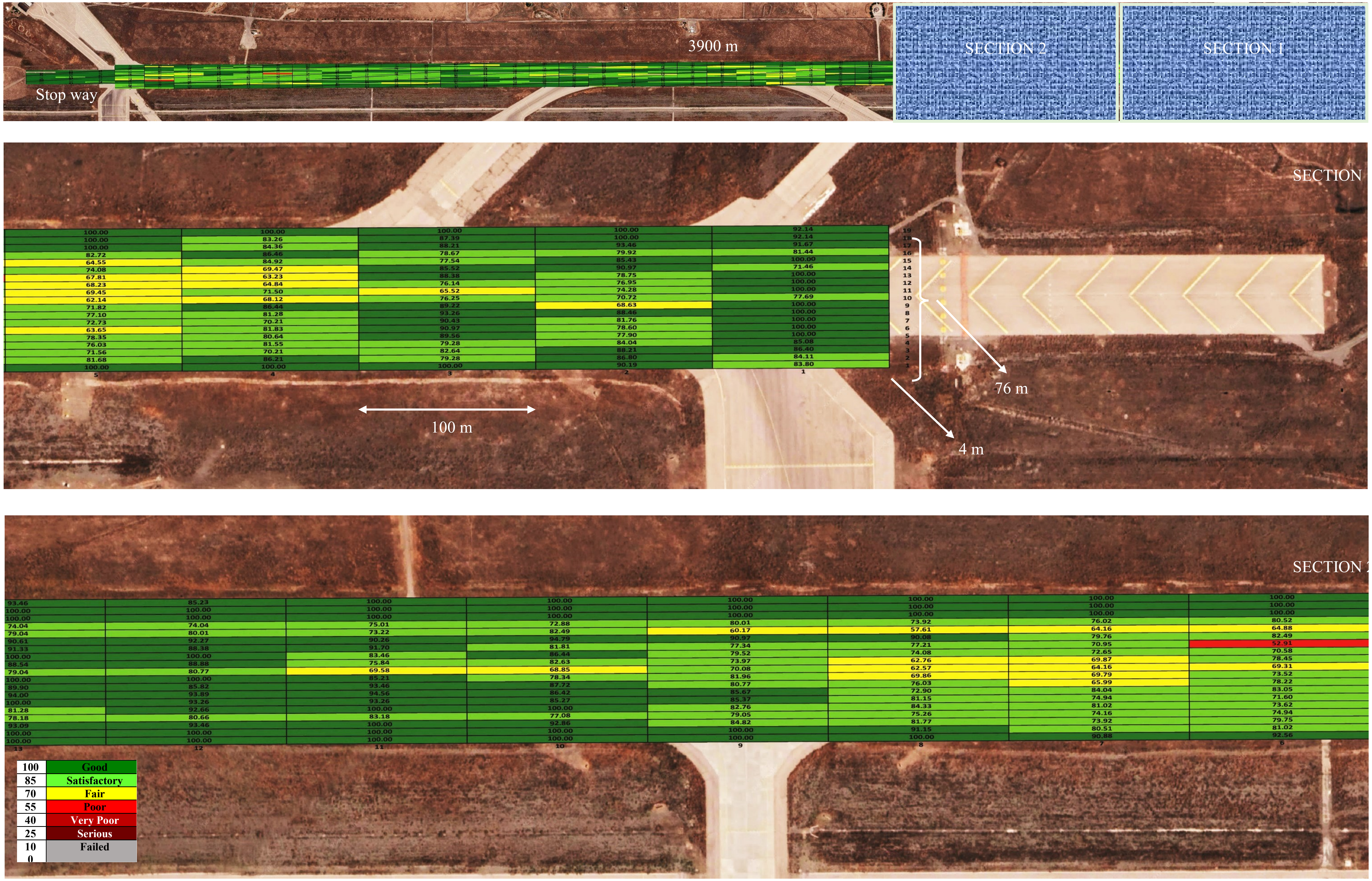
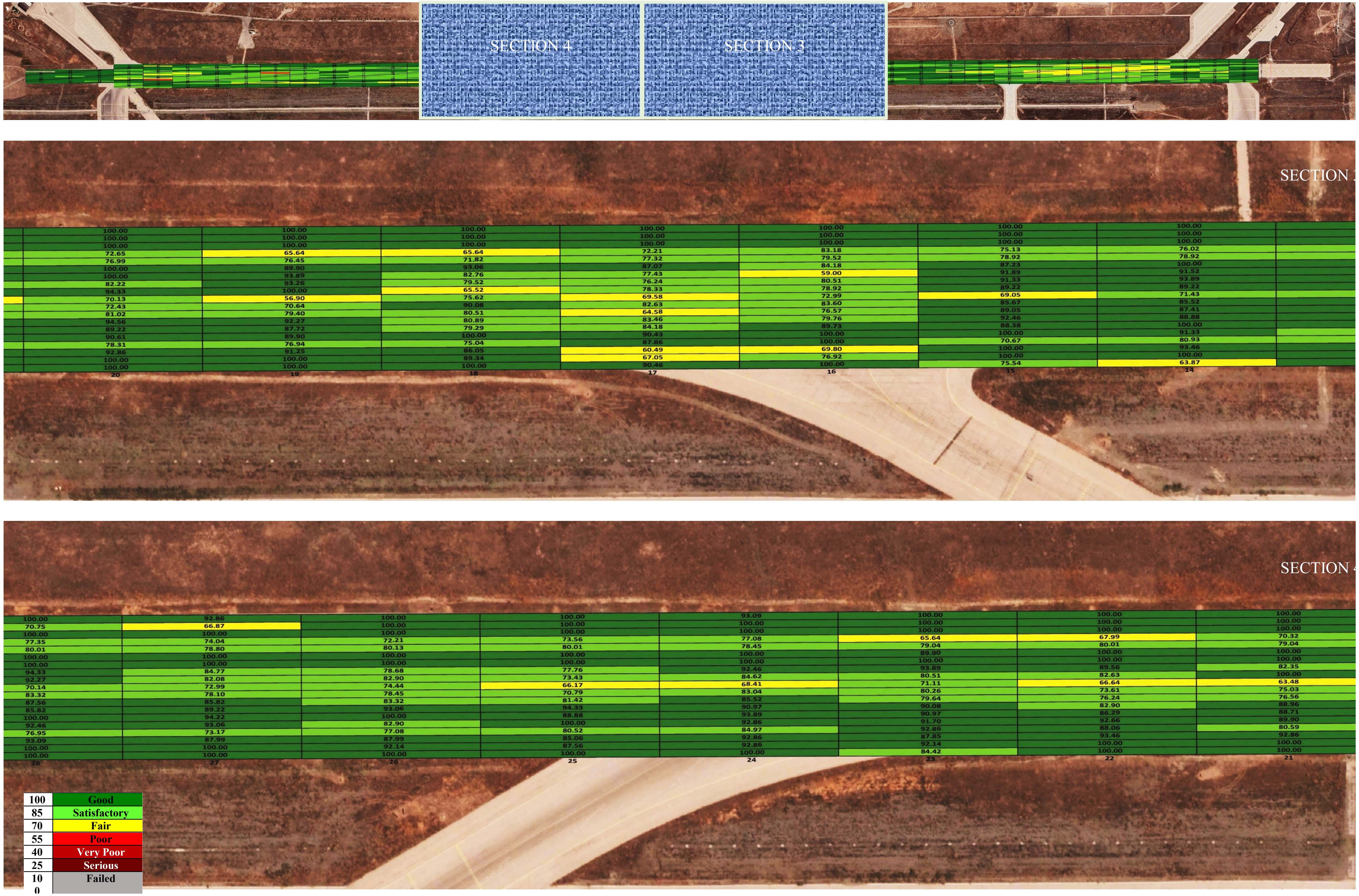
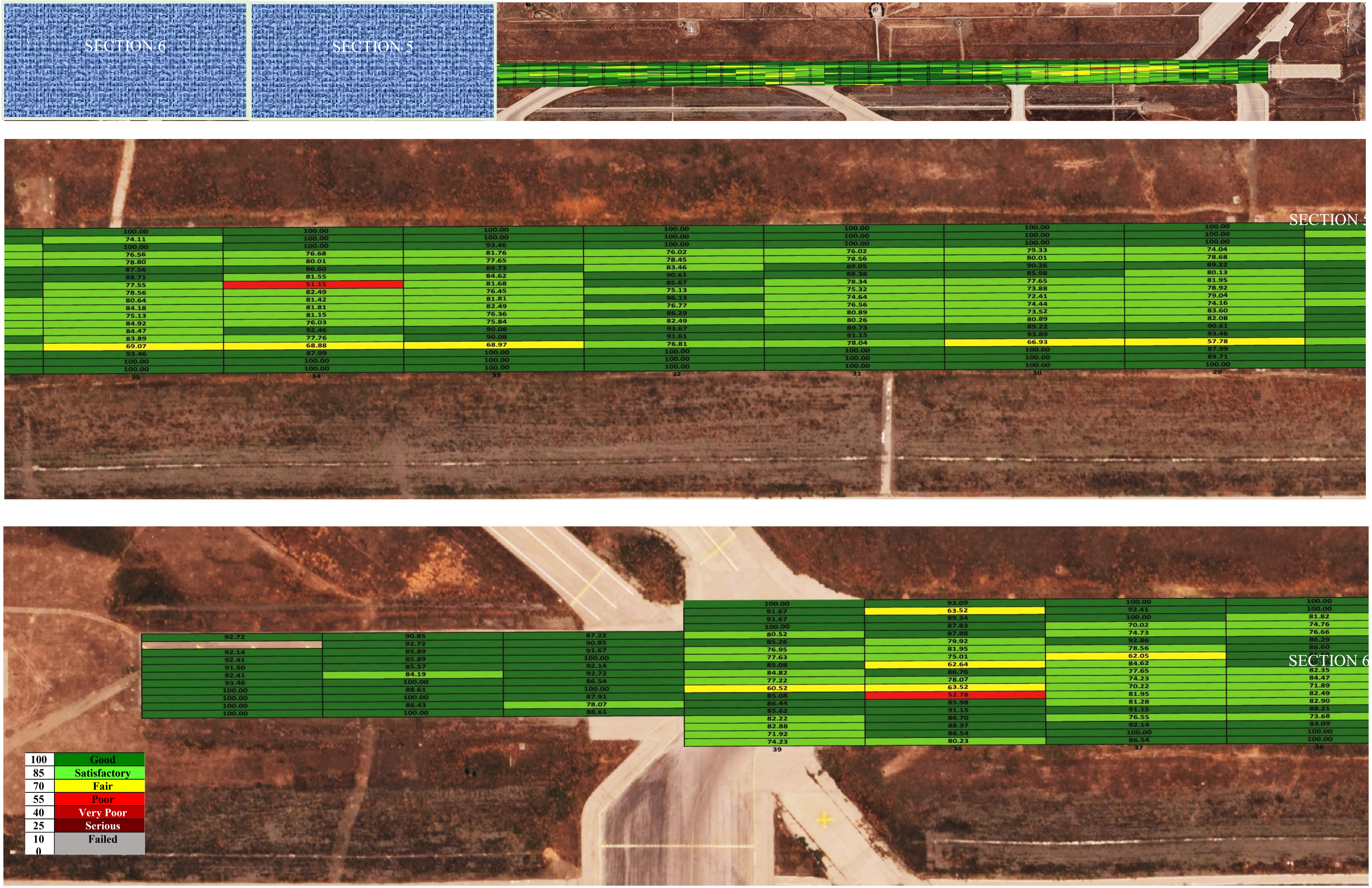


Figure20. **PCI calculated for Runway and PCI rating scale (section 1 , 2)**



PCI calculated for Runway and PCI rating scale (section 3 , 4) (continued)



PCI calculated for Runway and PCI rating scale (section 5 , 6)

The PCI results **(Figure19)** show that we can divide the apron in two separate sections as suggested on **figure 21,** to assign different type of maintenance and rehabilitation intervention's decision in future.

Table11. **Two-apron main part dimensions**

Section	Position	Area
1	Slab number 1 to 105, from the east border of the existing Apron	13.5 Ha
2	Slab number 106 to 213, to the west border of the existing Apron	13.5 Ha

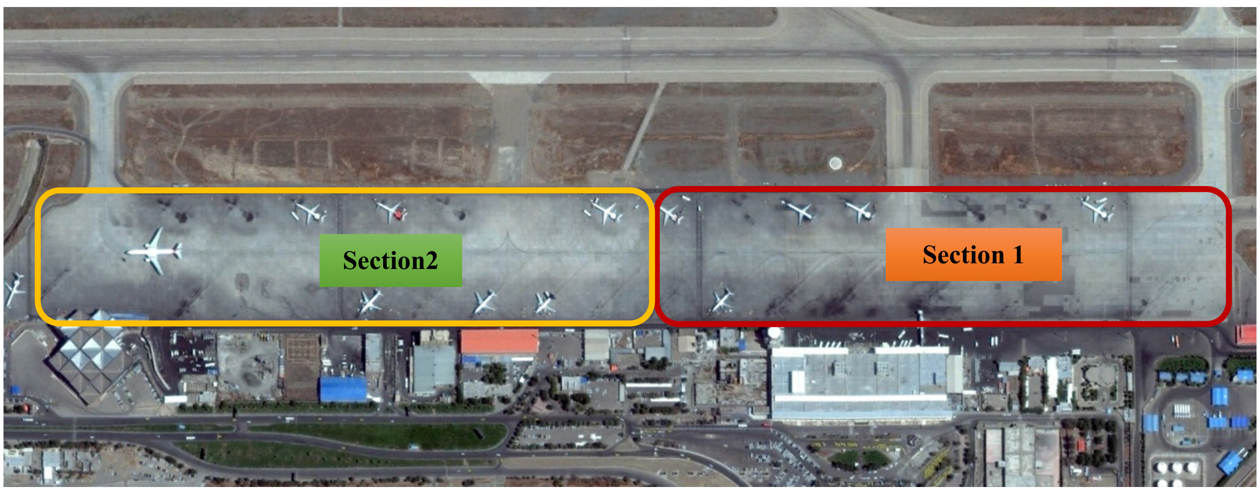


Figure21. **two different sections in Apron**

Due to the different conditions of the pavement regarding the severity and the density of distresses the apron was divided into two main parts. Pavement Condition Index (PCI) was calculated for the first and second half of the Apron, which is shown as follows.

PCI (East half of the APRON) = 35

PCI (West half of the APRON) = 79

By searching through the history of Mashhad apron extensions, section 2 was constructed in 2014 but for section one which goes back to more than 40 years ago, there is no accurate history of construction and rehabilitations that has been done during these years.

The PCI of the runway shown in **Figure 20** suggests that this facility can be divided into six zones, as indicated in **Table 12,** which could then be used to schedule specific types of maintenance and rehabilitation.

Table12. **PCI calculation for different zones of the runway**

Runway Zone	location	PCI
Paved strip	North	97.08
Shoulders	North	87.07
None Critical Zone	North	81.14
Critical zone	Middle	79.12
None Critical Zone	South	87.42
Shoulders	South	83.31
Paved strip	South	93.97
Stopway	West	92.22

CHAPTER 5
CASE STUDY 2: REMAINING LIFE OF MASHHAD INTERNATIONAL AIRPORT

This chapter presents a local calibration of the MEPDG fatigue damage towards an airport runway to enable an explicit estimation of the contribution of each aircraft operation on the remaining life of a runway pavement. The procedure of the applied method is based on the flight records of the airport, geotechnical testing and operational aircraft's characteristics. These data were provided by constant follow-up at Iran's Mashhad International Airport. Other information was collected from the airplane manual books and other sources.

5.1. Traffic

Mashhad Airport flight statistics date back to 2016, with all other calculations and observations performed at the same time. The number of flights in 2016 for each aeroplane is shown in **chapter 4, table 10.**

Since this study requires a forecast for the next 20 years, an assumption is made for each aircraft. The study of an airport fleet requires a grasp of the existing situation as well as the future plans of the airlines that will operate there. As a result, separate and in-depth analyses are required. However, the number of flight operations in the future is estimated in this research based on certain simple assumptions.

The growth in the number of older aircraft has declined, whereas new aircraft owned or hired by Iranian airlines in recent years have more operations in recent years.

On the other hand, due to economic issues, aircraft manufacturers have focused their production on producing C category aircraft for short-term flights and E category aircraft for long-term flights, and therefore aircrafts in category D will eventually be grounded.

The occurrence of a pandemic in 2019 has reduced the number of flights in the same way that it has in other countries.

Tabel l3 represents the number of flights in 2016 based on the statistic of Mashhad International airport and predictions for the next 20 years.

In this prediction, the existing capacity of the airport, such as the number of runways, apron stand positions and terminal capacity, are also considered.

5.2. Aircraft Characteristics

5.2.1. *Weights and loads*

Aircrafts characteristics are generally revealed in the aircraft manual book published by the manufacturers. For the operated fleet of the Mashhad airport, all the aircraft characters required for the calculations were taken from different references. These data comprise maximum take-off weight, gross weight, the portion of loads applied to the main gear, main wheel load and tire pressure. **Table 14** shows the proposed aircraft characteristics.

Table13. **Mashhad Airport Fleet distribution in 2016 and 20 years prediction**

Fleet	Fleet distribution																				
	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	total
MD83	12,609	13870	15257	16783	11748	12923	11630	10467	9421	7536	6029	4823	3859	3087	2470	1976	0	0	0	0	144487
MD82	11,098	12208	13429	14771	10340	11374	12511	13763	12386	11148	10033	9030	7224	5779	4623	3699	0	0	0	0	163415
MD88	5,259	4207	3366	2693	2154	1723	1379	1103	882	706	565	452	361	289	231	185	0	0	0	0	25555
F100	4,754	3803	3043	2434	1947	1558	1246	997	798	638	510	408	327	261	209	0	0	0	0	0	22934
A306	4,557	3646	2916	2333	1867	1493	1195	956	765	612	489	391	313	251	200	0	0	0	0	0	21983
B733	2,811	1687	1012	607	364	219	131	79	0	0	0	0	0	0	0	0	0	0	0	0	6909
B734	2,244	1346	808	485	291	174	105	63	0	0	0	0	0	0	0	0	0	0	0	0	5516
B735	1,411	1693	2032	2438	1951	2341	2809	3371	4045	4854	3398	2378	1665	1165	816	571	400	280	196	0	37811
B738	2,227	2450	2695	2964	2668	2934	3228	3551	3906	4296	4726	5199	5719	6290	6919	7611	8372	9210	10131	11144	106239
B739	132	158	190	228	182	219	263	315	378	454	545	654	785	942	1130	1356	1627	1952	2343	2811	16665
A332	1,209	1330	1463	1609	1448	1593	1752	1928	2120	2332	2566	2822	3104	3415	3756	4132	4545	5000	5500	6050	57676
B752	1,113	1224	1347	1481	1333	1467	1613	1775	1952	2147	2362	2598	2858	3144	3458	3804	4184	4603	5063	5569	53096
B727	1,475	885	531	319	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3210
A300	1,529	917	550	330	198	119	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3644
A310	592	474	379	303	242	194	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2184
A319	1,111	1222	1344	1479	1627	1789	1968	2165	2382	2620	2882	3170	3487	3835	4219	4641	5105	5616	6177	6795	63633
A320	11,233	12356	13592	14951	10466	11512	12664	13930	15323	15323	15323	15323	15323	13791	12412	11170	11170	11170	10053	9048	256134
A321	494	543	598	658	723	796	875	963	1059	1165	1281	1409	1550	1705	1876	2064	2064	2064	2270	2497	26653
B747	435	348	278	223	178	143	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1605
ATR72	345	449	583	758	531	690	897	1166	1515	1970	2561	2049	1639	1311	1049	839	671	537	430	344	20333
TU154	219	110	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	383
A343	174	191	211	232	255	280	308	339	305	275	247	222	200	180	162	146	131	118	106	96	4180
B772	152	167	184	202	223	245	269	296	267	240	216	194	175	157	142	128	115	103	93	84	3651
BAE	3,388	3727	4099	4509	4058	4464	4911	5402	5942	6536	7190	6471	5824	5241	4717	4246	3821	3439	3095	2785	93866
A359	0	100	110	121	133	146	161	177	195	214	236	259	285	314	345	380	418	459	505	556	5116
B767	0	150	165	182	200	220	242	266	292	322	354	389	428	471	518	570	627	689	758	834	7674
total	70,571	69261	70236	73093	55127	58616	60157	63069	63932	63388	61512	58243	55125	51629	49253	47516	43251	45240	46720	48613	1154550

Table14. **Mashhad operational aircraft characteristics(COMFAA,2014)**

Aircraft Model	MTOW* (LB)	MTOW (Tonnes)	Gross weight (KN)	Gross weight (Tonnes)	Gross weight on main gear %	wheel load (kg)	Tire pressure (Kpa)
MD83	154,390	70.03	716.4	73.028	94.76	17300	1344
MD82	154,390	70.03	716.4	73.028	94.76	17300	1344
MD88	149,500	67.8	-	-	95	16105	1140
F100	98,503	44.68	438.3	44.68	95.6	10679	980
A306	363,760	165.0	1693.2	172.6	95.00	20496	1340.0
B737-300	139,500	63.3	623.0	63.5	90.86	14425	1386
B734	150,000	68.0	669.7	68.3	93.82	16012	1276.0
B735	136,000	61.7	596.3	60.8	92.24	14016	1338
B738	174,200	79.0	777.4	79.2	93.6	18535	1413
B739	164,000	74.4	837.4	85.366	94.58	20185	1517
A332	313,055	142.0	2265.1	230.9	94.8	27362	1420.0
B752	255,000	115.7	1139.1	116.1	91.2	13235	1262.0
B727	209,500	95.0	756.4	77.1	95.3	22640	1138
A300-B4	363,760	165.0	1627.5	165.9	94.0	19493	1490
A310	330,750	150.0	1401.8	142.9	93.2	17478	1330.0
A319	141,095	64.0	631.8	64.4	92.6	14909	1190.0
A320	146,375	66.4	725.0	73.9	93.8	15570	1380
A321	206,000	93.4	877.0	89.4	95.0	22192	1460.0
B747	833,000	377.8	3720.0	379.2	90.96	21480	1379
ATR72	47,400	21.5	211.0	21.5	95.0	5106	864.84
TU154M	199,077	90.3	-	-	-	11050	930
A343	608,035	275.8	2706.5	275.9	79.6	18290	1572
B772	621,724	282.0	2923.5	298.0	91.8	21573	1413
BAE	94,997	43.1	398.3	40.6	94.2	10148	880.0
A350-900	-	-	2637.9	268.9	93.68	20992	1660
B767	-	-	1410.5	143.78	92.3	16589	1310

5.2.2. *Wheels configuration*

For Operational aircrafts in Mashhad Airport, the number of wheels and their configuration in addition to the number of gears, were extracted in **figure 22**.

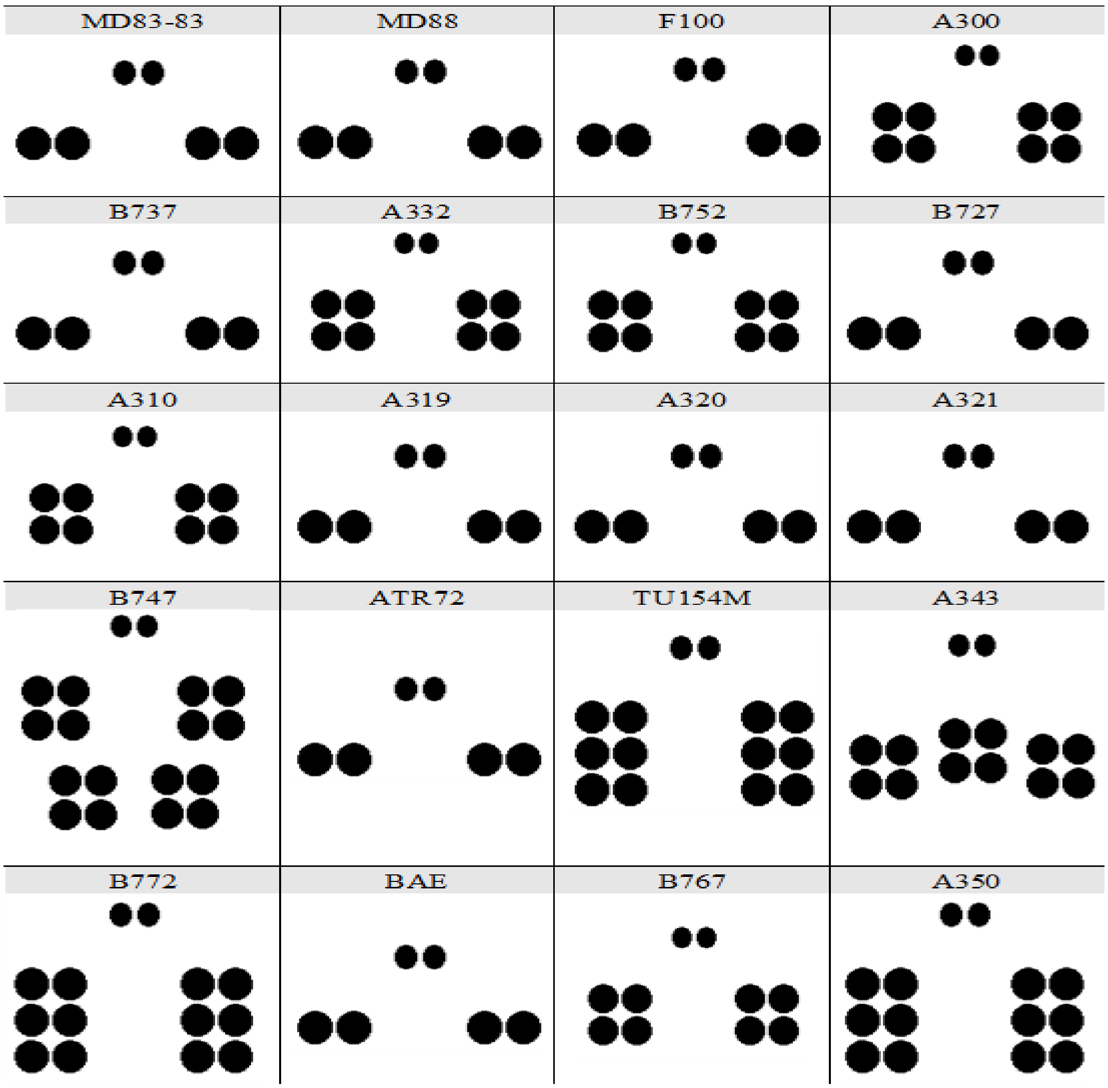
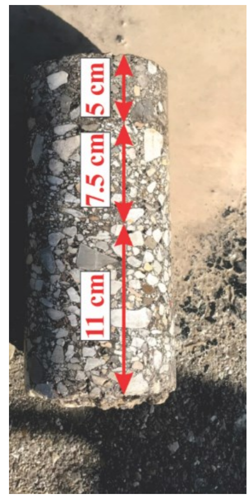


Figure22. **Mashhad Airport operational Aircrafts Wheel's configuration (COMFAA,2014)**

5.3. Pavement Thickness and Elastic Modulus

The existing pavement thickness for the airport main Runway, which is flexible and also for the apron with concrete pavement, was previously specified by destructive geotechnical tests. **Figure 23** shows two different cores extracted from the apron and the runway in 2016 and in 2020, respectively.

The concrete pavement core extracted from Apron



Asphalt Top layer in the runway core

Figure23. **Laboratory Test to obtain pavement thickness**

The concrete slabs in the apron have a thickness of 39 centimetres. The concrete slabs are lying on a subbase layer which is mostly the compaction of existing soil materials.

For the slabs, the elastic modulus assumes as 1.5×10^{6} and for the soil under the concrete, assumed as 1.74×10^{4}.

The critical stripe of the main runway has a thickness of 23.5 Cm, which contains 5 Cm wearing coarse, 2 layers of 7.5 and 11 Cm binder layers. The granular layer under the asphalt layer is mostly compacted existing soil.

Another assumption is made for the asphalt pavement, which is 9.42×10^{5} for asphalt layer and 1.67×10^{4} for the granular layer under the flexible pavement.

5.4. Fatigue damage analysis

As described in chapter3 the maximum allowable Number of loads before fatigue damage is :

$$N_f = f_1 \ (\varepsilon_t)^{-f_2} \ (E_1)^{-f_3}$$

And the critical tensile strain (e) is obtained by the following equation:

$$\varepsilon_t = \frac{q}{E1} * F_e$$

Contact pressure from a single wheel load (q) :

$$q = \frac{Qw}{\pi a2}$$

The load acting on the single wheel (Qw) is obtained from the following equation:

$$Qw = \frac{Qg}{r}$$

Qg is the distribution of the load between the aircraft gears and calculates from the following equation:

$$Q_g = r \times \frac{0.825 + 0.025 \times N}{R} \times Qt$$

Table 15 presented the calculation for Qg based on the maximum weight of the aircraft, number of landing gear, number of wheels of the main gear and Number of wheels of the leg of the main gear under consideration.

The contact area of the wheel on the pavement is obtained by dividing the main wheel load and tire pressure, and by having the area of contact, the radius of contact can be easily calculated.

Table15. **calculation of load distribution between wheels and gears in airplanes**

Aircraft	Tire pressure (kpa)	Wheels of the main gear	Landing gears	wheels of the leg of the main gear	Maximum weight (KN)	aircraft gear weight Distribution (KN)	single wheel Load (KN)	single wheel contact pressure (KN/m2)	Contact Area (in^2)	Contact radius (in)	main wheel load (LB)
		R	**N**	**R**	**Q_t**	**Q_g**	**Qw**	**q**	**A**	**a**	
MD83	1344	4	2	2	716.4	313.4	156.7	1241.0	195.7	7.9	38140.71
MD82	1344	4	2	2	716.4	313.4	156.7	1241.0	195.7	7.9	38140.71
MD88	1140	4	2	2	665.1	291.0	145.5	1049.8	214.8	8.3	35505.45
F100	980	4	2	2	438.3	191.8	95.9	897.0	165.7	7.3	23542.11
A306	1340.0	8	2	4	1693.2	740.8	185.2	1234.2	232.6	8.6	45186.50
B737-300	1386	4	2	2	623.0	272.5	136.3	1334.7	158.3	7.1	31801.04
B734	1276.0	4	2	2	669.7	293.0	146.5	1190.0	190.8	7.8	35299.96
B735	1338	4	2	2	596.3	260.9	130.4	1269.2	159.3	7.1	30899.70
B738	1413	4	2	2	777.4	340.1	170.0	1321.5	199.5	8.0	40862.34
B739	1517	4	2	2	837.4	366.4	183.2	1403.4	202.3	8.0	44499.85
A332	1420.0	8	2	4	2265.1	991.0	247.7	1310.7	293.0	9.7	60322.12
B752	1262.0	8	2	4	1139.1	498.4	124.6	1211.1	159.5	7.1	29177.69
B727	1138	4	2	2	756.4	330.9	165.5	866.6	296.0	9.7	48832.40
A300-B4	1490	8	2	4	1627.5	712.0	178.0	1328.6	207.7	8.1	44864.08
A310	1330.0	8	2	4	1401.8	613.3	153.3	1117.0	212.8	8.2	41028.03
A319	1190.0	4	2	2	631.8	276.4	138.2	1124.5	190.5	7.8	32867.84
A320	1380	4	2	2	725.0	317.2	158.6	2230.9	110.2	5.9	22046.23
A321	1460.0	4	2	2	877.0	383.7	191.8	1286.6	231.1	8.6	48925.01
B747	1379	16	5	4	3720.0	883.5	220.9	1921.3	178.2	7.5	35626.71
ATR72	864.84	4	2	2	210.9	92.3	46.1	796.6	89.8	5.3	11256.81
TU154M	930	12	2	6	885.8	387.6	64.6	554.2	180.7	7.6	24361.08
A343	1572	12	3	4	2706.5	812.0	203.0	1778.4	176.9	7.5	40322.86
B772	1413	12	2	6	2923.5	1279.0	213.2	142.2	232.2	8.6	21573
BAE	880.0	4	2	2	398.3	174.3	87.1	770.2	175.3	7.5	22371.84
A350-900	1660	12	2	6	2637.9	1154.1	192.3	1550.5	192.3	7.8	46279.73
B767	1310	8	2	4	1410.5	617.1	154.3	1241.9	192.5	7.8	36571.65

Tables 16 and 17 show the calculations to obtain tensile strain and calibrated f_2 coefficient for rigid and flexible pavements, respectively. Both **tables 17 and 18** use the following equation:

$$f_2 = \frac{-\log(N_f/f_1 \times \varepsilon_t^{(-f_3)})}{\log(\varepsilon_t)}$$

As shown in **Tables 16** and **17**, the summation of fatigue across all planes in the design life of the pavement amounts to 100% (1 in decimal base). This is true because the runway was inspected and assessed as ready for reconstruction after the considered period of time and plane loading. The calibrated value of f2 = 3.4547452 for the flexible pavements and f2 = 3.0383657 for the rigid pavement. **Figure 6** in **chapter 3** is used to calculate the strain factor (F) for a single wheel. For example, **Figure 24** shows the estimation of F for a plane B747-200 for the rigid and flexible pavement with red and green lines, respectively.

Table16. **Calculating the critical tensile strain and f2 for the apron rigid pavement**

Aircraft	main wheel load (lb)	q (psi)	a (in)	h_1/a	F	critical tensile strain ε_t	Predicted Load repetition in 20 years n	Allowed Load repetition N_f	Fatigue percentage (predicted /allowed) n/N_f
MD83	38140.71	180.00	7.89	1.95	0.67	8.04E-05	144487	1161282	0.123578
MD82	38140.71	180.00	7.89	1.95	0.67	8.04E-05	163415	1161282	0.139767
MD88	35505.45	152.27	8.27	1.86	0.72	7.31E-05	25555	1551331	0.01636
F100	23542.11	130.09	7.26	2.11	0.62	5.38E-05	22934	3940772	0.005779
A306	45186.50	179.01	8.60	1.78	0.76	9.07E-05	21983	805248	0.027118
B737-300	31801.04	193.59	7.10	2.16	0.6	7.74E-05	6909	1301587	0.005272
B734	35299.96	172.60	7.79	1.97	0.66	7.59E-05	5516	1380762	0.003968
B735	30899.70	184.09	7.12	2.16	0.6	7.36E-05	37811	1516551	0.024762
B738	40862.34	191.66	7.97	1.93	0.68	8.69E-05	106239	917346	0.115035
B739	44499.85	203.55	8.03	1.91	0.69	9.36E-05	16665	730949	0.022647
A332	60322.12	190.09	9.66	1.59	0.8	1.01E-04	57676	574094	0.099801
B752	29177.69	175.65	7.12	2.16	0.6	7.03E-05	53096	1748861	0.030152
B727	48832.40	125.69	9.71	1.58	0.81	6.79E-05	3210	1942408	0.001641
A300-B4	44864.08	192.69	8.13	1.89	0.7	8.99E-05	3644	826466	0.00438
A310	41028.03	162.01	8.23	1.87	0.71	7.67E-05	2184	1340727	0.001618
A319	32867.84	163.09	7.79	1.97	0.66	7.18E-05	63633	1640225	0.038529
A320	22046.23	323.56	5.92	2.59	0.39	8.41E-05	256134	1011951	0.251405
A321	48925.01	186.61	8.58	1.79	0.75	9.33E-05	26653	738866	0.035833
B747	35626.71	278.66	7.53	2.04	0.65	1.21E-04	1605	337539	0.004724
ATR72	11256.81	115.54	5.35	2.87	0.35	2.70E-05	20333	32095554	0.000629
TU154M	24361.08	80.37	7.58	2.02	0.66	3.54E-05	383	14073389	2.7E-05
A343	40322.86	257.94	7.50	2.05	0.64	1.10E-04	4180	447418	0.009281
B772	21573	142.2	8.6	1.79	0.76	1.05E-04	3651	522249	0.006945
BAE	22371.84	111.70	7.47	2.06	0.64	4.77E-05	93866	5685251	0.016393
A350-900	46279.73	224.88	7.82	1.96	0.66	9.89E-05	5116	618124	0.008222
B767	36571.65	180.12	7.83	1.96	0.66	7.93E-05	7674	1213050	0.006283
								Total :	1

Table17. **Calculating the critical tensile strain and f2 for the runway Flexible pavement**

Aircraft	main wheel load (lb)	q (psi)	a (in)	h_1/a	F	critical tensile strain ε_t	Predicted Load repetition in 20 years n	Allowable Load repetition N_f	Fatigue percentage (predicted /allowed) n/Nf
MD83	38140.71	180.00	7.89	1.17	1.55	2.96E-04	144487	973615	0.148402
MD82	38140.71	180.00	7.89	1.17	1.55	2.96E-04	163415	973615	0.167843
MD88	35505.45	152.27	8.27	1.12	1.6	2.59E-04	25555	1555161	0.016432
F100	23542.11	130.09	7.26	1.27	1.33	1.84E-04	22934	5072229	0.004521
A306	45186.50	179.01	8.60	1.08	1.7	3.23E-04	21983	721207	0.030481
B737-300	31801.04	193.59	7.10	1.30	1.31	2.69E-04	6909	1353836	0.005104
B734	35299.96	172.60	7.79	1.19	1.54	2.82E-04	5516	1150908	0.004793
B735	30899.70	184.09	7.12	1.30	1.3	2.54E-04	37811	1654102	0.022859
B738	40862.34	191.66	7.97	1.16	1.56	3.18E-04	106239	766480	0.138607
B739	44499.85	203.55	8.03	1.15	1.56	3.37E-04	16665	622606	0.026766
A332	60322.12	190.09	9.66	0.96	1.75	3.53E-04	57676	530155	0.10879
B752	29177.69	175.65	7.12	1.30	1.3	2.43E-04	53096	1945180	0.027296
B727	48832.40	125.69	9.71	0.95	1.75	2.34E-04	3210	2213528	0.00145
A300-B4	44864.08	192.69	8.13	1.14	1.56	3.19E-04	3644	752427	0.004843
A310	41028.03	162.01	8.23	1.12	1.57	2.70E-04	2184	1340064	0.00163
A319	32867.84	163.09	7.79	1.19	1.54	2.67E-04	63633	1399889	0.045455
A320	22046.23	323.56	5.92	1.56	0.72	2.47E-04	256134	1815215	0.141104
A321	48925.01	186.61	8.58	1.08	1.7	3.37E-04	26653	624730	0.042663
B747	35626.71	278.66	7.53	1.23	1.45	4.29E-04	1605	270822	0.005926
ATR72	11256.81	115.54	5.35	1.73	0.67	8.22E-05	20333	81654748	0.000249
TU154M	24361.08	80.37	7.58	1.22	1.48	1.26E-04	383	18509420	2.07E-05
A343	40322.86	257.94	7.50	1.23	1.47	4.03E-04	4180	337336	0.01239
B772	21573	206.43	8.6	1.08	1.7	3.73E-04	3651	440744	0.008284
BAE	22371.84	111.70	7.47	1.24	1.47	1.74E-04	93866	6077078	0.015446
A350-900	46279.73	224.88	7.82	1.18	1.54	3.68E-04	5116	461392	0.011088
B767	36571.65	180.12	7.83	1.18	1.54	2.95E-04	7674	993295	0.007726
								Total :	1

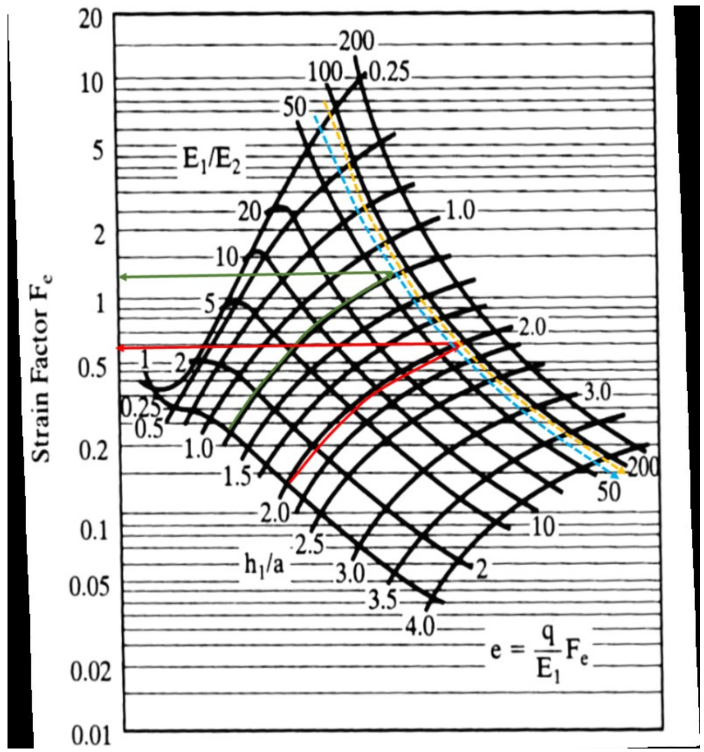


Figure24. **Obtaining strain factor for Rigid and Flexible pavement under the load of B747-200 main wheel load**

5.5. Results

As explained in **chapter 3**, the value of the coefficient f_2 is to be estimated because the N_f equation was originally developed for highway pavements. The overall summation across all planes for the coefficient of fatigue damage must add to 100 in this case, where the pavement went from new to ready for reconstruction. The approach to follow to estimate f_2 includes the following steps:

Step 1. Assume a fixed value for f_2. For example, use the same as that highway pavements

Step 2. Make the summation across all planes and verify if it is 100% or below

Step 3. Update the value of f_2 and repeat step 2

Step 4. Proceed repeating steps 3 and then 2 until the summation of values adds to 100, to accomplish a fast calculation, GOAL SEEK in EXCEL can be used.

By using the following equation, f_2 can be calculated for Mashhad airport

$$\sum \frac{n}{\mathrm{Nf}} = 1$$

The obtained f_2 is presented in **table 18**.

Table18. **calculated f_2 for rigid and flexible pavement in Mashhad Airport**

Pavement	f_2
apron rigid pavement	3.0383657
runway flexible pavement	3.4547452

By calculating f_2 the equation for calculating N_f, would be

$$N_f = 0.0796\ (\varepsilon_t)^{-3.0383}\ (\mathrm{E}_1)^{-0.854}$$

For the concrete pavement and

$$N_f = 0.0796\ (\varepsilon_t)^{-3.4547}\ (\mathrm{E}_1)^{-0.854}$$

For flexible pavement in Mashhad International Airport.

These equations are obtained for a newly constructed pavement with 20 years of long-life period. Actually, the pavement's failure will happen after 20 years. In the case study the first year which the statistics was available is 2016. Thus, the last year of this pavement can be 2036 and then reconstruction will be required. In that year the $\sum \frac{n}{\mathrm{Nf}}$ will reach 1.

The main goal here is how to find the remaining pavement life for the existing sections which the PCI has previously calculated for them.

In the calculations that led to obtain f_2, $\sum \frac{n}{\mathrm{Nf}}$ shows the remaining life of the pavement. When the pavement is brand new, $\sum \frac{n}{\mathrm{Nf}}$ is 0 and year by year it increases to 1 and then the failure will happen.

As mentioned before in chapter 3, the minimum PCI is 0 for the poor condition of the pavement and 100 for a newly constructed pavement.

Using the corresponding PCI for the accumulated $\frac{n}{\mathrm{Nf}}$ for different pavement life periods, represents the remaining pavement life.

In **table 19**, Mashhad airport traffic was calculated for different pavement life spans.

Table19. **The accumulated traffic for Mashhad airport for different pavement life span**

fleet	accumulated traffic for different pavement life period																			
	1 year	2 years	3 years	4 years	5 years	6 years	7 years	8 years	9 years	10 years	11 years	12 years	13 years	14 years	15 years	16 years	17 years	18 years	19 years	20 years
MD83	12,609	26,479	41,736	58,518	70,266	83,189	94,819	105,286	114,707	122,243	128,273	133,096	136,955	140,041	142,511	144,487	144,487	144,487	144,487	144,487
MD82	11,098	23,306	36,734	51,506	61,846	73,220	85,731	99,494	111,880	123,028	133,061	142,090	149,314	155,093	159,716	163,415	163,415	163,415	163,415	163,415
MD88	5,259	9,466	12,832	15,525	17,679	19,402	20,781	21,883	22,766	23,472	24,036	24,488	24,849	25,139	25,370	25,555	25,555	25,555	25,555	25,555
F100	4,754	8,557	11,600	14,034	15,981	17,539	18,785	19,782	20,580	21,218	21,728	22,137	22,463	22,725	22,934	22,934	22,934	22,934	22,934	22,934
A306	4,557	8,203	11,119	13,452	15,319	16,812	18,007	18,962	19,727	20,338	20,828	21,219	21,532	21,783	21,983	21,983	21,983	21,983	21,983	21,983
B737-300	2,811	4,498	5,510	6,117	6,481	6,700	6,831	6,909	6,909	6,909	6,909	6,909	6,909	6,909	6,909	6,909	6,909	6,909	6,909	6,909
B734	2,244	3,590	4,398	4,883	5,174	5,348	5,453	5,516	5,516	5,516	5,516	5,516	5,516	5,516	5,516	5,516	5,516	5,516	5,516	5,516
B735	1,411	3,104	5,136	7,574	9,525	11,865	14,674	18,045	22,090	26,943	30,341	32,719	34,384	35,549	36,365	36,936	37,336	37,615	37,811	37,811
B738	2,227	4,677	7,371	10,336	13,003	15,938	19,166	22,716	26,622	30,919	35,645	40,843	46,562	52,852	59,772	67,383	75,755	84,965	95,096	106,239
B739	132	290	480	709	891	1,110	1,373	1,688	2,066	2,521	3,065	3,719	4,504	5,445	6,575	7,931	9,558	11,510	13,853	16,665
A332	1,209	2,539	4,002	5,611	7,059	8,652	10,405	12,332	14,453	16,785	19,351	22,173	25,278	28,693	32,449	36,581	41,126	46,126	51,626	57,676
B752	1,113	2,337	3,684	5,165	6,499	7,965	9,579	11,353	13,305	15,452	17,814	20,412	23,270	26,414	29,872	33,676	37,861	42,463	47,526	53,096
B727	1,475	2,360	2,891	3,210	3,210	3,210	3,210	3,210	3,210	3,210	3,210	3,210	3,210	3,210	3,210	3,210	3,210	3,210	3,210	3,210
A300	1,529	2,446	2,997	3,327	3,525	3,644	3,644	3,644	3,644	3,644	3,644	3,644	3,644	3,644	3,644	3,644	3,644	3,644	3,644	3,644
A310	592	1,066	1,444	1,748	1,990	2,184	2,184	2,184	2,184	2,184	2,184	2,184	2,184	2,184	2,184	2,184	2,184	2,184	2,184	2,184
A319	1,111	2,333	3,677	5,156	6,783	8,572	10,540	12,705	15,087	17,706	20,588	23,758	27,245	31,080	35,299	39,940	45,045	50,661	56,838	63,633
A320	11,233	23,589	37,181	52,132	62,598	74,111	86,774	100,704	116,027	131,350	146,673	161,996	177,319	191,110	203,521	214,692	225,862	237,032	247,086	256,134
A321	494	1,037	1,635	2,293	3,016	3,812	4,687	5,649	6,708	7,873	9,154	10,564	12,114	13,820	15,696	17,759	19,823	21,886	24,156	26,653
B747	435	783	1,061	1,284	1,462	1,605	1,605	1,605	1,605	1,605	1,605	1,605	1,605	1,605	1,605	1,605	1,605	1,605	1,605	1,605
ATR72	345	794	1,377	2,135	2,665	3,355	4,252	5,417	6,933	8,903	11,464	13,512	15,151	16,463	17,512	18,351	19,022	19,559	19,989	20,333
TU154M	219	329	383	383	383	383	383	383	383	383	383	383	383	383	383	383	383	383	383	383
A343	174	365	576	808	1,062	1,343	1,651	1,990	2,295	2,570	2,817	3,039	3,240	3,420	3,582	3,728	3,859	3,977	4,084	4,180
B772	152	319	503	705	928	1,173	1,442	1,738	2,005	2,245	2,461	2,655	2,830	2,987	3,129	3,257	3,371	3,475	3,568	3,651
BAE	3,388	7,115	11,214	15,724	19,782	24,247	29,157	34,559	40,501	47,037	54,227	60,698	66,522	71,763	76,481	80,726	84,547	87,986	91,081	93,866
A350-900	0	100	210	331	464	611	772	949	1,144	1,358	1,594	1,853	2,138	2,452	2,797	3,177	3,595	4,054	4,560	5,116
B767	0	150	315	497	696	916	1,157	1,423	1,715	2,037	2,391	2,780	3,208	3,678	4,196	4,766	5,392	6,082	6,840	7,674
total	70,571	139,832	210,068	283,161	338,287	396,903	457,060	520,129	584,061	647,449	708,961	767,204	822,329	873,958	923,211	970,727	1,013,977	1,059,217	1,105,938	1,154,550

By using the Nf equation with the same f1, f2 and f3 and also the same tensile strain and allowable number of load repetition (Nf) for all fleet types, the $\sum \frac{n}{\mathrm{Nf}}$ can be calculated for every pavement life span. **Table 20 and 21** illustrates the calculations for concrete and asphalt pavement in Mashhad Airport, respectively. By multiplying $\sum \frac{n}{\mathrm{Nf}}$ by 100 and subtracting from 100, the equivalent PCI would be obtained.

The next step is to compare the calculated PCI and the equivalent PCI and to find the appropriate year corresponding to the PCI.

Finally, the remaining pavement life for each section is predicted.

Table20. **Calculation of total n/Nf for different Rigid pavement life span**

Fleet	critical tensile strain ε_z	allowable number of load repetition N_f	n/Nf for 1 year	n/Nf for 2 years	n/Nf for 3 years	n/Nf for 4 years	n/Nf for 5 years	n/Nf for 6 years	n/Nf for 7 years	n/Nf for 8 years	n/Nf for 9 years	n/Nf for 10 years	n/Nf for 11 years	n/Nf for 12 years	n/Nf for 13 years	n/Nf for 14 years	n/Nf for 15 years	n/Nf for 16 years	n/Nf for 17 years	n/Nf for 18 years	n/Nf for 19 years	n/Nf for 20 years
MD83	8.04E-05	1169193	0.011	0.023	0.036	0.050	0.060	0.071	0.081	0.090	0.098	0.105	0.110	0.114	0.117	0.120	0.122	0.124	0.124	0.124	0.124	0.124
MD82	8.04E-05	1169193	0.009	0.020	0.031	0.044	0.053	0.063	0.073	0.085	0.096	0.105	0.114	0.122	0.128	0.133	0.137	0.140	0.140	0.140	0.140	0.140
MD88	7.31E-05	1562006	0.003	0.006	0.008	0.010	0.011	0.012	0.013	0.014	0.015	0.015	0.015	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
F100	5.38E-05	3968767	0.001	0.002	0.003	0.004	0.004	0.004	0.005	0.005	0.005	0.005	0.005	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
A306	9.07E-05	810663	0.006	0.010	0.014	0.017	0.019	0.021	0.022	0.023	0.024	0.025	0.026	0.026	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027
B737-300	7.74E-05	1310490	0.002	0.003	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
B734	7.59E-05	1390225	0.002	0.003	0.003	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
B735	7.36E-05	1526979	0.001	0.002	0.003	0.005	0.006	0.008	0.010	0.012	0.014	0.018	0.020	0.021	0.023	0.023	0.024	0.024	0.024	0.025	0.025	0.025
B738	8.69E-05	923543	0.002	0.005	0.008	0.011	0.014	0.017	0.021	0.025	0.029	0.033	0.039	0.044	0.050	0.057	0.065	0.073	0.082	0.092	0.103	0.115
B739	9.36E-05	735848	0.000	0.000	0.001	0.001	0.001	0.002	0.002	0.002	0.003	0.003	0.004	0.005	0.006	0.007	0.009	0.011	0.013	0.016	0.019	0.023
A332	1.01E-04	577908	0.002	0.004	0.007	0.010	0.012	0.015	0.018	0.021	0.025	0.029	0.033	0.038	0.044	0.050	0.056	0.063	0.071	0.080	0.089	0.100
B752	7.03E-05	1760946	0.001	0.001	0.002	0.003	0.004	0.005	0.005	0.006	0.008	0.009	0.010	0.012	0.013	0.015	0.017	0.019	0.022	0.024	0.027	0.030
B727	6.79E-05	1955879	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
A300-B4	8.99E-05	832029	0.002	0.003	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
A310	7.67E-05	1349907	0.000	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
A319	7.18E-05	1651534	0.001	0.001	0.002	0.003	0.004	0.005	0.006	0.008	0.009	0.011	0.012	0.014	0.016	0.019	0.021	0.024	0.027	0.031	0.034	0.039
A320	8.41E-05	1018811	0.011	0.023	0.036	0.051	0.061	0.073	0.085	0.099	0.114	0.129	0.144	0.159	0.174	0.188	0.200	0.211	0.222	0.233	0.243	0.251
A321	9.33E-05	743820	0.001	0.001	0.002	0.003	0.004	0.005	0.006	0.008	0.009	0.011	0.012	0.014	0.016	0.019	0.021	0.024	0.027	0.029	0.032	0.036
B747	1.21E-04	339739	0.001	0.002	0.003	0.004	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
ATR72	2.70E-05	32339635	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001
TU154M	3.54E-05	14177643	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A343	1.10E-04	450364	0.000	0.001	0.001	0.002	0.002	0.003	0.004	0.004	0.005	0.006	0.006	0.007	0.007	0.008	0.008	0.008	0.009	0.009	0.009	0.009
B772	1.05E-04	525707	0.000	0.001	0.001	0.001	0.002	0.002	0.003	0.003	0.004	0.004	0.005	0.005	0.005	0.006	0.006	0.006	0.006	0.007	0.007	0.007
BAE	4.77E-05	5726137	0.001	0.001	0.002	0.003	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.011	0.012	0.013	0.013	0.014	0.015	0.015	0.016	0.016
A350-900	9.89E-05	622241	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.003	0.003	0.003	0.004	0.004	0.005	0.006	0.007	0.007	0.008
B767	7.93E-05	1221327	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.003	0.003	0.003	0.004	0.004	0.005	0.006	0.006
total		79860534	0.06	0.12	0.18	0.24	0.28	0.33	0.38	0.44	0.49	0.54	0.59	0.64	0.69	0.73	0.78	0.82	0.86	0.91	0.95	1.00
	Equivalent PCI		94	88	82	76	72	67	62	56	51	46	41	36	31	27	22	18	14	9	5	0

Table21. **Calculation of total n/Nf for different flexible pavement life span**

Fleet	critical tensile strain ε F	allowable number of load repetition N_f	n/Nf for 1 years	n/Nf for 2 years	n/Nf for 3 years	n/Nf for 4 years	n/Nf for 5 years	n/Nf for 6 years	n/Nf for 7 years	n/Nf for 8 years	n/Nf for 9 years	n/Nf for 10 years	n/Nf for 11 years	n/Nf for 12 years	n/Nf for 13 years	n/Nf for 14 years	n/Nf for 15 years	n/Nf for 16 years	n/Nf for 17 years	n/Nf for 18 years	n/Nf for 19 years	n/Nf for 20 years
MD83	2.96E-04	973615	0.013	0.027	0.043	0.060	0.072	0.085	0.097	0.108	0.118	0.126	0.132	0.137	0.141	0.144	0.146	0.148	0.148	0.148	0.148	0.148
MD82	2.96E-04	973615	0.011	0.024	0.038	0.053	0.064	0.075	0.088	0.102	0.115	0.126	0.137	0.146	0.153	0.159	0.164	0.168	0.168	0.168	0.168	0.168
MD88	2.59E-04	1555161	0.003	0.006	0.008	0.010	0.011	0.012	0.013	0.014	0.015	0.015	0.015	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
F100	1.84E-04	5072229	0.001	0.002	0.002	0.003	0.003	0.003	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.005	0.005	0.005	0.005	0.005	0.005
A306	3.23E-04	721207	0.006	0.011	0.015	0.019	0.021	0.023	0.025	0.026	0.027	0.028	0.029	0.029	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
B737-300	2.69E-04	1353836	0.002	0.003	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
B734	2.82E-04	1150908	0.002	0.003	0.004	0.004	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
B735	2.54E-04	1654102	0.001	0.002	0.003	0.005	0.006	0.007	0.009	0.011	0.013	0.016	0.018	0.020	0.021	0.021	0.022	0.022	0.023	0.023	0.023	0.023
B738	3.18E-04	766480	0.003	0.006	0.010	0.013	0.017	0.021	0.025	0.030	0.035	0.040	0.047	0.053	0.061	0.069	0.078	0.088	0.099	0.111	0.124	0.139
B739	3.37E-04	622606	0.000	0.000	0.001	0.001	0.001	0.002	0.002	0.003	0.003	0.004	0.005	0.006	0.007	0.009	0.011	0.013	0.015	0.018	0.022	0.027
A332	3.53E-04	530155	0.002	0.005	0.008	0.011	0.013	0.016	0.020	0.023	0.027	0.032	0.037	0.042	0.048	0.054	0.061	0.069	0.078	0.087	0.097	0.109
B752	2.43E-04	1945180	0.001	0.001	0.002	0.003	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.010	0.012	0.014	0.015	0.017	0.019	0.022	0.024	0.027
B727	2.34E-04	2213528	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
A300-B4	3.19E-04	752427	0.002	0.003	0.004	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
A310	2.70E-04	1340064	0.000	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
A319	2.67E-04	1399889	0.001	0.002	0.003	0.004	0.005	0.006	0.008	0.009	0.011	0.013	0.015	0.017	0.019	0.022	0.025	0.029	0.032	0.036	0.041	0.045
A320	2.47E-04	1815215	0.006	0.013	0.020	0.029	0.034	0.041	0.048	0.055	0.064	0.072	0.081	0.089	0.098	0.105	0.112	0.118	0.124	0.131	0.136	0.141
A321	3.37E-04	624730	0.001	0.002	0.003	0.004	0.005	0.006	0.008	0.009	0.011	0.013	0.015	0.017	0.019	0.022	0.025	0.028	0.032	0.035	0.039	0.043
B747	4.29E-04	270822	0.002	0.003	0.004	0.005	0.005	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
ATR72	8.22E-05	81654748	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TU154M	1.26E-04	18509420	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A343	4.03E-04	337336	0.001	0.001	0.002	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.008	0.009	0.010	0.010	0.011	0.011	0.011	0.012	0.012	0.012
B772	3.73E-04	440744	0.000	0.001	0.001	0.002	0.002	0.003	0.003	0.004	0.005	0.005	0.006	0.006	0.006	0.007	0.007	0.007	0.008	0.008	0.008	0.008
BAE	1.74E-04	6077078	0.001	0.001	0.002	0.003	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.010	0.011	0.012	0.013	0.013	0.014	0.014	0.015	0.015
A350-900	3.68E-04	461392	0.000	0.000	0.000	0.001	0.001	0.001	0.002	0.002	0.002	0.003	0.003	0.004	0.005	0.005	0.006	0.007	0.008	0.009	0.010	0.011
B767	2.95E-04	993295	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.003	0.003	0.004	0.004	0.005	0.005	0.006	0.007	0.008
total		134209781	**0.060**	**0.119**	**0.179**	**0.241**	**0.289**	**0.339**	**0.390**	**0.443**	**0.496**	**0.547**	**0.595**	**0.642**	**0.688**	**0.732**	**0.776**	**0.820**	**0.860**	**0.903**	**0.950**	**1.000**
	Equivalent PCI		94	88	82	76	71	66	61	56	50	45	40	36	31	27	22	18	14	10	5	0

For the east half of the APRON pavement which the PCI was calculated in chapter 4 equal to 35, the remaining pavement life would be 8 years. It seems that due to the construction time of this section which goes back to more than 40 years some rehabilitations have been done during these years.

For the west half of the APRON pavement which the PCI was calculated in chapter 4 equal to 79, the remaining pavement life would be 16-17 years. This part was constructed in 2013 and the inspection of pavement deterioration was conducted in 2016. Thus the remaining life of the pavement calculated by this method can be well evaluated.

And for the runway pavement **table 22** shows the remaining life.

Table22. **The remaining pavement life for Mashhad runway pavement**

Runway Zone	location	PCI	remaining pavement life
Paved strip	North	97.08	20 year
Shoulders	North	87.07	18 years
None Critical Zone	North	81.14	17 years
Critical zone	Middle	79.12	17 years
None Critical Zone	South	87.42	18 years
Shoulders	South	83.31	17 years
Paved strip	South	93.97	19 year
Stopway	West	92.22	19 year

5.6. Forecasting the effect of future aircraft operations

The mechanistic method proposed in this chapter can help forecasting the airport runway performance under various future scenarios of airplane configurations and can be used to test the ability of the airport to receive aircraft that is not currently fighting. For example assume we have the possibility to receive B739, A321 and A787 and other planes (**Table 23**) in the future and we have runway layers have thicknesses as follows:

asphalt layer	150	mm
granular base	300	mm
subbase	150	mm

The elastic modulus assumes as $9.42 \times 10^{\,5}$ for asphalt layer and $1.67 \times 10^{\,4}$ for the granular layer under the flexible pavement.

Two scenarios were defined for an airport receives 9 different fleet types with wheels' configuration represented in **figure 25**. The difference between 2 scenarios is that in the second scenario some new types of airplanes start operating later in the design period. Therefore the effect of this growth can be seen in the pavement deterioration rate.

The base year for both scenarios is 2021 and the annual number of flights for the next 20 years in scenario 1 are presented in **table 23**, based on 5 percent growth rate.

Other aircraft characteristics and related load parameters such as maximum take-off weight, gross weight, the portion of loads applied to the main gear, main wheel load and tire pressure and also contact area, aircraft weight distribution and aircraft main wheel loads are shown in **table 24** and **table 25** respectively.

In **table 26** the critical tensile strains for all aircraft types were calculated. Based on that the number of allowable load repetition before pavement failure were obtained. It means that by 20 years loading on the pavement with the same traffic that was predicted in **table 23**, the pavement will reach to failure and pavement reconstruction or serious intervention would be required.

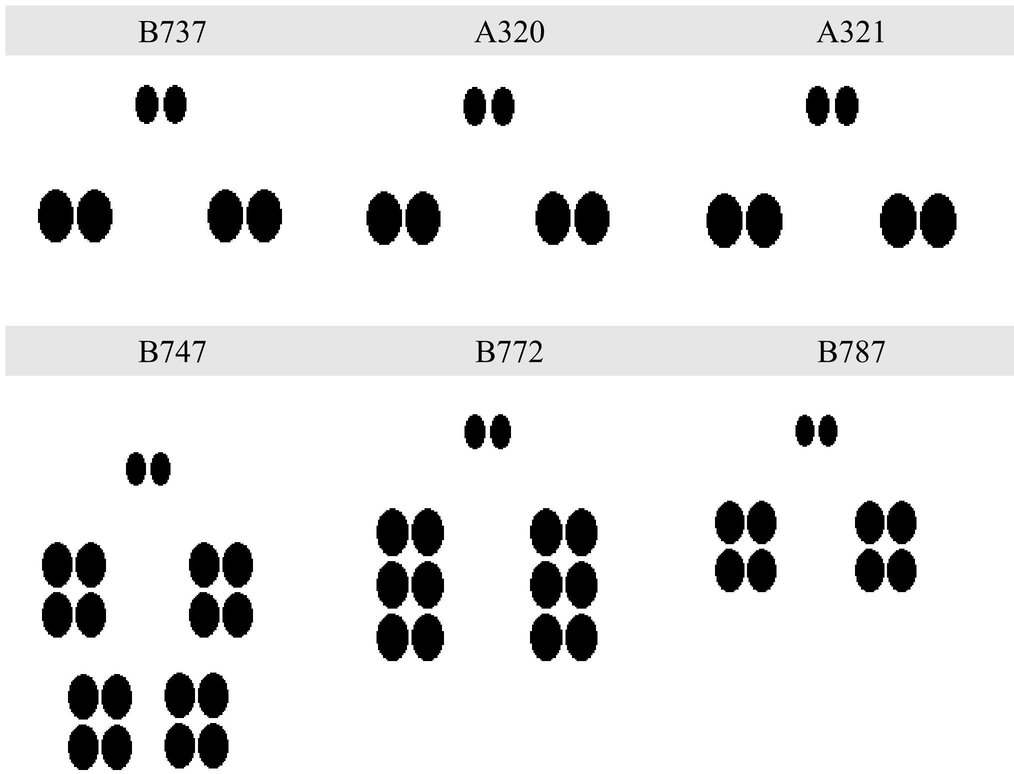


Figure25. **operational Aircrafts Wheel's configuration (COMFAA,2014)**

For calibration of f_2 coefficient in this scenario, the total fatigue of all aircrafts' types during the design life period, is considered equal to 1.

In the first scenario f_2 is 4.04 and N_f, would be

$$N_f = 0.0796 \ (\varepsilon_t)^{-4.043} \ (E_1)^{-0.854}$$

Table23. **Airport Fleet distribution in 2021 and 20 years prediction(scenario 1)**

Fleet	Fleet distribution																				
	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	total
B737-900	5450	5723	6009	6309	6625	6956	7304	7669	8052	8455	8877	9321	9787	10277	10791	11330	11897	12491	13116	13772	180209
A321	4360	4578	4807	5047	5300	5565	5843	6135	6442	6764	7102	7457	7830	8221	8633	9064	9517	9993	10493	11018	144168
A320	1272	1336	1402	1472	1546	1623	1705	1790	1879	1973	2072	2176	2284	2399	2518	2644	2777	2915	3061	3214	42060
B737-700	2726	2862	3005	3156	3313	3479	3653	3836	4028	4229	4440	4662	4896	5140	5397	5667	5951	6248	6560	6888	90138
B737-800	1636	1718	1804	1894	1989	2088	2192	2302	2417	2538	2665	2798	2938	3085	3239	3401	3571	3750	3937	4134	54096
B787	546	573	602	632	664	697	732	768	807	847	889	934	981	1030	1081	1135	1192	1251	1314	1380	18054
A340-600	546	573	602	632	664	697	732	768	807	847	889	934	981	1030	1081	1135	1192	1251	1314	1380	18054
B777-300	546	573	602	632	664	697	732	768	807	847	889	934	981	1030	1081	1135	1192	1251	1314	1380	18054
B747-400	364	382	401	421	442	465	488	512	538	565	593	623	654	686	721	757	795	834	876	920	12036
total	17446	18318	19234	20196	21206	22266	23379	24548	25776	27064	28418	29839	31331	32897	34542	36269	38082	39987	41986	44085	576869

Table24. **Operational aircraft characteristics(COMFAA,2014)**

Aircraft Model	MTOW* (LB)	MTOW (Tonnes)	Gross weight (KN)	Gross weight (Tonnes)	Gross weight on main gear %	wheel load (kg)	Tire pressure (Kpa)
B737-900	164,000	74.4	837.4	85.366	94.58	20185	1517
A321	206,000	93.4	877.0	89.4	95.0	22192	1460.0
A320	146,375	66.4	725.0	73.9	93.8	15570	1380
B737-700	154500	70.08	689.7	70.3	91.7	16066	1413
B737-800	174,200	79.0	777.4	79.2	93.6	18535	1413
B787-dreamliner	557,000	253	2498.5	254.7	93.6	59566	1544
A340-600	608,035	275.8	2706.5	275.9	79.6	18290	1572-1420
B777-300	621,704	282	2923.5	298.0	91.8	21573	1413
B747-400	833,000	377.8	3720.0	379.2	90.96	21480	1379

Table25. **calculation of load distribution between wheels and gears in airplanes**

Aircraft	Tire pressure (kpa)	Wheels of the main gear	Landing gears	wheels of the leg of the main gear	Maximum weight (KN)	aircraft gear weight Distribution (KN)	single wheel Load (KN)	single wheel contact pressure (KN/m2)	Contact Area (in^2)	Contact radius (in)	main wheel load (LB)
		R	**N**	**R**	Q_t	Q_g	**Qw**	**q**	**A**	**a**	
B737-900	1517	4	2	2	837.4	366.4	183.2	1403.4	202.3	8.0	44499.85
A321	1460.0	4	2	2	877.0	383.7	191.8	1286.6	231.1	8.6	48925.01
A320	1380	4	2	2	725.0	317.2	158.6	2230.9	110.2	5.9	22046.23
B737-700	1413	4	2	2	689.7	301.7	150.9	1352.6	172.9	7.4	35419.12
B737-800	1413	4	2	2	777.4	340.1	170.0	1321.5	199.5	8.0	40862.34
B787	1544	8	2	4	2498.5	1093.1	273.3	722.1	586.6	13.7	131320.84
A340-600	1572	12	3	4	2706.5	812.0	203.0	1778.4	176.9	7.5	40322.86
B777-300	1413	12	2	6	2923.5	1279.0	213.2	1423.3	232.2	8.6	47560.33
B747-400	1379	16	5	4	3720.0	883.5	220.9	1921.3	178.2	7.5	35626.71
B737-900	1517	4	2	2	837.4	366.4	183.2	1403.4	202.3	8.0	44499.85
A321	1460.0	4	2	2	877.0	383.7	191.8	1286.6	231.1	8.6	48925.01
A320	1380	4	2	2	725.0	317.2	158.6	2230.9	110.2	5.9	22046.23

Table26. **Calculating the critical tensile strain and f2 for the runway Flexible pavement(scenario 1)**

Aircraft	main wheel load (lb)	q (psi)	a (in)	h_1/a	F	critical tensile strain ε_t	Predicted Load repetition in 20 years n	Allowed Load repetition N_f	Fatigue percentage (predicted /allowed) n/N_f
B737-900	44499.85	203.55	8.03	0.74	1.5	1.62E-03	180209	474130	0.380084
A321	48925.01	186.61	8.58	0.69	1.6	1.59E-03	144168	519055	0.27775
A320	22046.23	323.56	5.92	1.00	1	1.72E-03	42060	375028	0.112151
B737-700	35419.12	196.19	7.42	0.80	1.1	1.15E-03	90138	1928633	0.046737
B737-800	40862.34	191.66	7.97	0.74	1.5	1.53E-03	54096	604736	0.089454
B787	131320.84	104.73	13.7	0.43	1.75	9.74E-04	18054	3733826	0.004835
A340-600	40322.86	257.94	7.5	0.79	1	1.37E-03	18054	937663	0.019254
B777-300	47560.33	206.43	8.6	0.69	1.6	1.76E-03	18054	345085	0.052318
B747-400	35626.71	278.66	7.53	0.78	1	1.48E-03	12036	686063	0.017544
								Total :	1

After calibrating f_2 coefficient obtaining the new equation for calculating the number of allowable load repetition for the airport, the calculation of pavement fatigue was conducted for 1 to 20 years pavement life spans.

The total n over N_f for the fleet shows the portion of deterioration and failure have occurred during that specific period. Therefore it can be assumed as an equivalent PCI by multiplying by 100 and then subtracting from 100.

For the second scenario, 3 aircraft types (B787, A321 and B739) started their operation later in the second decade of the total pavement life period. **Table 29** illustrates the pavement fatigue in the 2nd scenario.

In that scenario the calibrated f_2 coefficient is 3.99 and N_f, would be

$$N_f = 0.0796\ (\varepsilon_t)^{-3.99}\ (E_1)^{-0.854}$$

Table27. **The accumulated traffic for airport for different pavement life span**

Fleet	Accumulated traffic for different pavement life spans																			
	1 year	2 year	3 year	4 year	5 year	6 year	7 year	8 year	9 year	10 year	11 year	12 year	13 year	14 year	15 year	16 year	17 year	18 year	19 year	20 year
B737-900	5450	11173	17181	23490	30115	37070	44374	52043	60095	68550	77427	86748	96536	106813	117603	128933	140830	153321	166438	180209
A321	4360	8938	13745	18792	24092	29656	35499	41634	48076	54840	61942	69399	77229	85450	94083	103147	112664	122657	133150	144168
A320	1272	2608	4010	5482	7029	8652	10357	12146	14026	15999	18071	20247	22531	24929	27448	30092	32869	35784	38846	42060
B737-700	2726	5588	8594	11749	15063	18542	22195	26031	30058	34287	38728	43390	48286	53426	58823	64490	70441	76689	83249	90138
B737-800	1636	3354	5157	7051	9040	11128	13320	15622	18039	20577	23242	26040	28978	32063	35303	38704	42275	46025	49962	54096
B787-dreamliner	546	1119	1721	2353	3017	3714	4446	5214	6021	6868	7757	8691	9671	10701	11782	12917	14109	15360	16674	18054
A340-600	546	1119	1721	2353	3017	3714	4446	5214	6021	6868	7757	8691	9671	10701	11782	12917	14109	15360	16674	18054
B777-300	546	1119	1721	2353	3017	3714	4446	5214	6021	6868	7757	8691	9671	10701	11782	12917	14109	15360	16674	18054
B747-400	364	746	1148	1569	2011	2476	2964	3476	4014	4578	5171	5794	6448	7134	7855	8611	9406	10240	11116	12036

Table28. **Calculation of total n/Nf for different flexible pavement life span(Scenario 1)**

Fleet	critical tensile strain ε	allowable number of load repetition N_f	n/Nf for 1 years	n/Nf for 2 years	n/Nf for 3 years	n/Nf for 4 years	n/Nf for 5 years	n/Nf for 6 years	n/Nf for 7 years	n/Nf for 8 years	n/Nf for 9 years	n/Nf for 10 years	n/Nf for 11 years	n/Nf for 12 years	n/Nf for 13 years	n/Nf for 14 years	n/Nf for 15 years	n/Nf for 16 years	n/Nf for 17 years	n/Nf for 18 years	n/Nf for 19 years	n/Nf for 20 years
B737-900	0.001623104	474130	0.011495	0.023564	0.036237	0.049544	0.063516	0.078186	0.09359	0.109765	0.126747	0.14458	0.163303	0.182963	0.203606	0.225281	0.24804	0.271937	0.297028	0.323374	0.351038	0.380084
A321	0.001587167	519055	0.0084	0.01722	0.026481	0.036205	0.046415	0.057135	0.068392	0.080211	0.092622	0.105653	0.119335	0.133702	0.148787	0.164626	0.181257	0.19872	0.217056	0.236309	0.256524	0.27775
A320	0.001720015	375028	0.003392	0.006953	0.010692	0.014619	0.018742	0.02307	0.027616	0.032388	0.037399	0.042661	0.048186	0.053987	0.060078	0.066474	0.073189	0.08024	0.087644	0.095418	0.103581	0.112151
B737-700	0.001147199	1928633	0.001413	0.002898	0.004456	0.006092	0.00781	0.009614	0.011508	0.013497	0.015585	0.017778	0.02008	0.022498	0.025036	0.027701	0.0305	0.033438	0.036524	0.039763	0.043165	0.046737
B737-800	0.001528312	604736	0.002705	0.005546	0.008529	0.01166	0.014949	0.018401	0.022027	0.025833	0.02983	0.034027	0.038434	0.043061	0.047919	0.05302	0.058377	0.064001	0.069906	0.076107	0.082618	0.089454
B787	0.000974272	3733826	0.000146	0.0003	0.000461	0.00063	0.000808	0.000995	0.001191	0.001396	0.001612	0.001839	0.002077	0.002328	0.00259	0.002866	0.003155	0.003459	0.003779	0.004114	0.004466	0.004835
A340-600	0.001371202	937663	0.000582	0.001194	0.001836	0.00251	0.003218	0.003961	0.004741	0.00556	0.006421	0.007324	0.008273	0.009269	0.010314	0.011412	0.012565	0.013776	0.015047	0.016381	0.017783	0.019254
B777-300	0.001755779	345085	0.001582	0.003244	0.004988	0.00682	0.008743	0.010762	0.012882	0.015109	0.017446	0.019901	0.022478	0.025184	0.028026	0.031009	0.034142	0.037431	0.040885	0.044512	0.048319	0.052318
B747-400	0.001481354	686063	0.000531	0.001088	0.001673	0.002287	0.002932	0.003609	0.00432	0.005066	0.00585	0.006673	0.007538	0.008445	0.009398	0.010398	0.011449	0.012552	0.01371	0.014926	0.016203	0.017544
total		9604219	**0.030**	**0.062**	**0.095**	**0.130**	**0.167**	**0.206**	**0.246**	**0.289**	**0.334**	**0.380**	**0.430**	**0.481**	**0.536**	**0.593**	**0.653**	**0.716**	**0.782**	**0.851**	**0.924**	**1.000**
	Equivalent PCI		97	94	90	87	83	79	75	71	67	62	57	52	46	41	35	28	22	15	8	0

Table29. **Calculation of total n/Nf for different flexible pavement life span(Scenario 2)**

Fleet	critical tensile strain ε	allowable number of load repetition N_f	n/Nf for 1 years	n/Nf for 2 years	n/Nf for 3 years	n/Nf for 4 years	n/Nf for 5 years	n/Nf for 6 years	n/Nf for 7 years	n/Nf for 8 years	n/Nf for 9 years	n/Nf for 10 years	n/Nf for 11 years	n/Nf for 12 years	n/Nf for 13 years	n/Nf for 14 years	n/Nf for 15 years	n/Nf for 16 years	n/Nf for 17 years	n/Nf for 18 years	n/Nf for 19 years	n/Nf for 20 years
B737-900	0.001623104	355079	0	0	0	0	0	0	0	0	0	0	0.025	0.05125	0.078813	0.107754	0.138141	0.170049	0.203551	0.238729	0.275665	0.314449
A321	0.001587167	388331	0	0	0	0	0	0	0	0	0	0	0.018289	0.037491	0.057655	0.078826	0.101056	0.124397	0.148905	0.174639	0.201659	0.230031
A320	0.001720015	281595	0.004517	0.00926	0.01424	0.019469	0.02496	0.030725	0.036779	0.043135	0.049808	0.056816	0.064174	0.0719	0.080012	0.08853	0.097473	0.106864	0.116724	0.127078	0.137949	0.149363
B737-700	0.001147199	1421977	0.001917	0.00393	0.006043	0.008263	0.010593	0.01304	0.015609	0.018306	0.021138	0.024112	0.027235	0.030514	0.033957	0.037572	0.041367	0.045353	0.049537	0.053931	0.058545	0.063389
B737-800	0.001528312	451665	0.003622	0.007425	0.011419	0.015612	0.020015	0.024638	0.029492	0.034588	0.03994	0.045559	0.051459	0.057654	0.064159	0.070989	0.078161	0.085691	0.093598	0.1019	0.110617	0.11977
B787	0.000974272	2732770	0	0	0	0	0	0	0	0	0	0	0.00031	0.000635	0.000977	0.001336	0.001713	0.002108	0.002524	0.00296	0.003418	0.003898
A340-600	0.001371202	696910	0.000783	0.001606	0.00247	0.003377	0.004329	0.005329	0.006379	0.007481	0.008639	0.009854	0.01113	0.01247	0.013877	0.015355	0.016906	0.018535	0.020245	0.022041	0.023926	0.025906
B777-300	0.001755779	259352	0.002105	0.004316	0.006637	0.009074	0.011633	0.01432	0.017142	0.020106	0.023217	0.026485	0.029915	0.033518	0.0373	0.041271	0.045441	0.04982	0.054417	0.059245	0.064313	0.069635
B747-400	0.001481354	511687	0.000711	0.001458	0.002243	0.003066	0.003931	0.004839	0.00579	0.00679	0.007839	0.008941	0.010098	0.011312	0.012588	0.013927	0.015333	0.01681	0.01836	0.019988	0.021697	0.023492
total		7099366	**0.014**	**0.028**	**0.043**	**0.059**	**0.075**	**0.093**	**0.111**	**0.130**	**0.151**	**0.172**	**0.238**	**0.307**	**0.379**	**0.456**	**0.536**	**0.620**	**0.708**	**0.801**	**0.898**	**1.000**
	Equivalent PCI		99	97	96	94	92	91	89	87	85	83	76	69	62	54	46	38	29	20	10	0

Comparing two scenarios illustrates that the equivalent PCI in the second scenario before arriving the new fleet is significantly higher than PCI in the first one. For instance, the pavement in the first scenario may need some rehabilitations but in the other assumption the pavement is still in good condition.

Figure 26 is showing the differences between these two scenarios.

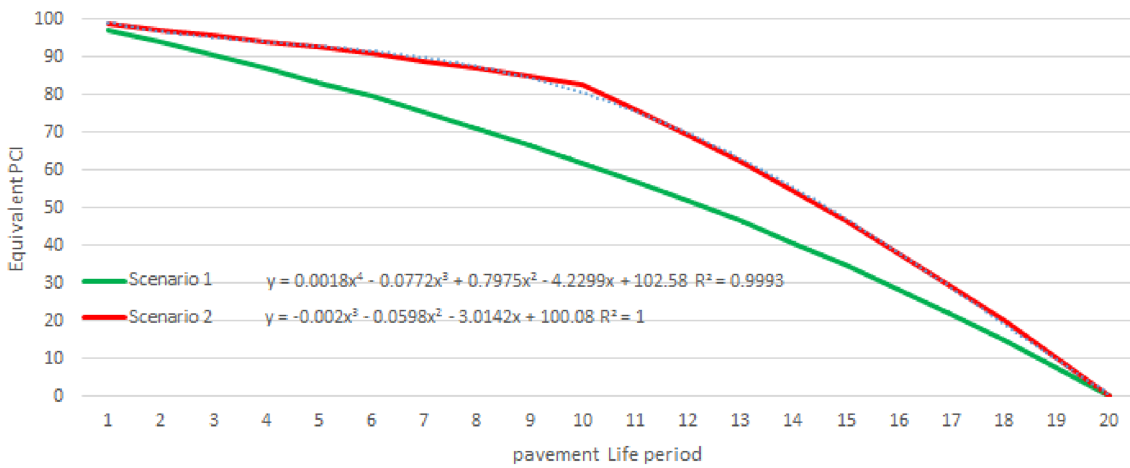


Figure26. **Two scenarios' equivalent PCI**

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

This research has presented a comprehensive method for the implementation of an airport pavement management system. Two approaches were combined in order to assist airport authorities for scheduling strategies for pavement maintenance and rehabilitation.

The automation of the procedure used for calculating pavement condition produced an approach for communicating overall pavement condition to stakeholders while holding a direct connection to individual distress elements. The Macro coded Excel templates can be employed for all airport pavements minimizing human error and the time consumed in the calculations. It enables fast visualization of the results through airport maps with colors based on the types, severity and density of distresses and also the final PCI results and this leads to extract beneficial information for decision making, however it requires the identification of the rate of deterioration and remaining service life. For instance, the PCI results calculated for the case study divided the apron into 2 parts. The first section had a PCI of 35 which was constructed more than 40 years ago and the second section with the PCI of 79 was constructed in 2013. For the asphalt pavement of the runway the PCI was calculated for 5 main stripes. The critical zone is mainly under the load of aircraft wheels (79.12) and 2 none critical stripes (81.14, 87.42), and 2 shoulders (87.07, 83.31).

Adapting and recalibrating the fatigue damage analysis equation of a mechanistic empirical pavement design method proved capable of predicting the remaining life of airport pavement and obtaining their rate of deterioration. The developed method can consider the influence of every single aircraft on the pavement deterioration and its final failure. In the fatigue damage analysis method the pavement fails when the load repetition reaches a specific number during the pavement design life. Based on the case study, the calibrated equation for calculating the number of aircraft load repetitions to reach failure for the concrete pavement is:

$$N_f = 0.0796\,(\varepsilon_t)^{-3.0383}\,(\mathrm{E}_1)^{-0.854}$$

And for flexible pavement is:

$$N_f = 0.0796\,(\varepsilon_t)^{-3.4547}\,(E_1)^{-0.854}$$

By combining the results of both approaches, one can predict the corresponding apparent age of the pavement based on its current degree of deterioration and forecast the remaining service life. The total actual load repetitions experience to date divided by the allowable load repetition shows the portion of deteriorations that has occurred to date and the apparent age.. In the case study for the apron first section with the PCI of 35, the remaining pavement life was calculated as 8 years. In the second section with the PCI of 79 which the real age of the pavement was 4 years before the inspection was done, the remaining pavement life was calculated as 16 years. This comparison can be used to evaluate the accuracy of similar calculations.

Other scenarios were designed to evaluate the sensitivity of the developed method to changes in the amount of traffic and the load types applied to the pavement.

In fact, by utilizing the results of this method, many other important factors that trigger pavement deterioration can be taken into account. In addition to the PCI indicator, which merely applies the pavement surface condition, the fatigue cracking analysis which is based on traffic, loadings and pavement structural parameters can be utilized as well. Having the PCI and remaining pavement life can assist airport authorities in making more accurate decisions for any intervention

The method that was conducted in this research can be utilized in airports that lack of pavement condition historical data. It means that by having only one year of condition data observations, the pavement remaining life and an approximate performance curve can be estimated.

6.2. Limitations and future research potentials

One of the limitations in this research was lack of multi-year pavement distress inspection that could serve to validate the pavement performance curve.

In addition, upcoming year's flight statistics are future expectations which introduce uncertainty which requires to be estimated in future research.

Future research should be devoted to automate the estimation of the strain factor for an entire airport fleet. The combination of both approaches can lead to a complete automation.

Runway Drainage issues were not considered and must be included in future deterioration models as they have a direct incidence on the rate of deterioration and can lead to premature damage of the pavements.

6.3. Recommendations

Two different solutions are recommended to evaluate the proposed method. The first one is by calculating the pavement remaining life based on the pavement age and the design life. The second way (which is more reliable than the first one) is obtaining the pavement performance curve. This should be prepared based on multi-year pavement inspection data. Therefore the remaining life of a pavement extracted from the pavement performance curve can be compared with the remaining life calculated from the apparent age which was revealed in the current method. By obtaining the existing pavement layer's elastic modulus from geotechnical tests, more accurate results will be obtained.

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APPENDIX A

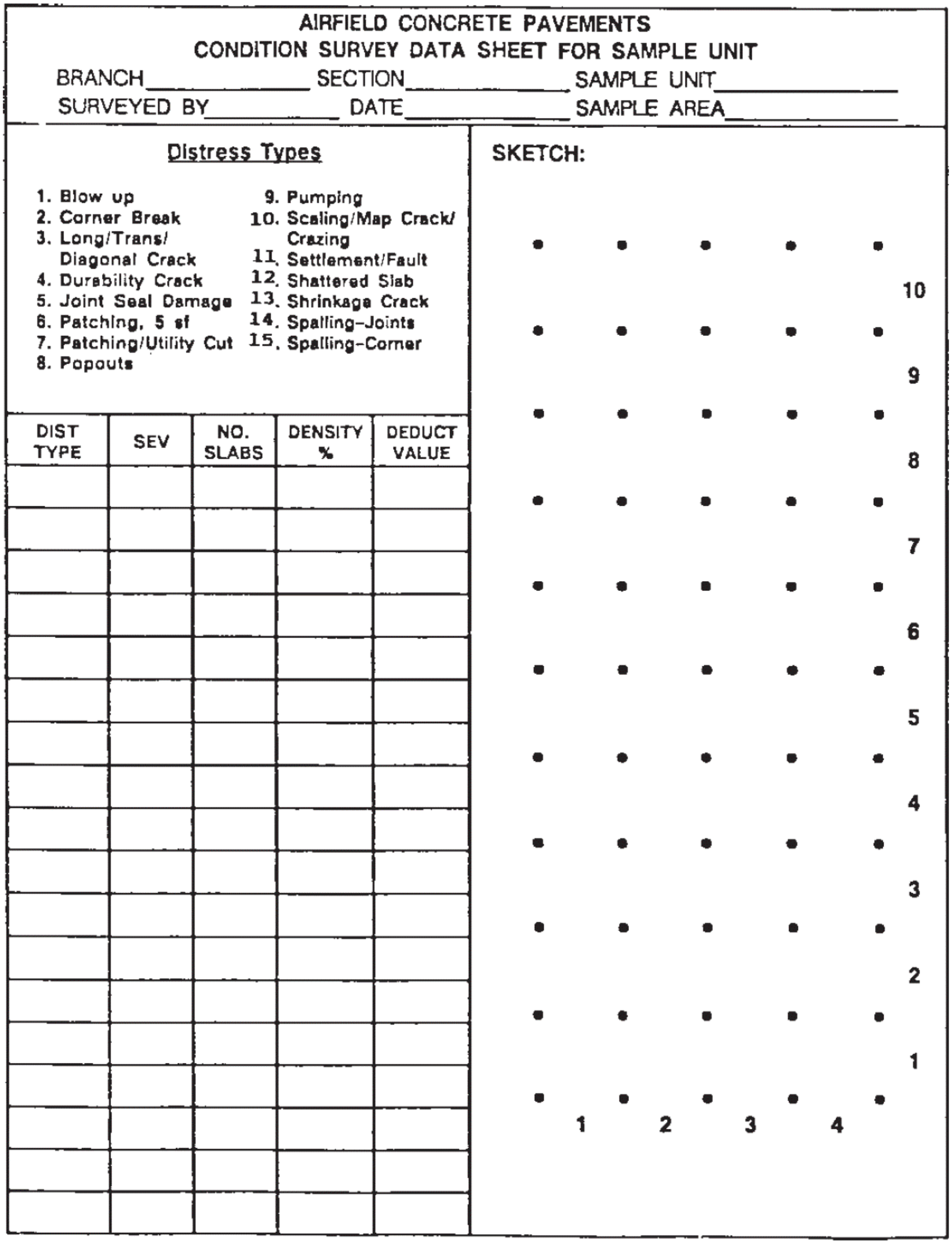
SURVEY DATA SHEETS

AIRFIELD ASPHALT PAVEMENT CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT	**SKETCH:**
BRANCH ____________ SECTION ________ SAMPLE UNIT ________ SURVEYED BY __________ DATE ________ SAMPLE AREA ________	

1. Alligator Cracking	5. Depression	9. Oil Spillage	13. Rutting
2. Bleeding	6. Jet Blast	10. Patching	14. Shoving from PCC
3. Block Cracking	7. Jt. Reflection (PCC)	11. Polished Aggregate	15. Slippage Cracking
4. Corrugation	8. Long. & Trans. Cracking	12. Raveling/Weathering	16. Swell

DISTRESS SEVERITY	QUANTITY									TOTAL	DENSITY %	DEDUCT VALUE

Flexible pavement condition survey data sheet for sample unit



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

DIST TYPE	SEV	NO. SLABS	DENSITY %	DEDUCT VALUE

SKETCH:

Jointed rigid pavement condition survey data sheet for sample unit

APPENDIX B

EQUATION OF DEDUCT VALUE CURVES

Equations for concrete pavement:

Distress code	Distress severity		
	Low	Medium	High
61	$y = 1E\text{-}07x^5 - 3E\text{-}05x^4 + 0.0026x^3 - 0.1036x^2 + 2.8925x + 1.2457$	$y = -6E\text{-}08x^6 + 1E\text{-}05x^5 - 0.001x^4 + 0.0425x^3 - 0.8813x^2 + 9.7165x + 1.4313$	
62	y = -9E-10x6 + 3E-07x5 - 4E-05x4 + 0.0026x3 - 0.0987x2 + 2.9817x - 0.3643	y = -7E-10x6 + 2E-07x5 - 3E-05x4 + 0.0019x3 - 0.0695x2 + 2.0327x + 0.0941	y = -3E-09x5 + 3E-07x4 + 5E-05x3 - 0.0096x2 + 0.9285x - 0.1696
63	$y = 6E\text{-}09x^5 - 2E\text{-}06x^4 + 0.0003x^3 - 0.0198x^2 + 0.9602x + 0.1753$	$y = -6E\text{-}10x^6 + 2E\text{-}07x^5 - 3E\text{-}05x^4 + 0.0023x^3 - 0.0922x^2 + 2.5545x + 0.109$	$y = -7E\text{-}10x^6 + 3E\text{-}07x^5 - 4E\text{-}05x^4 + 0.0025x^3 - 0.1052x^2 + 3.3046x + 0.2499$
64	$y = 8E\text{-}09x^5 - 2E\text{-}06x^4 + 0.0002x^3 - 0.0135x^2 + 0.7018x + 0.2804$	$y = -1E\text{-}09x^6 + 4E\text{-}07x^5 - 5E\text{-}05x^4 + 0.0032x^3 - 0.1114x^2 + 2.4663x + 0.5567$	$y = -1E\text{-}09x^6 + 4E\text{-}07x^5 - 6E\text{-}05x^4 + 0.004x^3 - 0.1555x^2 + 4.0067x + 0.396$
65	2	7	12
66	y =5E-09x5 - 1E-06x4 + 0.0001x3 - 0.0037x2 + 0.1866x + 0.0082	y = 4E-12x6 + 6E-09x5 - 2E-06x4 + 0.0002x3 - 0.0145x2 + 0.6874x + 0.186	y = -3E-10x6 + 1E-07x5 - 2E-05x4 + 0.0011x3 - 0.0427x2 + 1.3994x - 0.0232
67	y =6E-09x5 - 2E-06x4 + 0.0002x3 - 0.016x2 + 0.7604x + 0.1666	y = -9E-10x6 + 3E-07x5 - 4E-05x4 + 0.003x3 - 0.1093x2 + 2.4772x + 0.2797	y = -1E-09x6 + 4E-07x5 - 6E-05x4 + 0.0042x3 - 0.1601x2 + 4.0265x + 0.4483
68	$y = 2E\text{-}08x^5 - 5E\text{-}06x^4 + 0.0005x^3 - 0.0257x^2 + 0.9509x + 0.1272$		

69	y = 3E-09x5 - 1E-06x4 + 0.0001x3 - 0.0112x2 + 1.1117x - 0.0929		
70	y =1E-08x5 - 3E-06x4 + 0.0003x3 - 0.0142x2 + 0.5544x - 0.0542	y = -1E-10x6 + 5E-08x5 - 8E-06x4 + 0.0007x3 - 0.0362x2 + 1.5957x + 0.196	y =-8E-10x6 + 3E-07x5 - 3E-05x4 + 0.0022x3 - 0.09x2 + 3.2137x + 0.2572
71	y = -2E-09x5 + 5E-07x4 + 2E-06x3 - 0.0071x2 + 0.8422x + 0.1866	y = -9E-11x6 + 6E-08x5 - 1E-05x4 + 0.0011x3 - 0.053x2 + 1.8793x + 0.0931	y = -5E-10x6 + 2E-07x5 - 3E-05x4 + 0.0024x3 - 0.1078x2 + 3.3902x + 0.0946
72	y = 4E-08x5 - 1E-05x4 + 0.0014x3 - 0.0756x2 + 2.4446x + 0.1551	y = -2E-09x6 + 8E-07x5 - 0.0001x4 + 0.0065x3 - 0.2159x2 + 4.3113x + 0.8538	y = -7E-09x6 + 2E-06x5 - 0.0002x4 + 0.0139x3 - 0.4165x2 + 6.9011x + 1.7583
73	y = 5E-09x5 - 1E-06x4 + 0.0001x3 - 0.0038x2 + 0.1739x + 0.409		
74	y = 3E-09x5 - 9E-07x4 + 9E-05x3 - 0.0058x2 + 0.3638x + 0.1591	y = -2E-10x6 + 7E-08x5 - 1E-05x4 + 0.0006x3 - 0.0232x2 + 0.9475x + 0.1671	y =-8E-10x6 + 3E-07x5 - 4E-05x4 + 0.0029x3 - 0.1172x2 + 2.9222x + 0.1796
75	y = -7E-09x5 + 1E-06x4 - 8E-05x3 - 0.0017x2 + 0.4062x + 0.0709	y = = -3E-10x6 + 9E-08x5 - 1E-05x4 + 0.0008x3 - 0.0319x2 + 0.9963x - 0.0797	y = -4E-10x6 + 1E-07x5 - 1E-05x4 + 0.0008x3 - 0.0277x2 + 1.1421x + 0.0356

Equations for flexible pavement:

Distress code	Distress severity		
	Low	Medium	High
41	y =0.031x6 - 0.6175x5 + 2.6239x4 - 2.6701x3 + 2.1512x2 + 20.808x + 20.739	y =1.733x6 - 4.6986x5 - 0.6836x4 + 7.3905x3 + 2.518x2 + 20.297x + 29.481	y =1.6348x6 - 5.7219x5 - 0.4539x4 + 10.066x3 + 5.5293x2 + 23.149x + 36.809
42	y =3.1992x6 - 8.5964x5 - 5.4698x4 + 17.106x3 + 15.246x2 + 10.702x + 6.2217		
43	y =-0.3386x6 + 0.951x5 + 0.4081x4 - 1.4534x3 + 2.7571x2 + 6.304x + 7.9088	y =0.9904x6 - 1.5921x5 - 1.8701x4 + 3.2926x3 + 5.5664x2 + 6.2132x + 11.249	y = -0.3355x6 + 1.3835x5 - 0.9859x4 - 1.4707x3 + 8.046x2 + 15.861x + 18.985
44	y =0.242x6 - 0.2955x5 - 0.2064x4 + 0.9942x3 + 6.3414x2 + 13.162x + 9.4866	y =1.4647x6 - 3.2687x5 + 0.2098x4 + 3.7226x3 + 6.8632x2 + 20.81x + 18.817	y =1.0645x6 - 1.2755x5 - 1.0527x4 + 2.5807x3 + 6.8618x2 + 27.032x + 32.451
45	y =0.069x6 - 0.0086x5 + 0.0429x4 - 0.8245x3 + 7.1486x2 + 14.384x + 6.3462	y =-0.2778x6 + 1.0663x5 + 0.3713x4 - 2.7069x3 + 7.3907x2 + 19.356x + 15.232	y =-0.245x6 + 0.9761x5 - 0.1083x4 - 0.8075x3 + 6.1996x2 + 19.68x + 25.948
46	y =1.6863x6 - 6.3218x5 + 0.9547x4 + 10.439x3 + 3.8424x2 + 8.0677x + 5.7815		
47	y =-2.7524x6 + 13.459x5 - 20.663x4 + 6.2965x3 + 12.801x2 - 0.327x - 0.0747	y =-0.0641x6 + 0.8854x5 - 4.455x4 + 6.2122x3 + 7.722x2 + 7.8556x + 3.0891	y =-4.1995x6 + 16.667x5 - 19.371x4 + 1.8675x3 + 18.727x2 + 12.423x + 5.5876

48	y =-2.1821x6 + 7.1384x5 - 5.1705x4 + 0.3926x3 + 5.4105x2 + 1.8587x + 3.1657	y =-2.52x6 + 6.9725x5 - 1.8547x4 - 3.1344x3 + 5.4215x2 + 8.3226x + 6.558	y =-4.3382x^6 + 17.941x^5 - 21.611x^4 + 4.2659x3 + 14.769x2 + 10.926x + 11.177
49	y = 1.1082x6 - 4.1351x5 + 0.1961x4 + 7.984x3 + 3.1645x2 + 2.999x + 4.3324		
50	y =0.9656x6 - 3.3238x5 + 0.8933x4 + 6.3309x3 + 1.678x2 + 3.5781x + 4.5656	y =0.3941x6 - 1.4177x5 - 0.2141x4 + 5.1625x3 + 7.0785x2 + 6.947x + 9.9159	y =-0.1913x6 + 0.0697x5 + 0.375x4 + 3.4513x3 + 9.2586x2 + 10.303x + 19.358
51	y =0.6821x6 - 1.8986x5 - 0.6729x4 + 5.0618x3 + 6.1885x2 + 4.7115x + 2.9053		
52	y =0.1342x6 - 0.5512x5 + 0.5112x4 + 1.113x3 + 2.0727x2 + 3.7922x + 3.1724	y = -1.0167x6 + 1.8185x5 + 2.9255x4 - 2.0956x3 + 2.1063x2 + 8.1255x + 8.7176	y =-0.5464x6 + 4.2242x5 - 7.7401x4 - 7.5586x3 + 21.089x2 + 26.608x + 16.854
53	y =0.7584x6 - 2.2679x5 + 0.3789x4 + 3.9018x3 + 1.9355x2 + 8.4888x + 15.565	y =0.6508x6 - 1.69x5 + 0.4546x4 + 2.0166x3 + 3.2222x2 + 14.955x + 24.492	y =0.7217x6 - 0.9291x5 - 1.3176x4 + 2.7037x3 + 7.2603x2 + 19.143x + 34.337
54	y =0.0501x6 - 0.3031x5 + 0.2653x4 + 0.6963x3 + 3.3192x2 + 7.7076x + 6.9723	y = -0.1553x6 + 0.643x5 + 0.0053x4 - 1.2318x3 + 4.8546x2 + 14.288x + 15.05	y =-0.2193x6 + 0.6275x5 + 0.454x4 - 1.5312x3 + 5.0744x2 + 20.943x + 24.689
55	y =2.5487x6 - 6.2997x5 - 6.3481x4 + 11.642x3 + 20.012x2 + 17.632x + 11.827		
56	y= 0.5525x6 - 2.0177x5 + 0.26x4 + 4.8955x3 + 4.5358x2 + 5.1067x + 3.6463	y =0.7109x6 - 2.9345x5 + 1.0405x4 + 6.7749x3 + 5.4558x2 + 8.0633x + 14.729	y =0.0071x6 - 0.2462x5 - 0.2143x4 + 3.1037x3 + 8.8557x2 + 11.194x + 33.925

APPENDIX C

PCI CALCULATION MACRO

1- Macro for concrete pavement PCI calculation:

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Sub deduction()
For i = 5 To 19 ' calculating deduct values based on equations which have obtained from ASTM graphs
    x = Cells(i, 17)
    x2 = x * x
    x3 = x * x2
    x4 = x * x3
    x5 = x * x4
    x6 = x * x5
    If Cells(i, 5) = 61 Then
        If Cells(i, 7) = "L" Then
            y = 0.0000001 * x5 - 0.00003 * x4 + 0.0026 * x3 - 0.1036 * x2 + 2.8925 * x + 1.2457
        End If
        If Cells(i, 7) = "M" Then
            y = -0.00000006 * x6 + 0.00001 * x5 - 0.001 * x4 + 0.0425 * x3 - 0.8813 * x2 + 9.7165 * x + 1.4313
        End If
        If Cells(i, 7) = "H" Then
            y = "DO not have High severity"
        End If
    End If
    If Cells(i, 5) = 62 Then
        If Cells(i, 7) = "L" Then
            y = -0.000000003 * x5 + 0.0000003 * x4 + 0.00005 * x3 - 0.0096 * x2 + 0.9285 * x - 0.1696
        End If
        If Cells(i, 7) = "M" Then
            y = -0.0000000007 * x6 + 0.0000002 * x5 - 0.00003 * x4 + 0.0019 * x3 - 0.0695 * x2 + 2.0327 * x
+    0.0941
        End If
        If Cells(i, 7) = "H" Then
            y = -0.0000000009 * x6 + 0.0000003 * x5 - 0.00004 * x4 + 0.0026 * x3 - 0.0987 * x2 + 2.9817 * x
- 0.3643
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            End If
    End If
    If Cells(i, 5) = 63 Then
        If Cells(i, 7) = "L" Then
            y = 0.000000006 * x5 - 0.000002 * x4 + 0.0003 * x3 - 0.0198 * x2 + 0.9602 * x + 0.1753
        End If
        If Cells(i, 7) = "M" Then
            y = -0.0000000006 * x6 + 0.0000002 * x5 - 0.00003 * x4 + 0.0023 * x3 - 0.0922 * x2 + 2.5545 * x
+ 0.109
        End If
        If Cells(i, 7) = "H" Then
            y = -0.0000000007 * x6 + 0.0000003 * x5 - 0.00004 * x4 + 0.0025 * x3 - 0.1052 * x2 + 3.3046 * x
+ 0.2499
        End If
    End If
    If Cells(i, 5) = 64 Then
        If Cells(i, 7) = "L" Then
            y = 0.000000008 * x5 - 0.000002 * x4 + 0.0002 * x3 - 0.0135 * x2 + 0.7018 * x + 0.2804
        End If
        If Cells(i, 7) = "M" Then
            y = -0.000000001 * x6 + 0.0000004 * x5 - 0.00005 * x4 + 0.0032 * x3 - 0.1114 * x2 + 2.4663 * x
+ 0.5567
        End If
        If Cells(i, 7) = "H" Then
            y = -0.000000001 * x6 + 0.0000004 * x5 - 0.00006 * x4 + 0.004 * x3 - 0.1555 * x2 + 4.0067 * x +
0.396
        End If
    End If
    If Cells(i, 5) = 65 Then
        If Cells(i, 7) = "L" Then
            y = 2
        End If
        If Cells(i, 7) = "M" Then
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            y = 7
        End If
        If Cells(i, 7) = "H" Then
            y = 12
        End If
    End If
    If Cells(i, 5) = 66 Then
        If Cells(i, 7) = "L" Then
            y = 0.000000005 * x5 - 0.000001 * x4 + 0.0001 * x3 - 0.0037 * x2 + 0.1866 * x + 0.0082
        End If
        If Cells(i, 7) = "M" Then
            y = 0.000000000004 * x6 + 0.000000006 * x5 - 0.000002 * x4 + 0.0002 * x3 - 0.0145 * x2 + 0.6874
* x + 0.186
        End If
        If Cells(i, 7) = "H" Then
            y = -0.0000000003 * x6 + 0.0000001 * x5 - 0.00002 * x4 + 0.0011 * x3 - 0.0427 * x2 + 1.3994 * x
- 0.0232
        End If
    End If
    If Cells(i, 5) = 67 Then
        If Cells(i, 7) = "L" Then
            y = 0.000000006 * x5 - 0.000002 * x4 + 0.0002 * x3 - 0.016 * x2 + 0.7604 * x + 0.1666
        End If
        If Cells(i, 7) = "M" Then
            y = -0.0000000009 * x6 + 0.0000003 * x5 - 0.00004 * x4 + 0.003 * x3 - 0.1093 * x2 + 2.4772 * x
+ 0.2797
        End If
        If Cells(i, 7) = "H" Then
            y = -0.000000001 * x6 + 0.0000004 * x5 - 0.00006 * x4 + 0.0042 * x3 - 0.1601 * x2 + 4.0265 * x
+ 0.4483
        End If
    End If
    If Cells(i, 5) = 68 Then
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      y = 0.00000002 * x5 - 0.000005 * x4 + 0.0005 * x3 - 0.0257 * x2 + 0.9509 * x + 0.1272
    End If
    If Cells(i, 5) = 69 Then
      y = 0.000000003 * x5 - 0.000001 * x4 + 0.0001 * x3 - 0.0112 * x2 + 1.1117 * x - 0.0929
    End If
    If Cells(i, 5) = 70 Then
      If Cells(i, 7) = "L" Then
        y = 0.00000001 * x5 - 0.000003 * x4 + 0.0003 * x3 - 0.0142 * x2 + 0.5544 * x - 0.0542
      End If
      If Cells(i, 7) = "M" Then
        y = -0.0000000001 * x6 + 0.00000005 * x5 - 0.000008 * x4 + 0.0007 * x3 - 0.0362 * x2 + 1.5957
* x + 0.196
      End If
      If Cells(i, 7) = "H" Then
        y = -0.0000000008 * x6 + 0.0000003 * x5 - 0.00003 * x4 + 0.0022 * x3 - 0.09 * x2 + 3.2137 * x +
0.2572
      End If
    End If
    If Cells(i, 5) = 71 Then
      If Cells(i, 7) = "L" Then
        y = -0.000000002 * x5 + 0.0000005 * x4 + 0.000002 * x3 - 0.0071 * x2 + 0.8422 * x + 0.1866
      End If
      If Cells(i, 7) = "M" Then
        y = -0.00000000009 * x6 + 0.00000006 * x5 - 0.00001 * x4 + 0.0011 * x3 - 0.053 * x2 + 1.8793 *
x + 0.0931
      End If
      If Cells(i, 7) = "H" Then
        y = -0.0000000005 * x6 + 0.0000002 * x5 - 0.00003 * x4 + 0.0024 * x3 - 0.1078 * x2 + 3.3902 * x
+ 0.0946
      End If
    End If
    If Cells(i, 5) = 72 Then
      If Cells(i, 7) = "L" Then
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            y = 0.00000004 * x5 - 0.00001 * x4 + 0.0014 * x3 - 0.0756 * x2 + 2.4446 * x + 0.1551
        End If
        If Cells(i, 7) = "M" Then
            y = -0.000000002 * x6 + 0.0000008 * x5 - 0.0001 * x4 + 0.0065 * x3 - 0.2159 * x2 + 4.3113 * x +
0.8538
        End If
        If Cells(i, 7) = "H" Then
            y = -0.000000007 * x6 + 0.000002 * x5 - 0.0002 * x4 + 0.0139 * x3 - 0.4165 * x2 + 6.9011 * x +
1.7583
        End If
    End If
    If Cells(i, 5) = 73 Then
        y = 0.000000005 * x5 - 0.000001 * x4 + 0.0001 * x3 - 0.0038 * x2 + 0.1739 * x + 0.409
    End If
    If Cells(i, 5) = 74 Then
        If Cells(i, 7) = "L" Then
            y = 0.000000003 * x5 - 0.0000009 * x4 + 0.00009 * x3 - 0.0058 * x2 + 0.3638 * x + 0.1591
        End If
        If Cells(i, 7) = "M" Then
            y = -0.0000000002 * x6 + 0.00000007 * x5 - 0.00001 * x4 + 0.0006 * x3 - 0.0232 * x2 + 0.9475 *
x + 0.1671
        End If
        If Cells(i, 7) = "H" Then
            y = -0.0000000008 * x6 + 0.0000003 * x5 - 0.00004 * x4 + 0.0029 * x3 - 0.1172 * x2 + 2.9222 * x
+ 0.1796
        End If
    End If
    If Cells(i, 5) = 75 Then
        If Cells(i, 7) = "L" Then
            y = -0.000000007 * x5 + 0.000001 * x4 - 0.00008 * x3 - 0.0017 * x2 + 0.4062 * x + 0.0709
        End If
        If Cells(i, 7) = "M" Then
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            y = -0.0000000003 * x6 + 0.00000009 * x5 - 0.00001 * x4 + 0.0008 * x3 - 0.0319 * x2 + 0.9963 *
x - 0.0797
        End If
        If Cells(i, 7) = "H" Then
            y = -0.0000000004 * x6 + 0.0000001 * x5 - 0.00001 * x4 + 0.0008 * x3 - 0.0277 * x2 + 1.1421 * x
+ 0.0356
        End If
    End If
Cells(i, 18) = y ' putting all deduct values in a column in excel
If Cells(i, 17) = 0 And Cells(i, 5) <> 65 Then
            Cells(i, 18) = 0
End If
Next
Cells(4, 19) = "Sorted" ' sorting all deduct values
For t = 5 To 19
Cells(t, 19) = Cells(t, 18)
Next t
For j = 1 To 15
    For i = 5 To 19
    A = Cells(i, 19)
    b = Cells(i + 1, 19)
    If Cells(i, 19) > Cells(i + 1, 19) Then
        Cells(i, 19) = A
        Cells(i + 1, 19) = b
    Else
        Cells(i + 1, 19) = A
        Cells(i, 19) = b
    End If
    Next
Next
m = Cells(22, 12)
q = 0
```

```
For n = 1 To m ' moving deduct valued in another table horizontally
    Cells(28, n + 5) = Cells(n + 4, 19)
    If Cells(23, 11) <> 0 Then
    Cells(28, m + 6) = Cells(23, 11) * Cells(m + 5, 19)
    End If
    If Cells(28, n + 5) > 5 Then
    q = q + 1
    End If
Next n
Cells(28, 17) = q
If Cells(23, 11) <> 0 Then
c = m + 1
Else
c = m
End If
d = q - 1
For p = 1 To q - 1
    For Z = 1 To c
        Cells(28 + p, Z + 5) = Cells(27 + p, Z + 5)
    Next Z
    For r = m To 1 Step -1
        If Cells(28 + p, r + 5) > 5 Then ' based on the method
    Cells(28 + p, r + 5) = 5
    m = m - 1
    GoTo 10
    End If
Next r
10
Cells(28 + p, 17) = d
d = d - 1
Next p
```

```
 For s = 1 To q
x = Cells(27 + s, 16)
x2 = x * x
x3 = x * x2
x4 = x * x3
x5 = x * x4
x6 = x * x5
If Cells(27 + s, 17) = 8 Then ' calculating CDV from the equation obtained from graph
        Cells(27 + s, 18) = 0.0000001 * x4 - 0.00006 * x3 + 0.0082 * x2 + 0.1262 * x + 10.783
    End If
    If Cells(27 + s, 17) = 7 Then
        Cells(27 + s, 18) = -0.000000005 * x4 + 0.000002 * x3 - 0.0019 * x2 + 0.8718 * x - 7.1859
    End If
    If Cells(27 + s, 17) = 6 Then
        Cells(27 + s, 18) = -0.00000009 * x4 + 0.00004 * x3 - 0.0081 * x2 + 1.3534 * x - 19.205
         End If
    If Cells(27 + s, 17) = 5 Then
        Cells(27 + s, 18) = 0.00000001 * x4 + 0.000004 * x3 - 0.0021 * x2 + 0.9178 * x - 6.6186
    End If
    If Cells(27 + s, 17) = 4 Then
        Cells(27 + s, 18) = -0.00000001 * x4 + 0.000002 * x3 - 0.0014 * x2 + 0.8599 * x - 4.1296
    End If
    If Cells(27 + s, 17) = 3 Then
        Cells(27 + s, 18) = -0.0000001 * x4 + 0.00003 * x3 - 0.0034 * x2 + 0.9221 * x - 3.113
    End If
    If Cells(27 + s, 17) = 2 Then
        Cells(27 + s, 18) = -0.0000003 * x4 + 0.00006 * x3 - 0.0031 * x2 + 0.8748 * x + 0.4487
    End If
    If Cells(27 + s, 17) = 1 Then
        Cells(27 + s, 18) = x
    End If
```

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Next s
If Cells(38, 20) > 85 Then
        Cells(38, 21) = "GOOD"
Else
If Cells(38, 20) > 70 Then
        Cells(38, 21) = "Satisfactory"
Else
        If Cells(38, 20) > 55 Then
        Cells(38, 21) = "Fair"
Else
If Cells(38, 20) > 40 Then
        Cells(38, 21) = "Poor"
Else
        If Cells(38, 20) > 25 Then
Cells(38, 21) = "Very Poor"
Else
If Cells(38, 20) > 10 Then
        Cells(38, 21) = "Serious"
        Cells(38, 21) = "Failed"
End If
End If
End If
End If
End If
End If
End Sub
```

2- Macro for flexible pavement PCI calculation:

```
Sub AsphaltDeduction()
For i = 5 To 19 ' calculating deduct values based on equations which have obtained from ASTM graphs
  If Cells(i, 17) <> 0 Then
  x = Application.WorksheetFunction.Log(Cells(i, 17))
  x2 = x * x
  x3 = x * x2
  x4 = x * x3
  x5 = x * x4
  x6 = x * x5
  End If
  If Cells(i, 5) = 41 Then
    If Cells(i, 7) = "L" Then
      y = 0.031 * x6 - 0.6175 * x5 + 2.6239 * x4 - 2.6701 * x3 + 2.1512 * x2 + 20.808 * x + 20.739
    End If
    If Cells(i, 7) = "M" Then
      y = 1.733 * x6 - 4.6986 * x5 - 0.6836 * x4 + 7.3905 * x3 + 2.518 * x2 + 20.297 * x + 29.481
    End If
    If Cells(i, 7) = "H" Then
      y = 1.6348 * x6 - 5.7219 * x5 - 0.4539 * x4 + 10.066 * x3 + 5.5293 * x2 + 23.149 * x + 36.809
    End If
  End If
  If Cells(i, 5) = 42 Then
    y = 3.1992 * x6 - 8.5964 * x5 - 5.4698 * x4 + 17.106 * x3 + 15.246 * x2 + 10.702 * x + 6.2217
  End If
  If Cells(i, 5) = 43 Then
    If Cells(i, 7) = "L" Then
      y = -0.3386 * x6 + 0.951 * x5 + 0.4081 * x4 - 1.4534 * x3 + 2.7571 * x2 + 6.304 * x + 7.9088
    End If
    If Cells(i, 7) = "M" Then
      y = 0.9904 * x6 - 1.5921 * x5 - 1.8701 * x4 + 3.2926 * x3 + 5.5664 * x2 + 6.2132 * x + 11.249
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    End If
    If Cells(i, 7) = "H" Then
        y = -0.3355 * x6 + 1.3835 * x5 - 0.9859 * x4 - 1.4707 * x3 + 8.046 * x2 + 15.861 * x + 18.985
    End If
End If
If Cells(i, 5) = 44 Then
    If Cells(i, 7) = "L" Then
        y = 0.242 * x6 - 0.2955 * x5 - 0.2064 * x4 + 0.9942 * x3 + 6.3414 * x2 + 13.162 * x + 9.4866
    End If
    If Cells(i, 7) = "M" Then
        y = 1.4647 * x6 - 3.2687 * x5 + 0.2098 * x4 + 3.7226 * x3 + 6.8632 * x2 + 20.81 * x + 18.817
    End If
    If Cells(i, 7) = "H" Then
        y = 1.0645 * x6 - 1.2755 * x5 - 1.0527 * x4 + 2.5807 * x3 + 6.8618 * x2 + 27.032 * x + 32.451
    End If
End If
If Cells(i, 5) = 45 Then
    If Cells(i, 7) = "L" Then
        y = 0.069 * x6 - 0.0086 * x5 + 0.0429 * x4 - 0.8245 * x3 + 7.1486 * x2 + 14.384 * x + 6.3462
    End If
    If Cells(i, 7) = "M" Then
        y = -0.2778 * x6 + 1.0663 * x5 + 0.3713 * x4 - 2.7069 * x3 + 7.3907 * x2 + 19.356 * x + 15.232
    End If
    If Cells(i, 7) = "H" Then
        y = -0.245 * x6 + 0.9761 * x5 - 0.1083 * x4 - 0.8075 * x3 + 6.1996 * x2 + 19.68 * x + 25.948
    End If
End If
If Cells(i, 5) = 46 Then
    y = 1.6863 * x6 - 6.3218 * x5 + 0.9547 * x4 + 10.439 * x3 + 3.8424 * x2 + 8.0677 * x + 5.7815
End If
If Cells(i, 5) = 47 Then
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    If Cells(i, 7) = "L" Then
        y = -2.7524 * x6 + 13.459 * x5 - 20.663 * x4 + 6.2965 * x3 + 12.801 * x2 - 0.327 * x - 0.0747
    End If
    If Cells(i, 7) = "M" Then
        y = -0.0641 * x6 + 0.8854 * x5 - 4.455 * x4 + 6.2122 * x3 + 7.722 * x2 + 7.8556 * x + 3.0891
    End If
    If Cells(i, 7) = "H" Then
        y = -4.1995 * x6 + 16.667 * x5 - 19.371 * x4 + 1.8675 * x3 + 18.727 * x2 + 12.423 * x + 5.5876
    End If
End If
If Cells(i, 5) = 48 Then
    If Cells(i, 7) = "L" Then
        y = -2.1821 * x6 + 7.1384 * x5 - 5.1705 * x4 + 0.3926 * x3 + 5.4105 * x2 + 1.8587 * x + 3.1657
    End If
    If Cells(i, 7) = "M" Then
        y = 1.1735 * x6 - 4.5786 * x5 - 0.0577 * x4 + 9.7812 * x3 + 8.4479 * x2 + 10.798 * x + 10.529
    End If
    If Cells(i, 7) = "H" Then
        y = -4.3382 * x6 + 17.941 * x5 - 21.611 * x4 + 4.2659 * x3 + 14.769 * x2 + 10.926 * x + 11.177
    End If
End If
If Cells(i, 5) = 49 Then
    y = 1.1082 * x6 - 4.1351 * x5 + 0.1961 * x4 + 7.984 * x3 + 3.1645 * x2 + 2.999 * x + 4.3324
End If
If Cells(i, 5) = 50 Then
    If Cells(i, 7) = "L" Then
        y = 0.9656 * x6 - 3.3238 * x5 + 0.8933 * x4 + 6.3309 * x3 + 1.678 * x2 + 3.5781 * x + 4.5656
    End If
    If Cells(i, 7) = "M" Then
        y = 0.3941 * x6 - 1.4177 * x5 - 0.2141 * x4 + 5.1625 * x3 + 7.0785 * x2 + 6.947 * x + 9.9159
    End If
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```
    If Cells(i, 7) = "H" Then
        y = -0.1913 * x6 + 0.0697 * x5 + 0.375 * x4 + 3.4513 * x3 + 9.2586 * x2 + 10.303 * x + 19.358
    End If
End If
If Cells(i, 5) = 51 Then
    If Cells(i, 7) = "L" Then
        y = 0.6821 * x6 - 1.8986 * x5 - 0.6729 * x4 + 5.0618 * x3 + 6.1885 * x2 + 4.7115 * x + 2.9053
    End If
End If
If Cells(i, 5) = 52 Then
    If Cells(i, 7) = "L" Then
        y = 0.1342 * x6 - 0.5512 * x5 + 0.5112 * x4 + 1.113 * x3 + 2.0727 * x2 + 3.7922 * x + 3.1724
    End If
    If Cells(i, 7) = "M" Then
        y = -1.0167 * x6 + 1.8185 * x5 + 2.9255 * x4 - 2.0956 * x3 + 2.1063 * x2 + 8.1255 * x + 8.7176
    End If
    If Cells(i, 7) = "H" Then
        y = -0.5464 * x6 + 4.2242 * x5 - 7.7401 * x4 - 7.5586 * x3 + 21.089 * x2 + 26.608 * x + 16.854
    End If
End If
If Cells(i, 5) = 53 Then
    If Cells(i, 7) = "L" Then
        y = 0.7584 * x6 - 2.2679 * x5 + 0.3789 * x4 + 3.9018 * x3 + 1.9355 * x2 + 8.4888 * x + 15.565
    End If
    If Cells(i, 7) = "M" Then
        y = 0.6508 * x6 - 1.69 * x5 + 0.4546 * x4 + 2.0166 * x3 + 3.2222 * x2 + 14.955 * x + 24.492
    End If
    If Cells(i, 7) = "H" Then
        y = 0.7217 * x6 - 0.9291 * x5 - 1.3176 * x4 + 2.7037 * x3 + 7.2603 * x2 + 19.143 * x + 34.337
    End If
End If
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```
    If Cells(i, 5) = 54 Then
        If Cells(i, 7) = "L" Then
            y = 0.0501 * x6 - 0.3031 * x5 + 0.2653 * x4 + 0.6963 * x3 + 3.3192 * x2 + 7.7076 * x + 6.9723
        End If
        If Cells(i, 7) = "M" Then
            y = -0.1553 * x6 + 0.643 * x5 + 0.0053 * x4 - 1.2318 * x3 + 4.8546 * x2 + 14.288 * x + 15.05
        End If
        If Cells(i, 7) = "H" Then
            y = -0.2193 * x6 + 0.6275 * x5 + 0.454 * x4 - 1.5312 * x3 + 5.0744 * x2 + 20.943 * x + 24.689
        End If
    End If
    If Cells(i, 5) = 55 Then
            y = 2.5487 * x6 - 6.2997 * x5 - 6.3481 * x4 + 11.642 * x3 + 20.012 * x2 + 17.632 * x + 11.82
    End If
    If Cells(i, 5) = 56 Then
        If Cells(i, 7) = "L" Then
            y = 0.5525 * x6 - 2.0177 * x5 + 0.26 * x4 + 4.8955 * x3 + 4.5358 * x2 + 5.1067 * x + 3.6463
        End If
        If Cells(i, 7) = "M" Then
            y = 0.7109 * x6 - 2.9345 * x5 + 1.0405 * x4 + 6.7749 * x3 + 5.4558 * x2 + 8.0633 * x + 14.729
        End If
        If Cells(i, 7) = "H" Then
            y = 0.0071 * x6 - 0.2462 * x5 - 0.2143 * x4 + 3.1037 * x3 + 8.8557 * x2 + 11.194 * x + 33.925
        End If
    End If
Cells(i, 18) = y ' putting all deduct values in a column in excel
    If Cells(i, 17) = 0 Then
        Cells(i, 18) = 0
    End If
Next i
Cells(4, 19) = "Sorted" ' sorting all deduct values
```

```
For t = 5 To 19
Cells(t, 19) = Cells(t, 18)
Next t
For j = 1 To 15
    For i = 5 To 19
    A = Cells(i, 19)
    b = Cells(i + 1, 19)
    If Cells(i, 19) > Cells(i + 1, 19) Then
        Cells(i, 19) = A
        Cells(i + 1, 19) = b
    Else
        Cells(i + 1, 19) = A
        Cells(i, 19) = b
    End If
    Next
Next
m = Cells(22, 12)
q = 0
For n = 1 To m ' moving deduct valued in another table horizontally
    Cells(28, n + 5) = Cells(n + 4, 19)
    If Cells(23, 11) <> 0 Then
    Cells(28, m + 6) = Cells(23, 11) * Cells(m + 5, 19)
    End If
    If Cells(28, n + 5) > 5 Then
    q = q + 1
    End If
Next n
Cells(28, 17) = q
If Cells(23, 11) <> 0 Then
c = m + 1
Else
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```
c = m
End If
d = q - 1
For p = 1 To q - 1
    For Z = 1 To c
        Cells(28 + p, Z + 5) = Cells(27 + p, Z + 5)
    Next Z
    For r = m To 1 Step -1
        If Cells(28 + p, r + 5) > 5 Then ' based on the method
    Cells(28 + p, r + 5) = 5
    m = m - 1
    GoTo 10
    End If
Next r
10
Cells(28 + p, 17) = d
d = d - 1
Next p
 For s = 1 To q
x = Cells(27 + s, 16)
x2 = x * x
x3 = x * x2
x4 = x * x3
x5 = x * x4
x6 = x * x5
     If Cells(27 + s, 17) = 6 Then
        Cells(27 + s, 18) = 0.00000004 * x4 - 0.00001 * x3 - 0.0005 * x2 + 0.8195 * x - 15.264
    End If
    If Cells(27 + s, 17) = 5 Then
        Cells(27 + s, 18) = 0.00000004 * x4 - 0.00001 * x3 - 0.0008 * x2 + 0.8471 * x - 16.185
    End If
```

```
    If Cells(27 + s, 17) = 4 Then
        Cells(27 + s, 18) = 0.00000009 * x4 - 0.00003 * x3 + 0.002 * x2 + 0.6747 * x - 12.739
    End If
    If Cells(27 + s, 17) = 3 Then
        Cells(27 + s, 18) = 0.0000002 * x4 - 0.00007 * x3 + 0.0087 * x2 + 0.3516 * x - 3.9998
    End If
    If Cells(27 + s, 17) = 2 Then
        Cells(27 + s, 18) = 0.000000009 * x4 - 0.00001 * x3 + 0.001 * x2 + 0.7026 * x - 3.6661
    End If
    If Cells(27 + s, 17) = 1 Then
        Cells(27 + s, 18) = x
    End If
Next s
If Cells(38, 20) > 85 Then
            Cells(38, 21) = "GOOD"
Else
If Cells(38, 20) > 70 Then
            Cells(38, 21) = "Satisfactory"
Else
If Cells(38, 20) > 55 Then
            Cells(38, 21) = "Fair"
Else
If Cells(38, 20) > 40 Then
            Cells(38, 21) = "Poor"
Else
If Cells(38, 20) > 25 Then
            Cells(38, 21) = "Very Poor"
Else
If Cells(38, 20) > 10 Then
            Cells(38, 21) = "Serious"
            Cells(38, 21) = "Failed"
```

```
End If
End If
End If
End If
End If
End If
End Sub
```

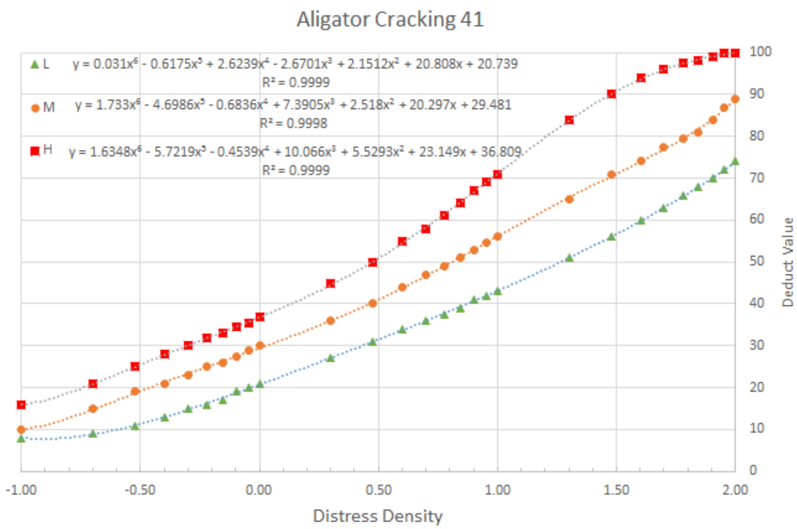
3- Macro for cleaning the sheets for inputting new data:

```
Sub dataclean()
For i = 5 To 19
        Cells(i, 5) = ""
        Cells(i, 18) = ""
        Cells(i, 19) = ""
        For j = 7 To 15
                Cells(i, j) = ""
        Next
Next
For k = 28 To 37
        Cells(k, 17) = ""
        Cells(k, 18) = ""
        For m = 6 To 15
                Cells(k, m) = ""
        Next
Next
End Sub
```

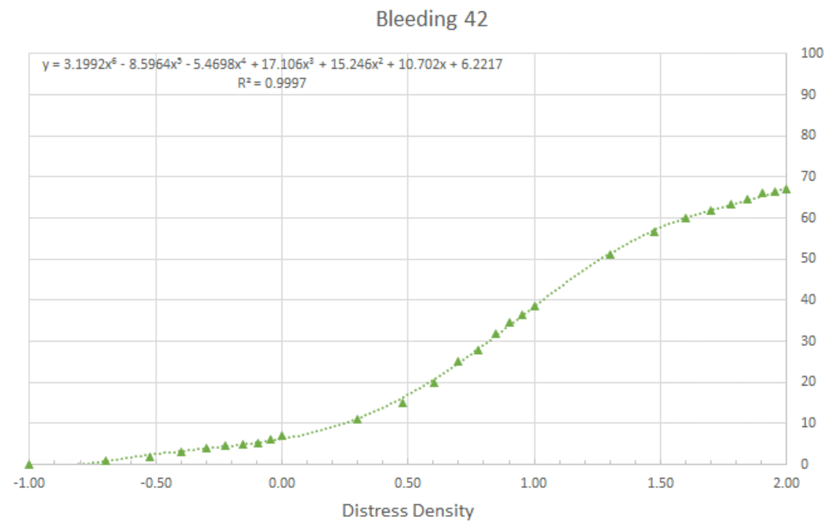
APPENDIX D

DEDUCT VALUE CURVES

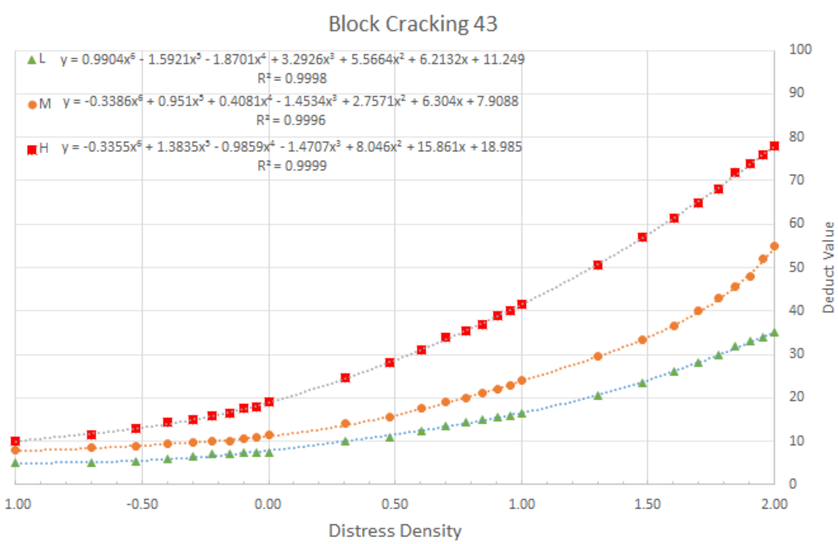
FLEXIBLE PAVEMENT AIRFIELDS



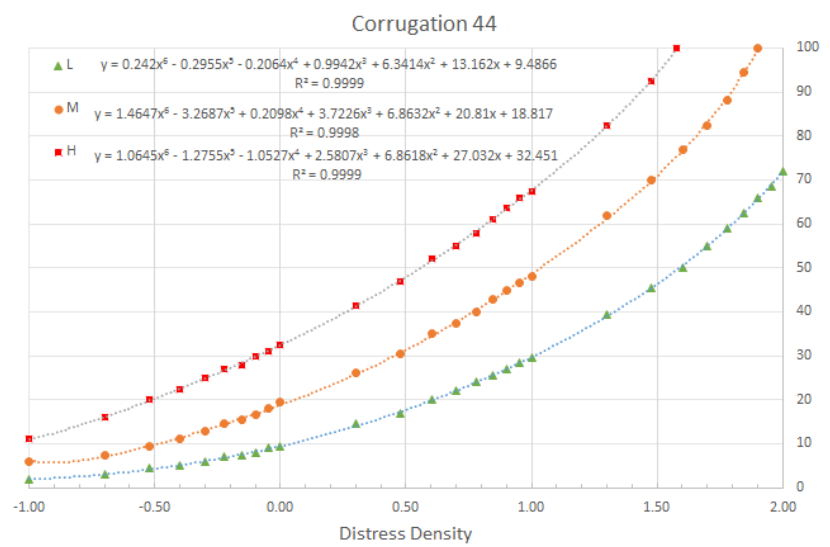
Aligator Cracking 41
L y = 0.031x⁶ - 0.6175x⁵ + 2.6239x⁴ - 2.6701x³ + 2.1512x² + 20.808x + 20.739
R² = 0.9999
M y = 1.733x⁶ - 4.6986x⁵ - 0.6836x⁴ + 7.3905x³ + 2.518x² + 20.297x + 29.481
R² = 0.9998
H y = 1.6348x⁶ - 5.7219x⁵ - 0.4539x⁴ + 10.066x³ + 5.5293x² + 23.149x + 36.809
R² = 0.9999
Deduct Value
Distress Density



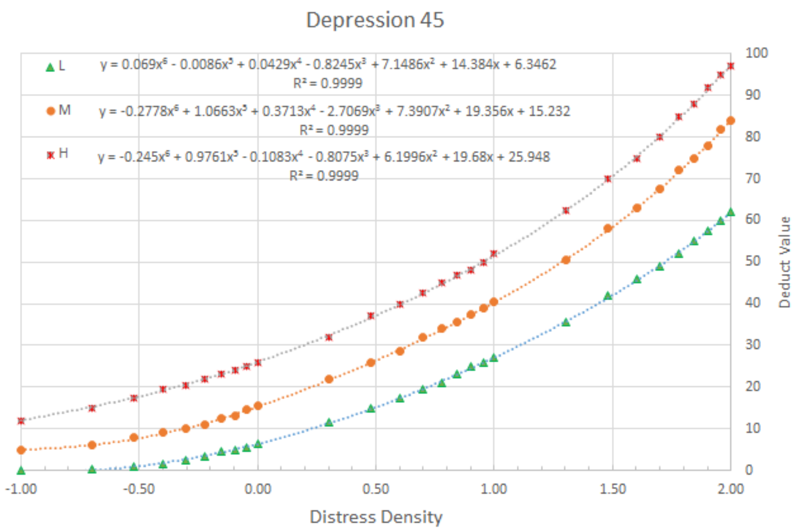
Bleeding 42
y = 3.1992x⁶ - 8.5964x⁵ - 5.4698x⁴ + 17.106x³ + 15.246x² + 10.702x + 6.2217
R² = 0.9997
Deduct Value
Distress Density



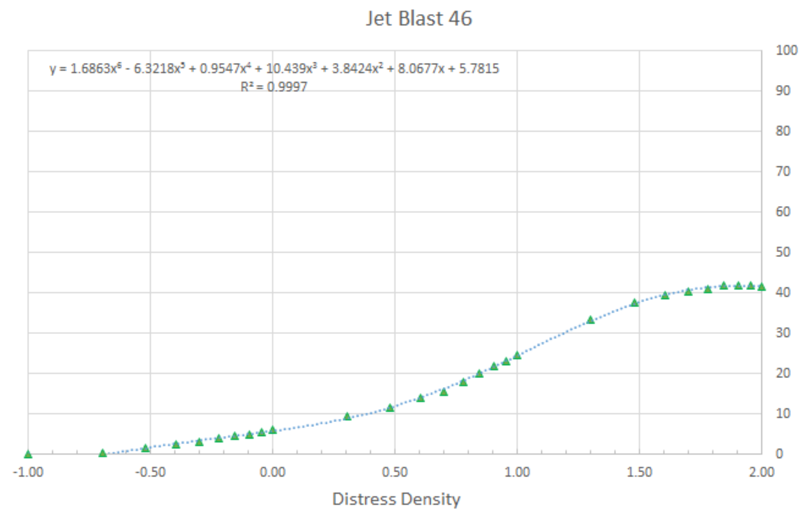
Block Cracking 43
L y = 0.9904x⁶ - 1.5921x⁵ - 1.8701x⁴ + 3.2926x³ + 5.5664x² + 6.2132x + 11.249
R² = 0.9998
M y = -0.3386x⁶ + 0.951x⁵ + 0.4081x⁴ - 1.4534x³ + 2.7571x² + 6.304x + 7.9088
R² = 0.9996
H y = -0.3355x⁶ + 1.3835x⁵ - 0.9859x⁴ - 1.4707x³ + 8.046x² + 15.861x + 18.985
R² = 0.9999
Deduct Value
Distress Density



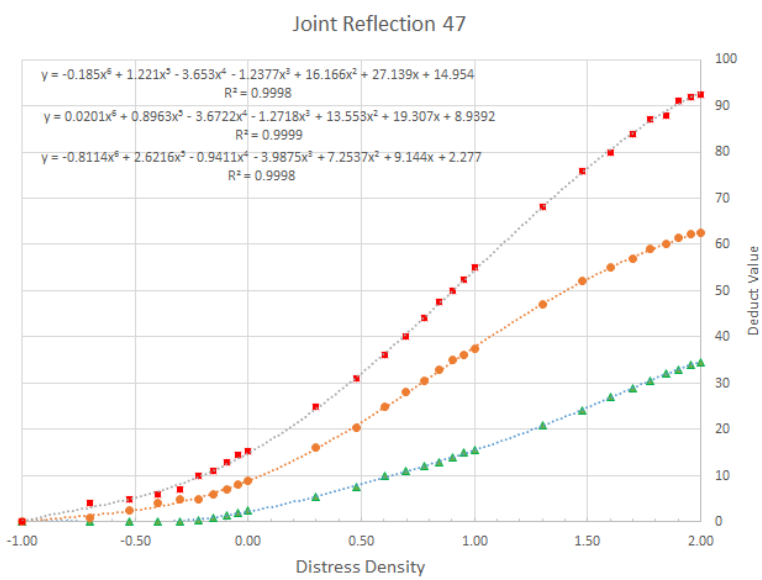
Corrugation 44
L y = 0.242x⁶ - 0.2955x⁵ - 0.2064x⁴ + 0.9942x³ + 6.3414x² + 13.162x + 9.4866
R² = 0.9999
M y = 1.4647x⁶ - 3.2687x⁵ + 0.2098x⁴ + 3.7226x³ + 6.8632x² + 20.81x + 18.817
R² = 0.9998
H y = 1.0645x⁶ - 1.2755x⁵ - 1.0527x⁴ + 2.5807x³ + 6.8618x² + 27.032x + 32.451
R² = 0.9999
Deduct Value
Distress Density



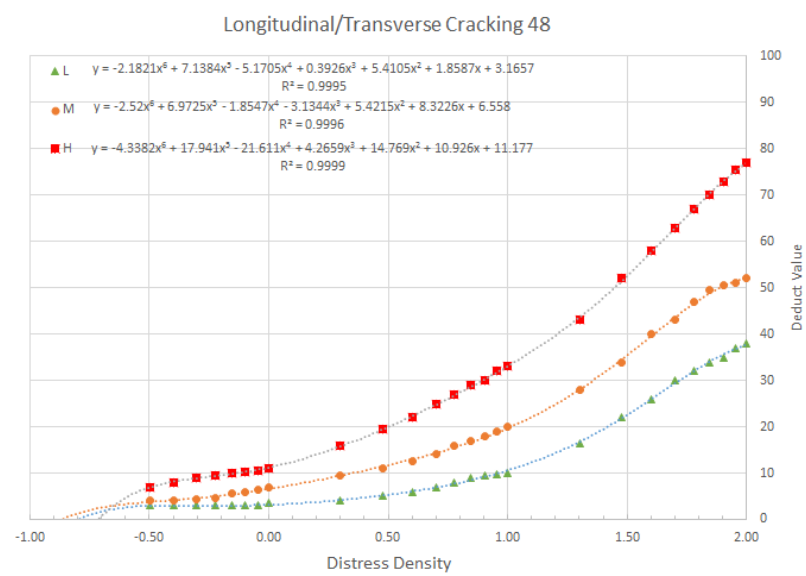
Depression 45
L y = 0.069x⁶ - 0.0086x⁵ + 0.0429x⁴ - 0.8245x³ + 7.1486x² + 14.384x + 6.3462
R² = 0.9999
M y = -0.2778x⁶ + 1.0663x⁵ + 0.3713x⁴ - 2.7069x³ + 7.3907x² + 19.356x + 15.232
R² = 0.9999
H y = -0.245x⁶ + 0.9761x⁵ - 0.1083x⁴ - 0.8075x³ + 6.1996x² + 19.68x + 25.948
R² = 0.9999
-1.00 -0.50 0.00 0.50 1.00 1.50 2.00
0 10 20 30 40 50 60 70 80 90 100
Distress Density
Deduct Value



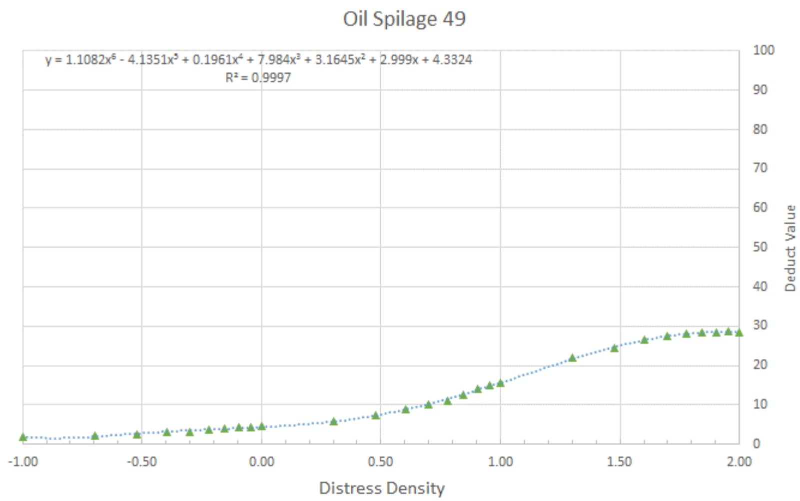
Jet Blast 46
y = 1.6863x⁶ - 6.3218x⁵ + 0.9547x⁴ + 10.439x³ + 3.8424x² + 8.0677x + 5.7815
R² = 0.9997
-1.00 -0.50 0.00 0.50 1.00 1.50 2.00
0 10 20 30 40 50 60 70 80 90 100
Distress Density
Deduct Value



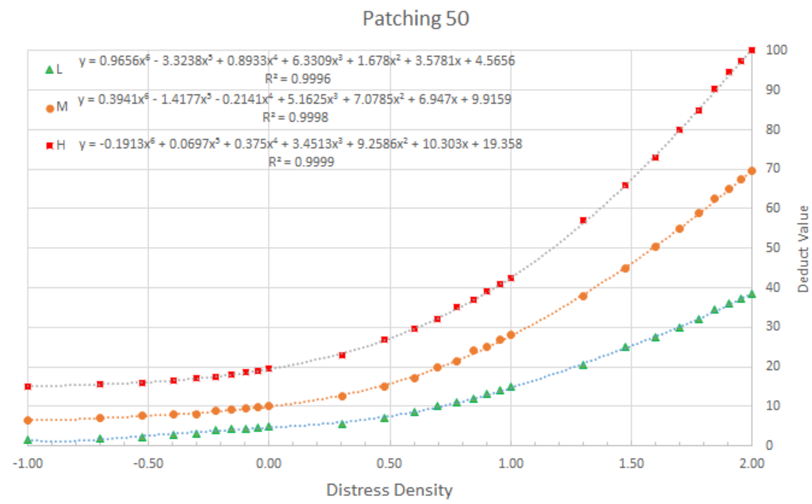
Joint Reflection 47
y = -0.185x⁶ + 1.221x⁵ - 3.653x⁴ - 1.2377x³ + 16.166x² + 27.139x + 14.954
R² = 0.9998
y = 0.0201x⁶ + 0.8963x⁵ - 3.6722x⁴ - 1.2718x³ + 13.553x² + 19.307x + 8.9392
R² = 0.9999
y = -0.8114x⁶ + 2.6216x⁵ - 0.9411x⁴ - 3.9875x³ + 7.2537x² + 9.144x + 2.277
R² = 0.9998
-1.00 -0.50 0.00 0.50 1.00 1.50 2.00
0 10 20 30 40 50 60 70 80 90 100
Distress Density
Deduct Value



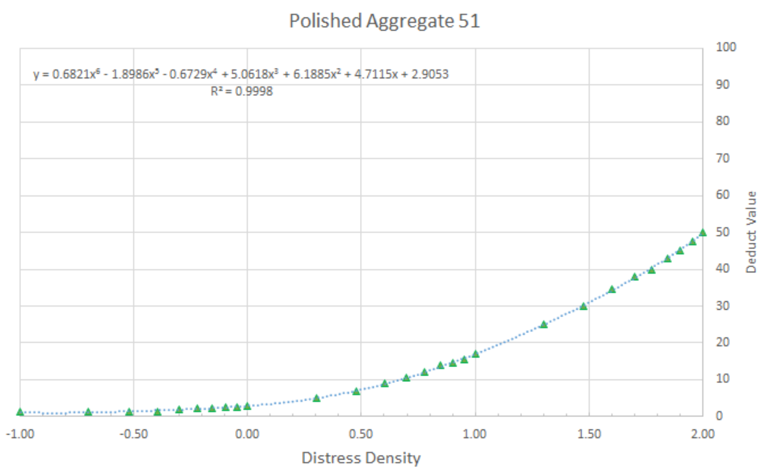
Longitudinal/Transverse Cracking 48
L y = -2.1821x⁶ + 7.1384x⁵ - 5.1705x⁴ + 0.3926x³ + 5.4105x² + 1.8587x + 3.1657
R² = 0.9995
M y = -2.52x⁶ + 6.9725x⁵ - 1.8547x⁴ - 3.1344x³ + 5.4215x² + 8.3226x + 6.558
R² = 0.9996
H y = -4.3382x⁶ + 17.941x⁵ - 21.611x⁴ + 4.2659x³ + 14.769x² + 10.926x + 11.177
R² = 0.9999
-1.00 -0.50 0.00 0.50 1.00 1.50 2.00
0 10 20 30 40 50 60 70 80 90 100
Distress Density
Deduct Value



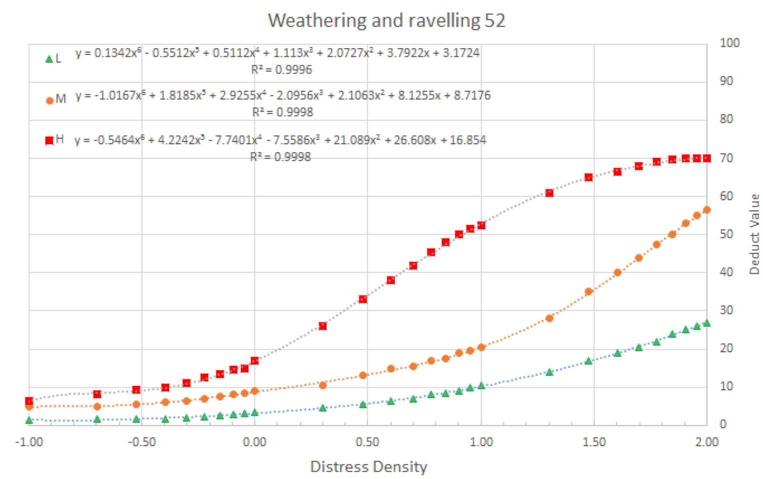
Oil Spilage 49
y = 1.1082x⁶ - 4.1351x⁵ + 0.1961x⁴ + 7.984x³ + 3.1645x² + 2.999x + 4.3324
R² = 0.9997
Deduct Value
Distress Density



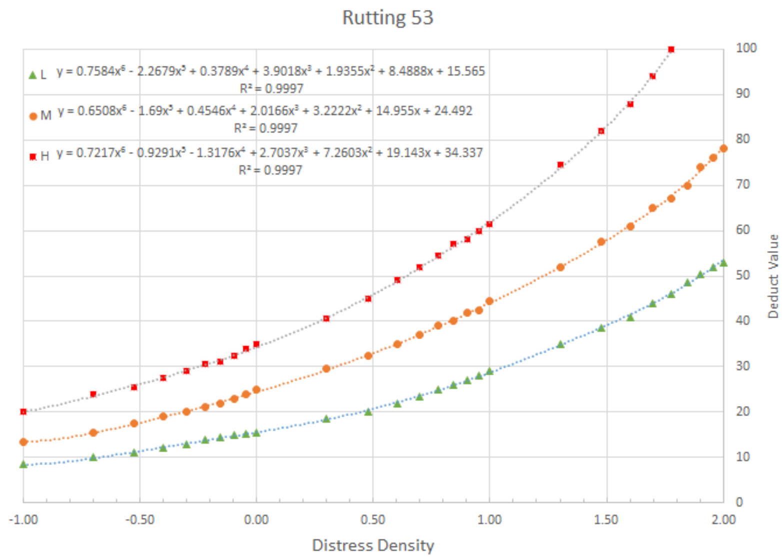
Patching 50
L y = 0.9656x⁶ - 3.3238x⁵ + 0.8933x⁴ + 6.3309x³ + 1.678x² + 3.5781x + 4.5656
R² = 0.9996
M y = 0.3941x⁶ - 1.4177x⁵ - 0.2141x⁴ + 5.1625x³ + 7.0785x² + 6.947x + 9.9159
R² = 0.9998
H y = -0.1913x⁶ + 0.0697x⁵ + 0.375x⁴ + 3.4513x³ + 9.2586x² + 10.303x + 19.358
R² = 0.9999
Deduct Value
Distress Density

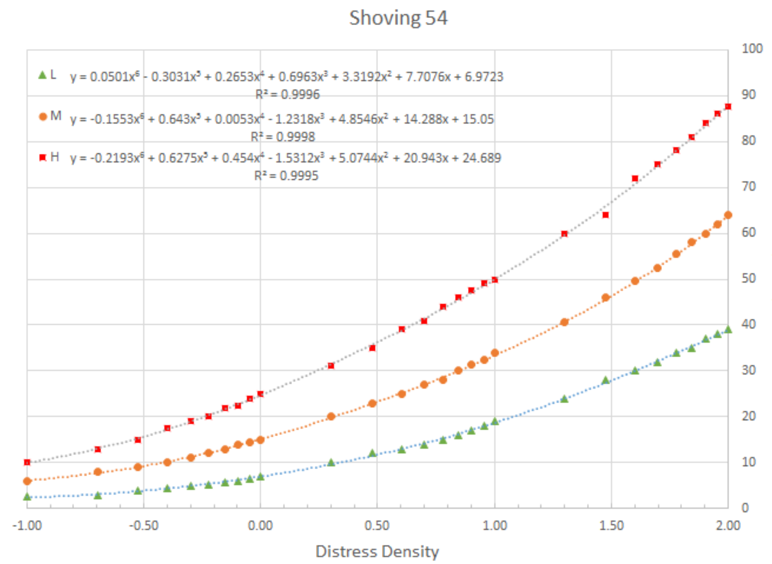


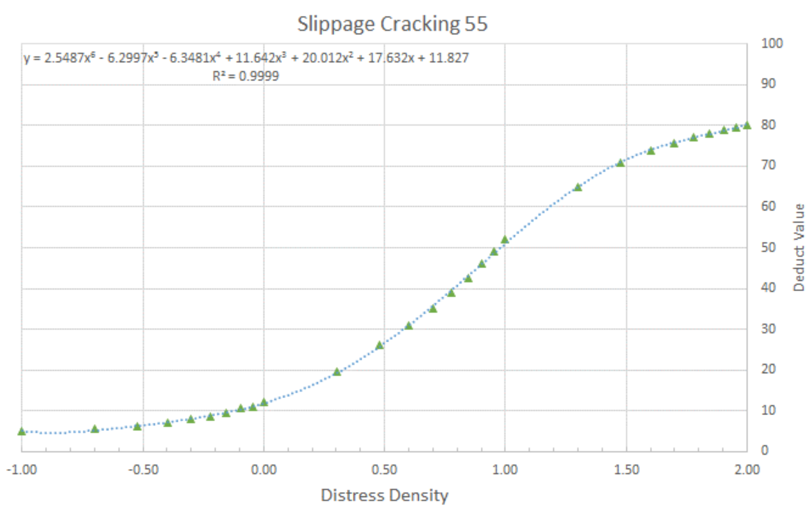
Polished Aggregate 51
y = 0.6821x⁶ - 1.8986x⁵ - 0.6729x⁴ + 5.0618x³ + 6.1885x² + 4.7115x + 2.9053
R² = 0.9998
Deduct Value
Distress Density

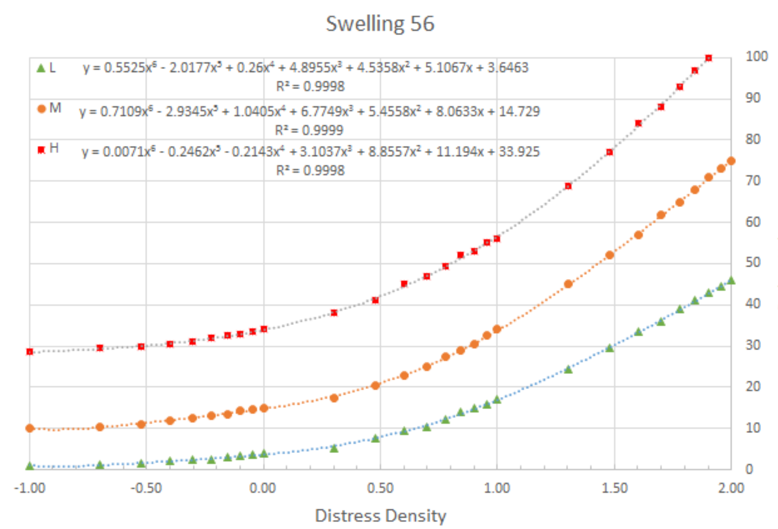


Weathering and ravelling 52
L y = 0.1342x⁶ - 0.5512x⁵ + 0.5112x⁴ + 1.113x³ + 2.0727x² + 3.7922x + 3.1724
R² = 0.9996
M y = -1.0167x⁶ + 1.8185x⁵ + 2.9255x⁴ - 2.0956x³ + 2.1063x² + 8.1255x + 8.7176
R² = 0.9998
H y = -0.5464x⁶ + 4.2242x⁵ - 7.7401x⁴ - 7.5586x³ + 21.089x² + 26.608x + 16.854
R² = 0.9998
Deduct Value
Distress Density


Rutting 53
L y = 0.7584x⁶ - 2.2679x⁵ + 0.3789x⁴ + 3.9018x³ + 1.9355x² + 8.4888x + 15.565
R² = 0.9997
M y = 0.6508x⁶ - 1.69x⁵ + 0.4546x⁴ + 2.0166x³ + 3.2222x² + 14.955x + 24.492
R² = 0.9997
H y = 0.7217x⁶ - 0.9291x⁵ - 1.3176x⁴ + 2.7037x³ + 7.2603x² + 19.143x + 34.337
R² = 0.9997
Deduct Value
Distress Density


Shoving 54
L y = 0.0501x⁶ - 0.3031x⁵ + 0.2653x⁴ + 0.6963x³ + 3.3192x² + 7.7076x + 6.9723
R² = 0.9996
M y = -0.1553x⁶ + 0.643x⁵ + 0.0053x⁴ - 1.2318x³ + 4.8546x² + 14.288x + 15.05
R² = 0.9998
H y = -0.2193x⁶ + 0.6275x⁵ + 0.454x⁴ - 1.5312x³ + 5.0744x² + 20.943x + 24.689
R² = 0.9995
Deduct Value
Distress Density

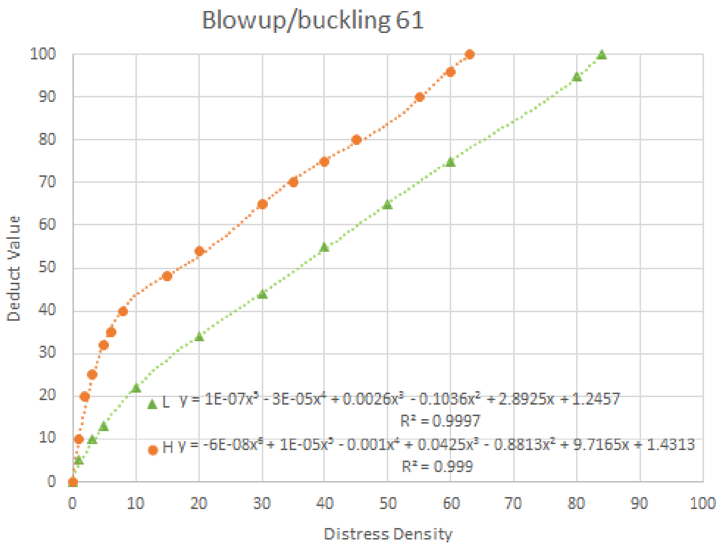

Slippage Cracking 55
y = 2.5487x⁶ - 6.2997x⁵ - 6.3481x⁴ + 11.642x³ + 20.012x² + 17.632x + 11.827
R² = 0.9999
Deduct Value
Distress Density

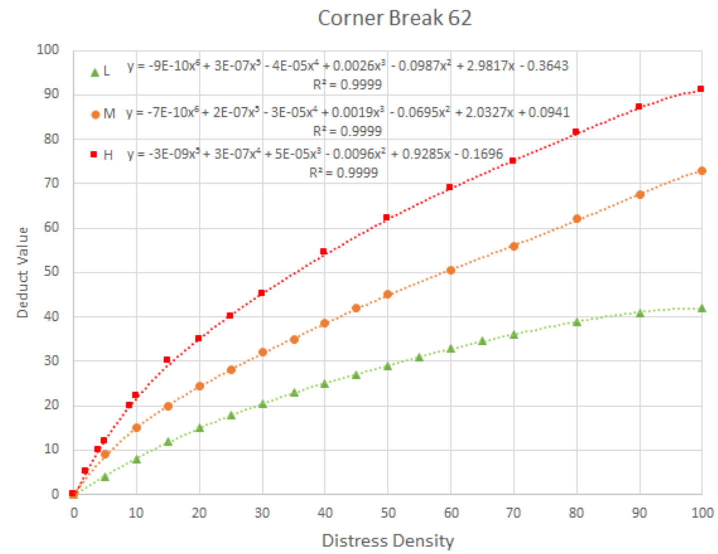

Swelling 56
L y = 0.5525x⁶ - 2.0177x⁵ + 0.26x⁴ + 4.8955x³ + 4.5358x² + 5.1067x + 3.6463
R² = 0.9998
M y = 0.7109x⁶ - 2.9345x⁵ + 1.0405x⁴ + 6.7749x³ + 5.4558x² + 8.0633x + 14.729
R² = 0.9999
H y = 0.0071x⁶ - 0.2462x⁵ - 0.2143x⁴ + 3.1037x³ + 8.8557x² + 11.194x + 33.925
R² = 0.9998
Deduct Value
Distress Density

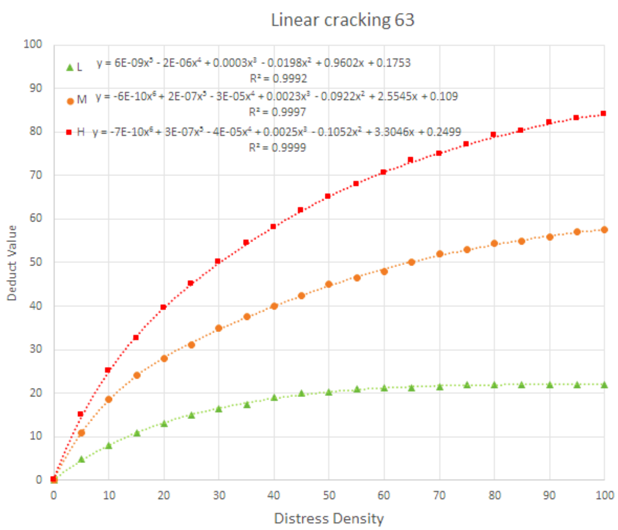
APPENDIX E

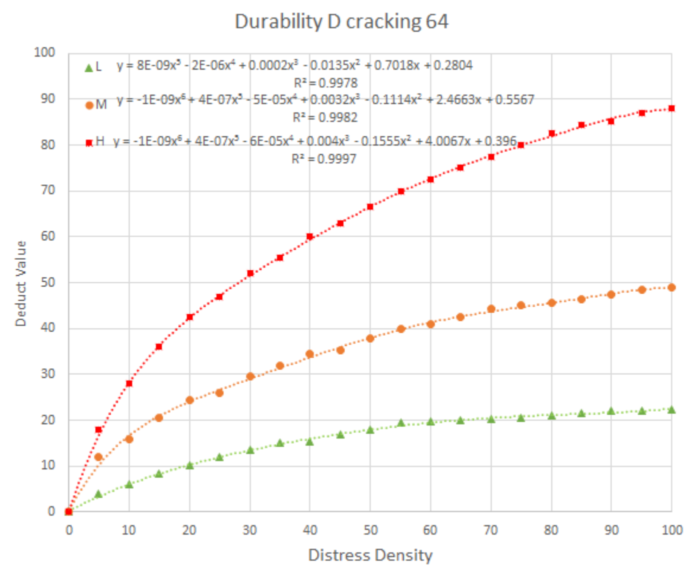
DEDUCT VALUE CURVES

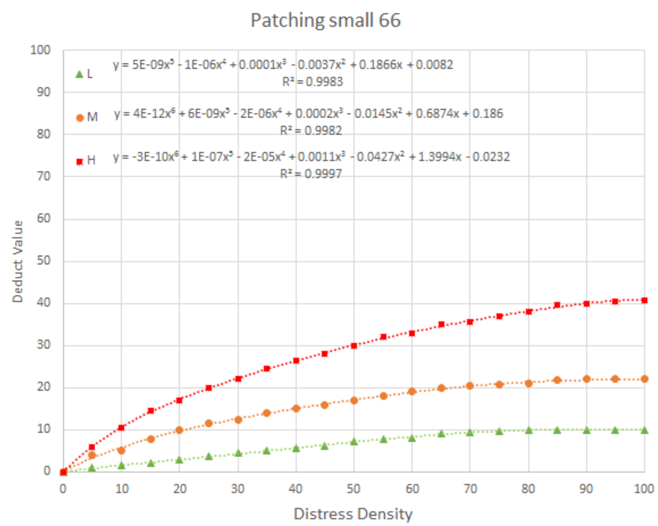
CEMENT CONCRETE PAVEMENT AIRFIELDS

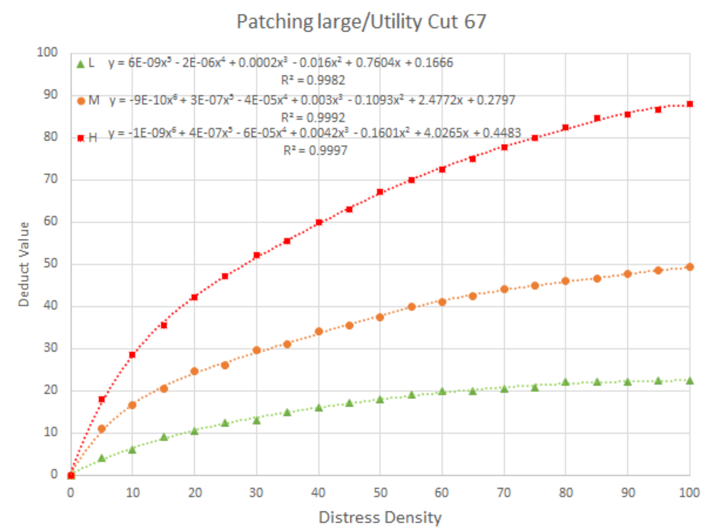

Blowup/buckling 61
Deduct Value
L $y = 1E-07x^5 - 3E-05x^4 + 0.0026x^3 - 0.1036x^2 + 2.8925x + 1.2457$
$R^2 = 0.9997$
H $y = -6E-08x^6 + 1E-05x^5 - 0.001x^4 + 0.0425x^3 - 0.8813x^2 + 9.7165x + 1.4313$
$R^2 = 0.999$
Distress Density

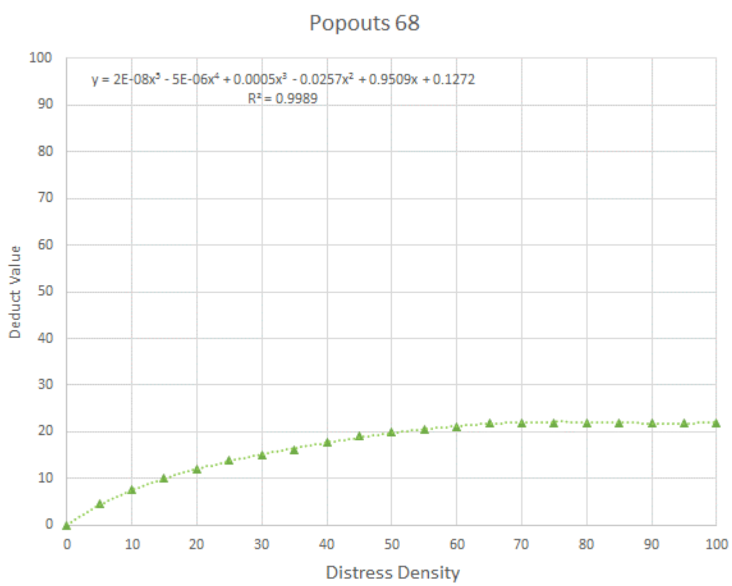

Corner Break 62
Deduct Value
L $y = -9E-10x^6 + 3E-07x^5 - 4E-05x^4 + 0.0026x^3 - 0.0987x^2 + 2.9817x - 0.3643$
$R^2 = 0.9999$
M $y = -7E-10x^6 + 2E-07x^5 - 3E-05x^4 + 0.0019x^3 - 0.0695x^2 + 2.0327x + 0.0941$
$R^2 = 0.9999$
H $y = -3E-09x^5 + 3E-07x^4 + 5E-05x^3 - 0.0096x^2 + 0.9285x - 0.1696$
$R^2 = 0.9999$
Distress Density

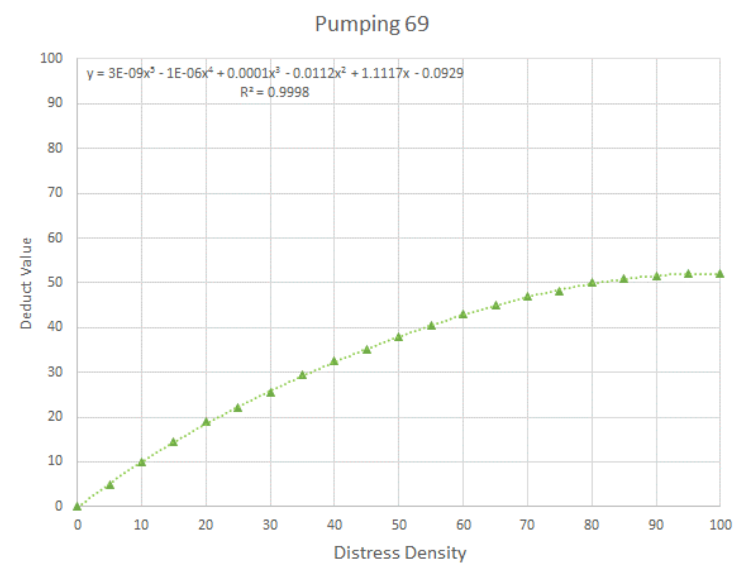

Linear cracking 63
Deduct Value
L $y = 6E-09x^5 - 2E-06x^4 + 0.0003x^3 - 0.0198x^2 + 0.9602x + 0.1753$
$R^2 = 0.9992$
M $y = -6E-10x^6 + 2E-07x^5 - 3E-05x^4 + 0.0023x^3 - 0.0922x^2 + 2.5545x + 0.109$
$R^2 = 0.9997$
H $y = -7E-10x^6 + 3E-07x^5 - 4E-05x^4 + 0.0025x^3 - 0.1052x^2 + 3.3046x + 0.2499$
$R^2 = 0.9999$
Distress Density

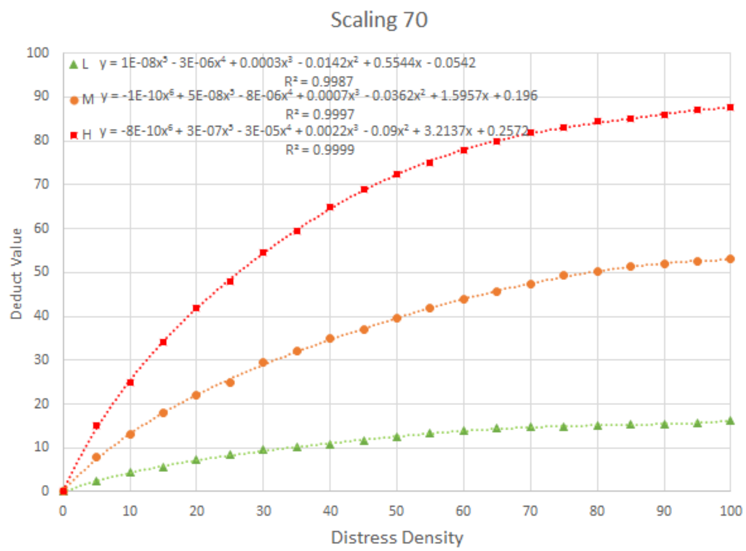

Durability D cracking 64
Deduct Value
L $y = 8E-09x^5 - 2E-06x^4 + 0.0002x^3 - 0.0135x^2 + 0.7018x + 0.2804$
$R^2 = 0.9978$
M $y = -1E-09x^6 + 4E-07x^5 - 5E-05x^4 + 0.0032x^3 - 0.1114x^2 + 2.4663x + 0.5567$
$R^2 = 0.9982$
H $y = -1E-09x^6 + 4E-07x^5 - 6E-05x^4 + 0.004x^3 - 0.1555x^2 + 4.0067x + 0.396$
$R^2 = 0.9997$
Distress Density

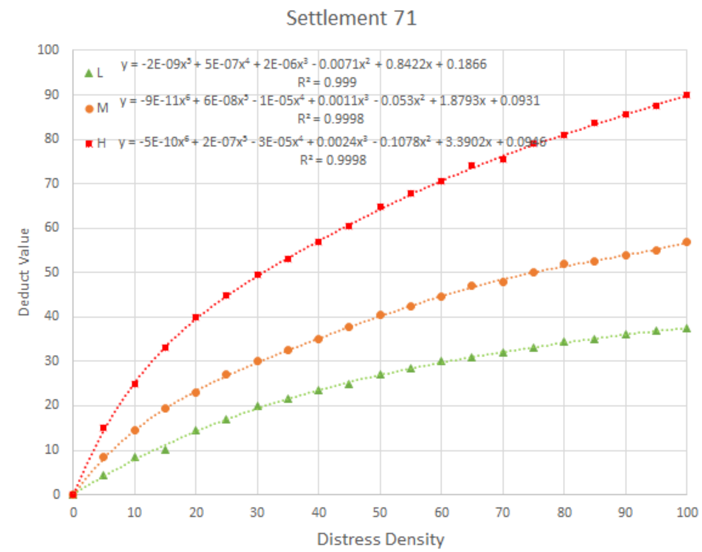

Patching small 66
L y = 5E-09x⁵ - 1E-06x⁴ + 0.0001x³ - 0.0037x² + 0.1866x + 0.0082
R² = 0.9983
M y = 4E-12x⁶ + 6E-09x⁵ - 2E-06x⁴ + 0.0002x³ - 0.0145x² + 0.6874x + 0.186
R² = 0.9982
H y = -3E-10x⁶ + 1E-07x⁵ - 2E-05x⁴ + 0.0011x³ - 0.0427x² + 1.3994x - 0.0232
R² = 0.9997
Deduct Value
Distress Density

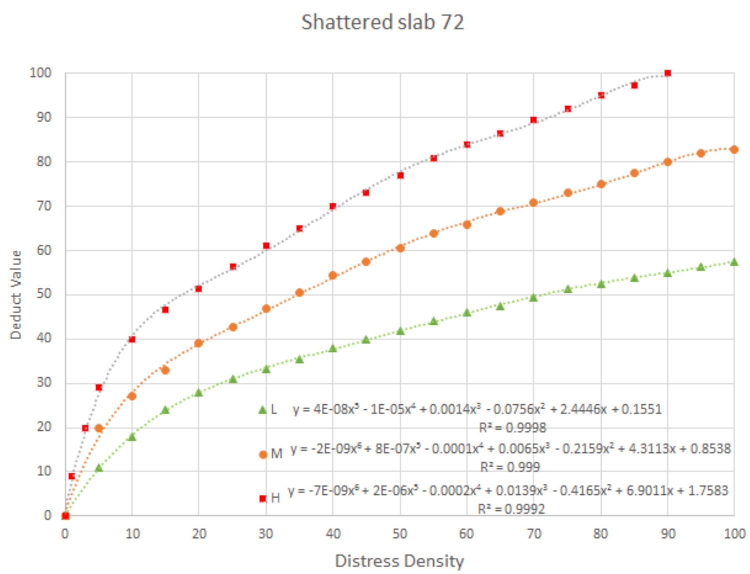

Patching large/Utility Cut 67
L y = 6E-09x⁵ - 2E-06x⁴ + 0.0002x³ - 0.016x² + 0.7604x + 0.1666
R² = 0.9982
M y = -9E-10x⁶ + 3E-07x⁵ - 4E-05x⁴ + 0.003x³ - 0.1093x² + 2.4772x + 0.2797
R² = 0.9992
H y = -1E-09x⁶ + 4E-07x⁵ - 6E-05x⁴ + 0.0042x³ - 0.1601x² + 4.0265x + 0.4483
R² = 0.9997
Deduct Value
Distress Density

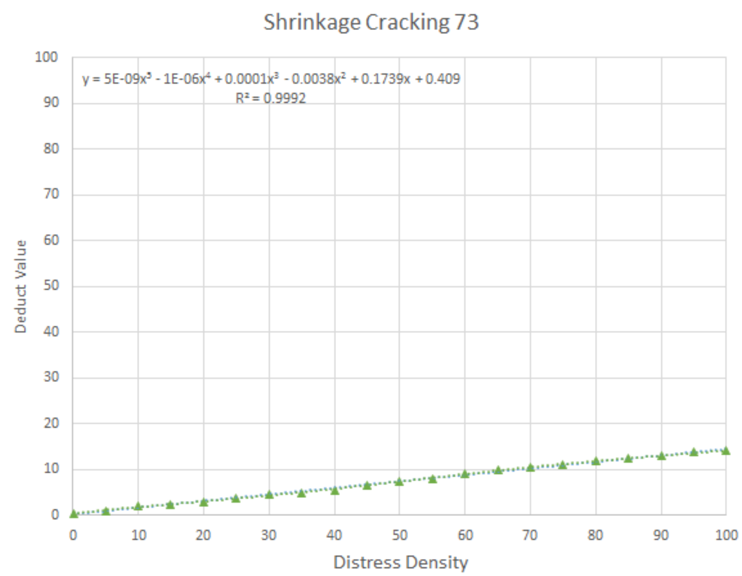

Popouts 68
y = 2E-08x⁵ - 5E-06x⁴ + 0.0005x³ - 0.0257x² + 0.9509x + 0.1272
R² = 0.9989
Deduct Value
Distress Density


Pumping 69
y = 3E-09x⁵ - 1E-06x⁴ + 0.0001x³ - 0.0112x² + 1.1117x - 0.0929
R² = 0.9998
Deduct Value
Distress Density

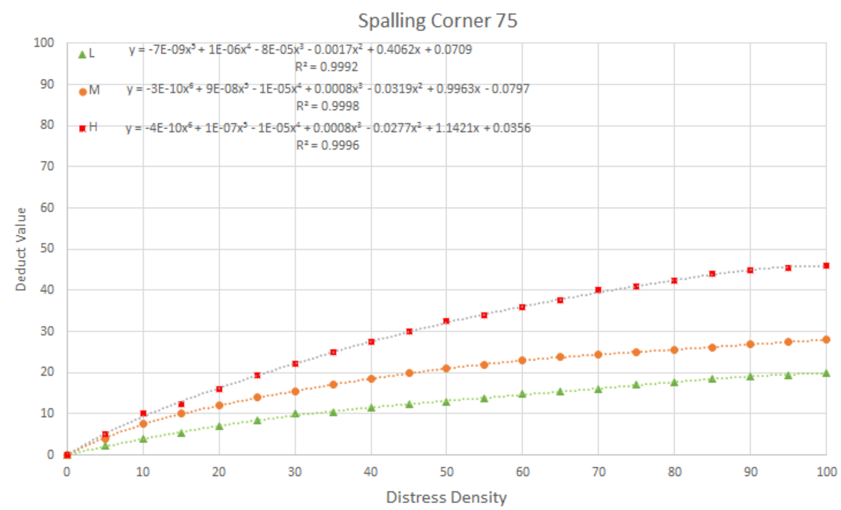

Scaling 70
L y = 1E-08x⁵ - 3E-06x⁴ + 0.0003x³ - 0.0142x² + 0.5544x - 0.0542
R² = 0.9987
M y = -1E-10x⁶ + 5E-08x⁵ - 8E-06x⁴ + 0.0007x³ - 0.0362x² + 1.5957x + 0.196
R² = 0.9997
H y = -8E-10x⁶ + 3E-07x⁵ - 3E-05x⁴ + 0.0022x³ - 0.09x² + 3.2137x + 0.2572
R² = 0.9999
Deduct Value
Distress Density


Settlement 71
L y = -2E-09x⁵ + 5E-07x⁴ + 2E-06x³ - 0.0071x² + 0.8422x + 0.1866
R² = 0.999
M y = -9E-11x⁶ + 6E-08x⁵ - 1E-05x⁴ + 0.0011x³ - 0.053x² + 1.8793x + 0.0931
R² = 0.9998
H y = -5E-10x⁶ + 2E-07x⁵ - 3E-05x⁴ + 0.0024x³ - 0.1078x² + 3.3902x + 0.0946
R² = 0.9998
Deduct Value
Distress Density


Shattered slab 72
L y = 4E-08x⁵ - 1E-05x⁴ + 0.0014x³ - 0.0756x² + 2.4446x + 0.1551
R² = 0.9998
M y = -2E-09x⁶ + 8E-07x⁵ - 0.0001x⁴ + 0.0065x³ - 0.2159x² + 4.3113x + 0.8538
R² = 0.999
H y = -7E-09x⁶ + 2E-06x⁵ - 0.0002x⁴ + 0.0139x³ - 0.4165x² + 6.9011x + 1.7583
R² = 0.9992
Deduct Value
Distress Density

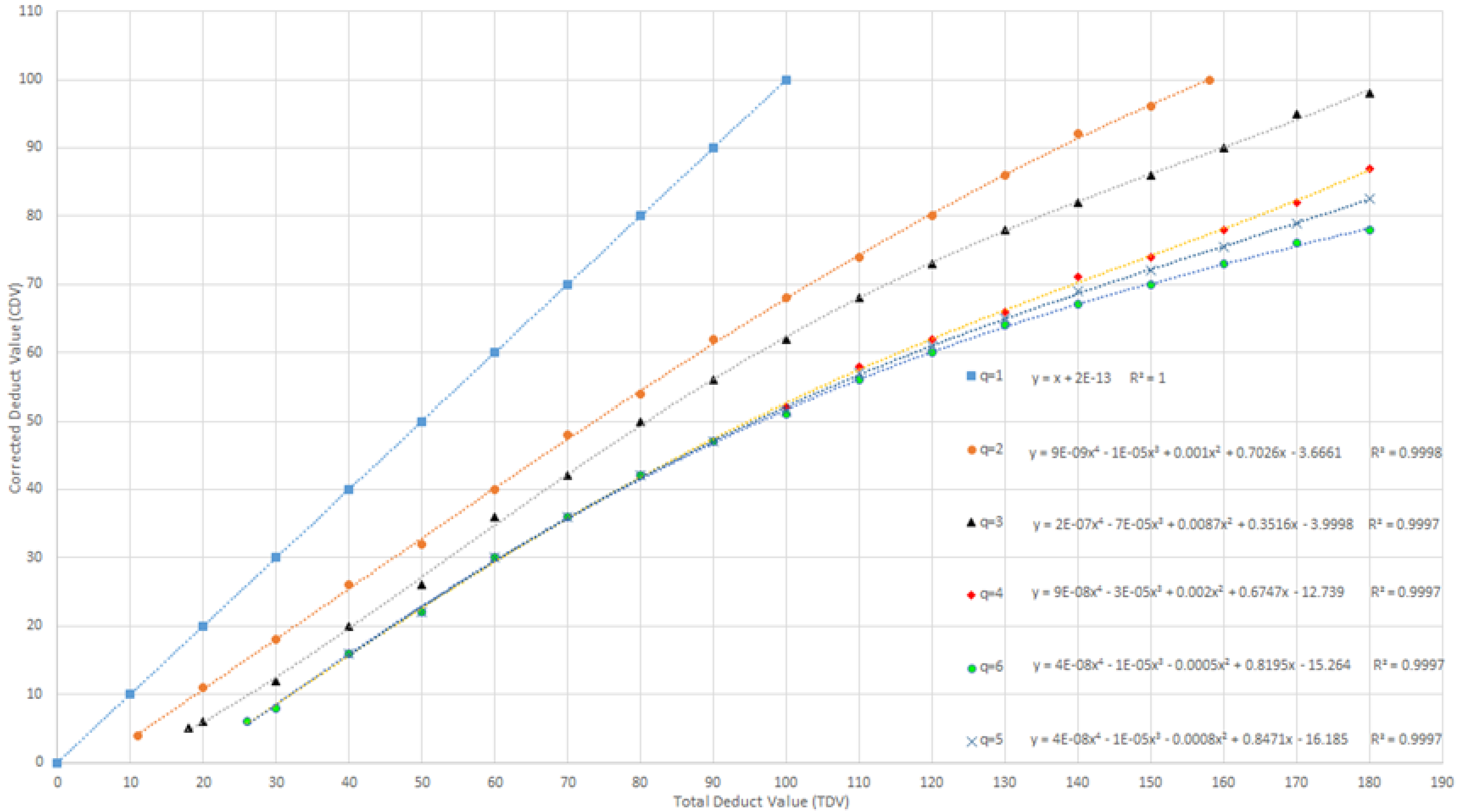

Shrinkage Cracking 73
y = 5E-09x⁵ - 1E-06x⁴ + 0.0001x³ - 0.0038x² + 0.1739x + 0.409
R² = 0.9992
Deduct Value
Distress Density


Join Spalling 74
L y = 3E-09x⁵ - 9E-07x⁴ + 9E-05x³ - 0.0058x² + 0.3638x + 0.1591
R² = 0.9974
M y = -2E-10x⁶ + 7E-08x⁵ - 1E-05x⁴ + 0.0006x³ - 0.0232x² + 0.9475x + 0.1671
R² = 0.9995
H y = -8E-10x⁶ + 3E-07x⁵ - 4E-05x⁴ + 0.0029x³ - 0.1172x² + 2.9222x + 0.1796
R² = 0.9996
Deduct Value
Distress Density
0
10
20
30
40
50
60
70
80
90
100

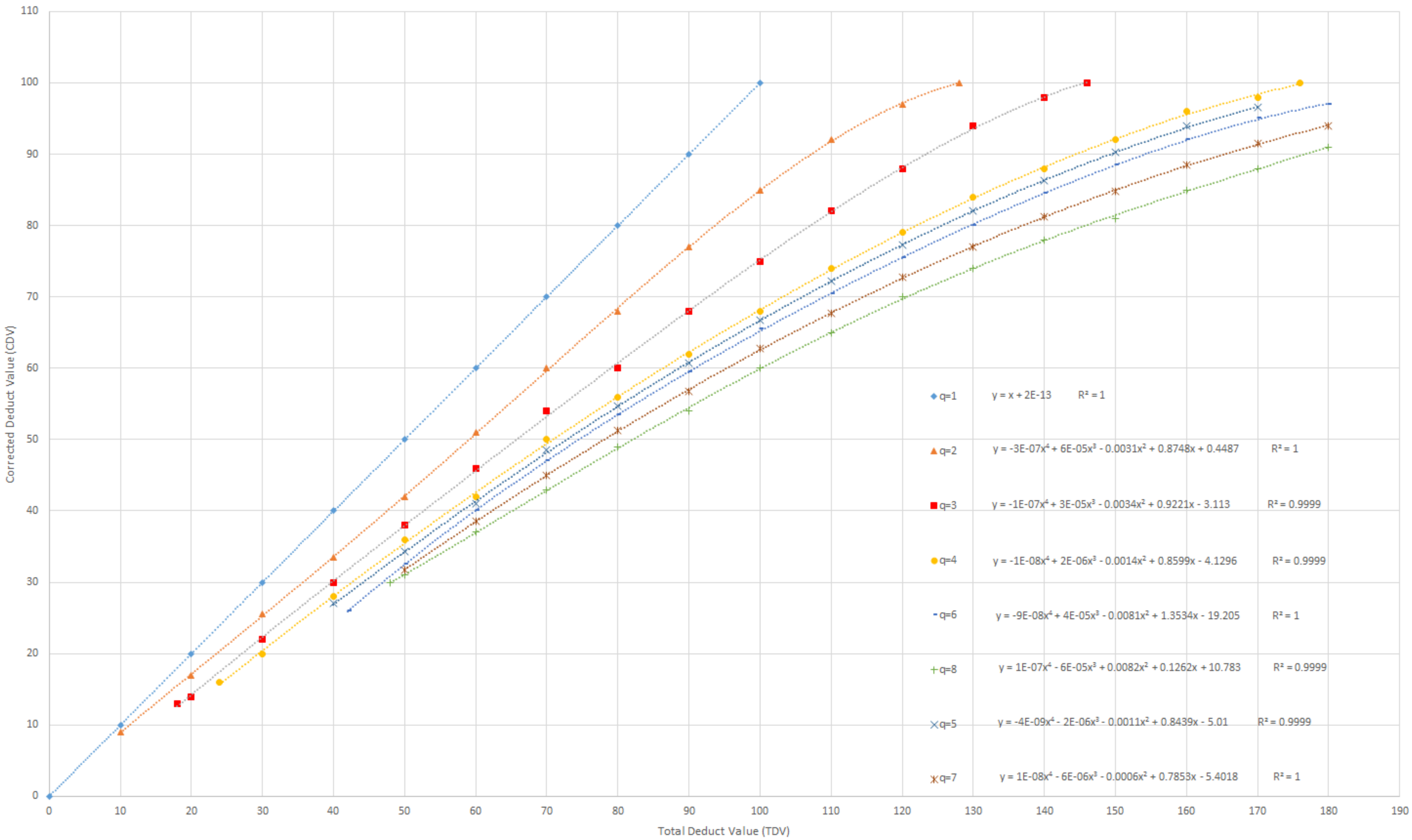

Spalling Corner 75
L y = -7E-09x⁵ + 1E-06x⁴ - 8E-05x³ - 0.0017x² + 0.4062x + 0.0709
R² = 0.9992
M y = -3E-10x⁶ + 9E-08x⁵ - 1E-05x⁴ + 0.0008x³ - 0.0319x² + 0.9963x - 0.0797
R² = 0.9998
H y = -4E-10x⁶ + 1E-07x⁵ - 1E-05x⁴ + 0.0008x³ - 0.0277x² + 1.1421x + 0.0356
R² = 0.9996
Deduct Value
Distress Density
0
10
20
30
40
50
60
70
80
90
100

APPENDIX F

CORRECTION CURVES



Flexible Pavement Air Fields



Cement Concret Pavement Air Fields

APPENDIX G

PCI CALCULATOR TEMPLATE

Airfields Asphalt Pavement

Distress types:

code	Distress	Cause
41	Alligator Cracking	Load
42	Bleeding	other
43	Block cracking	Climate
44	Corrugation	other
45	Depression	other
46	Jet blast	other
47	Joint reflection/cracking	Climate
48	Longitudinal and transverse crackir	Climate
49	Oil spillage	other
50	Patching	other
51	Polished aggregate	other
52	Weathering and ravelling	Climate
53	Rutting	Load
54	Shoving	other
55	Slippage cracking	other
56	sweling	other

Distress severity	
L	Low
M	Medium
H	High

Step 1 | Clean Data | **Sample Area =** 5000 m^2

Section = **Sample unit =** **Date=** / /

Step2		Step3	Step 4										
Distres	Distress type	Distress sev	Quantity								Total	Density	Deduct Value
48	Longitudinal and transverse c	L	10	20	17						47	0.940	3.12
48	Longitudinal and transverse c	M	7	9							16	0.320	6.22
41	Alligator Cracking	L	53								53	1.060	21.27
45	Depression	L	10	5							15	0.300	0.90
53	Rutting	L	20	45	10						75	1.500	17.14
53	Rutting	M	25								25	0.500	20.24
	#N/A										0	0.000	0
	#N/A										0	0.000	0
	#N/A										0	0.000	0
	#N/A										0	0.000	0
	#N/A										0	0.000	0
	#N/A										0	0.000	0
	#N/A										0	0.000	0
	#N/A										0	0.000	0
	#N/A										0	0.000	0
												HDV=	21.26689984

for airfields

mi= maximum allowable number of deducts 1+(9/95)*(100-HDV) 8.458925 8

HDV highest individual deduct value for sample unit i

q Determine the number of deducts with a value >5 for airfields

	Deduct Values										Total	q	CDV
1	21.27	20.24	17.14	6.22	3.12	0.90	0.00	0.00			68.88	4.00	35.45
2	21.27	20.24	17.14	5.00	3.12	0.90	0.00	0.00			67.67	3.00	42.13
3	21.27	20.24	5.00	5.00	3.12	0.90	0.00	0.00			55.52	2.00	36.80
4	21.27	5.00	5.00	5.00	3.12	0.90	0.00	0.00			40.29	1.00	40.29
5													
6													
7													
8													
9													
10													

Step5

Calculate PCI

Rating Scale

CDV(MAX) 42.13 PCI= 57.87 **Poor**

APPENDIX H

SOME AIRCRAFT'S WEIGHTS AND LOAD

Aircraft Model	MTOW* (LB)	MTOW (Tonnes)	Gross weight (KN)	Gross weight (Tonnes)	Gross weight on main gear %	wheel load (kg)	Tire pressure (Kpa)
MD83	154,390	70.03	716.4	73.028	94.76	17300	1344
MD82	154,390	70.03	716.4	73.028	94.76	17300	1344
MD88	149,500	67.8	-	-	95	16105	1140
F100	98,503	44.68	438.3	44.68	95.6	10679	980
A306	363,760	165.0	1693.2	172.6	95.00	20496	1340.0
B737-300	139,500	63.3	623.0	63.5	90.86	14425	1386
B734	150,000	68.0	669.7	68.3	93.82	16012	1276.0
B735	136,000	61.7	596.3	60.8	92.24	14016	1338
B738	174,200	79.0	777.4	79.2	93.6	18535	1413
B739	164,000	74.4	837.4	85.366	94.58	20185	1517
A332	313,055	142.0	2265.1	230.9	94.8	27362	1420.0
B752	255,000	115.7	1139.1	116.1	91.2	13235	1262.0
B727	209,500	95.0	756.4	77.1	95.3	22640	1138
A300-B4	363,760	165.0	1627.5	165.9	94.0	19493	1490
A310	330,750	150.0	1401.8	142.9	93.2	17478	1330.0
A319	141,095	64.0	631.8	64.4	92.6	14909	1190.0
A320	146,375	66.4	725.0	73.9	93.8	15570	1380
A321	206,000	93.4	877.0	89.4	95.0	22192	1460.0
B747	833,000	377.8	3720.0	379.2	90.96	21480	1379
ATR72	47,400	21.5	211.0	21.5	95.0	5106	864.84
TU154M	199,077	90.3	-	-	-	11050	930
A343	608,035	275.8	2706.5	275.9	79.6	18290	1572
B772	6,223,650	2823.0	2923.5	298.0	91.8	215960	1413
BAE	94,997	43.1	398.3	40.6	94.2	10148	880.0
A350-900	-	-	2637.9	268.9	93.68	20992	1660
B767	-	-	1410.5	143.78	92.3	16589	1310

*Maximum Takeoff Weight